# A TECHNLOGY SCOUTING AND ROADMAPPING APPROACH OF FUTURE COMMERCIAL PASSENGER AIRCRAFT

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**Abstract**
Advancements in aircraft technologies such as new propulsion systems, new materials, aerodynamic improvements and better avionic systems are pivotal for fostering a more efficient and sustainable aviation system. This paper proposes a systematic approach with the potential to increase the effectiveness of technology roadmapping, scouting and impact assessment. A technology taxonomy with special focus towards environmental impact assessment also including non-$CO_2$ climate effects of aircraft technologies is proposed. Initially, a database containing aircraft technologies and their vehicle-level impacts is compiled. Subsequently, an aircraft design tool is used to incorporate information from the technology scouting and assess their environmental impact for different reference aircraft across all market segments of commercial aviation. The insights gained from this mission-level investigation framework result in technology trends, outlining the fuel savings for future technologies. The trends further highlight technology combination/portfolio effects for narrow- and wide body aircraft. To give researchers, decision makers and other stakeholders an overview of the impacts of upcoming aircraft technology trends, the results are presented in a roadmap. Furthermore, this review and taxonomy will contribute in laying the groundwork towards holistic environmental impact assessments of aircraft technologies, which need to include specific engine and atmospheric data for investigating aviation's non-$CO_2$ emissions and effects in the future.

**Keywords**
Aircraft Technologies, Technology Factors, Taxonomy, Technology Trendlines

## 1. INTRODUCTION

Anthropogenic climate change poses one of the biggest threats to life as currently known on earth, as climate change effects can already be observed around the world including extreme weather events, rising sea levels and the endangerment of living species. It simultaneously offers one of the biggest tasks to humanity in adjusting their activities to slow and potentially stop the climate from warming. Aviation attributes to approximately 5% of the anthropogenic climate change due to the emission of gaseous species such as carbon dioxide ($CO_2$), water vapor from incomplete combustion and particulates such as soot. The species ($CO_2$ and non-$CO_2$) are emitted into the atmosphere and alter a wide range of atmospheric processes including the formation of contrail-cirrus, ozone and the depletion of methane. [1]
Lee et al. [2] describes that the radiative forcing from aviation is around three times larger than that from $CO_2$ alone, highlighting especially the importance of non-$CO_2$ $NO_x$ emissions, aircraft induced cloudiness and aerosol emissions. Aviation's contributions to climate change are expected to increase as air transport is expected to continue to grow in the coming decades. In its Global Market Forecast, Airbus predicts continued annual growth of 3.6% in revenue passenger kilometers in the next two decades [3].

The fuel efficiency of jet aircraft has been increasing ever since the beginning of jet aviation in the late 1950s / early 1960s, due to improvements of several factors, such as airframe aerodynamics, weight reductions, larger component efficiencies and more efficient engines. Leading to an average reduction in fuel consumption per passenger-km at global fleet level of 1.3% per year over the years 1960-2014. This trend is expected to continue at a similar rate until 2037 without the employment of additional measures [1].

The Paris Agreement, as a creation of nationally determined contributions in 2015, set the goal to limit global warming to below 2°C above pre-industrial levels and to pursue efforts limiting warming further to 1.5°C. According to the Sixth Assessment Report of the IPCC the current nationally determined contributions will fail to meet the greenhouse gas emission reductions that would be required to limit global warming to 2°C [4]. Additionally, the Paris Agreement does not include the aviation industry due to its international nature, however some member states have placed restrictions and requirements on domestic aviation. In Europe the European Green Deal [5] and the Clean Aviation Joint Undertaking [6] thrive towards the EU's ambition of climate neutrality by 2050. Clean Aviation's goals include reducing greenhouse gas emissions emitted from air vehicles by 30% compared to 2020 state of the art, replacing 75% of the world's civil aviation fleet by 2050. This will support the goal of the EU Green Deal to reduce $CO_2$ emissions of the transport sector up to 90% until 2050.

Therefore, the aviation industry faces the challenge to decouple its emissions and climate impacts from its expected growth to satisfy society's mobility needs while meeting international goals towards climate neutral aviation. Ongoing research and innovation activities are focusing on breakthrough technology initiatives, including



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for example fully electric or hydrogen powered aircraft technologies, while additionally introducing technologies to accelerate the already ongoing average reductions in fuel consumptions of yearly 1.3% mentioned above. Meanwhile ensuring aviation remains safe, reliable, cost-effective and efficient in means of passenger and freight transportation during the transition towards climate neutrality. This transition is expected to trigger the research, development and market introduction of new aircraft technologies and can already be observed in growing future aircraft technology portfolios and the acceleration in technology introduction timelines.

In order to monitor and ensure a successful transition of the aviation industry, technology roadmaps and environmental impact assessment are essential tools for strategic decision-making for sustainable development and innovation management. However, the process of collecting, comparing, and analyzing technologies and their roadmaps alongside environmental impact assessments poses significant challenges due to the complexity and dynamic nature of technological landscapes, environmental- and uncertainty considerations. This paper proposes a technology taxonomy and a heuristic approach aimed at enhancing the efficacy of these processes, while developing an interactive future aircraft technology database. It will contribute in laying the groundwork towards full environmental technology impact assessments, including aviation's non-$CO_2$ emissions and effects. Additionally, an aircraft mission-level assessment is conducted in order to compare the impacts of technological progress on future aircraft vehicles. The emissions for a fixed reference mission are investigated in an Assessment Framework.

## 2. ASSESSMENT FRAMEWORK

To access the mission level impact of a broad selection of aircraft technologies an aggregated methodology is used in this paper. Starting with an extensive literature study on novel aircraft technologies and the storage of this information in a database. The technology explorer (see chapter 3.2), which represents an interactive database containing over 100 novel aircraft technologies, is the database that is conducted from the literature study. The technology explorer directly involves a taxonomy to filter, sort and collect technologies and their impacts. The first assessment of the technologies then leads to an aircraft design process which is explained in detail in chapter 5.

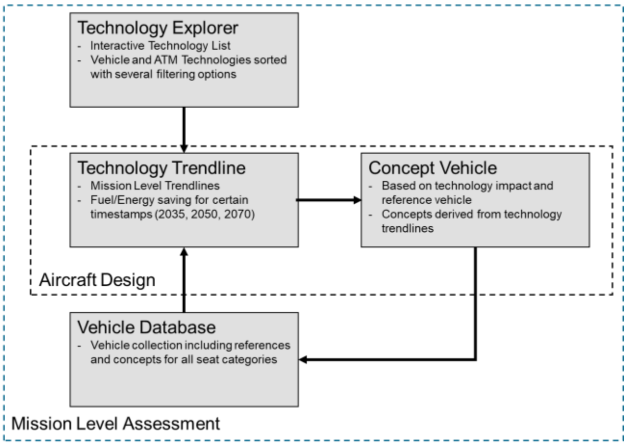


Figure 1: Mission Level Assessment Framework

The aircraft design process utilizes the technology explorer in combination with a vehicle database, that contains a set of reference aircraft vehicles. The concept vehicles resulting from the aircraft design process are then used to generate technology trendlines, by comparing their performance to the design mission of the reference aircraft. Subsequently, the vehicle concepts are forwarded into the vehicle database and can be used for further fleet assessments with different payload range characteristics. The vehicle database then contains a set of reference vehicle and a set of concept vehicles for all ICAO seating classes to be forwarded to a global fleet assessment. The generated technology trendlines are used in the roadmaps for narrow body- and wide body aircraft and can also be used to generate a reduction factor (fuel burn-, emission reduction) for a representative category of aircraft and a specific time stamp.

## 3. TECHNOLOGY ASSESSMENT

### 3.1. Technology scouting

To increase the effectiveness of technology roadmapping and impact assessments a technology database is being created containing aircraft technologies and their vehicle-level impacts. It is based on a comprehensive external and internal literature study, refined with DLR expert interviews and workshops. The process starts with a broad screening on technology roadmaps by different stakeholders and the analysis of them. A systematic literature review on existing aviation technology roadmaps, transitions strategies and future pathways and projections is being conducted, starting with literature from the year 2020. The comprehensive external and internal literature study includes the scouting for future and currently being developed aircraft technologies, architectures and concepts. After completing a broader investigation, more detailed information is collected for all scouted technologies. This process is concluded with expert interviews on technologies with a low confident level based on the scouted literature. The schematic approach is shown in figure 2.

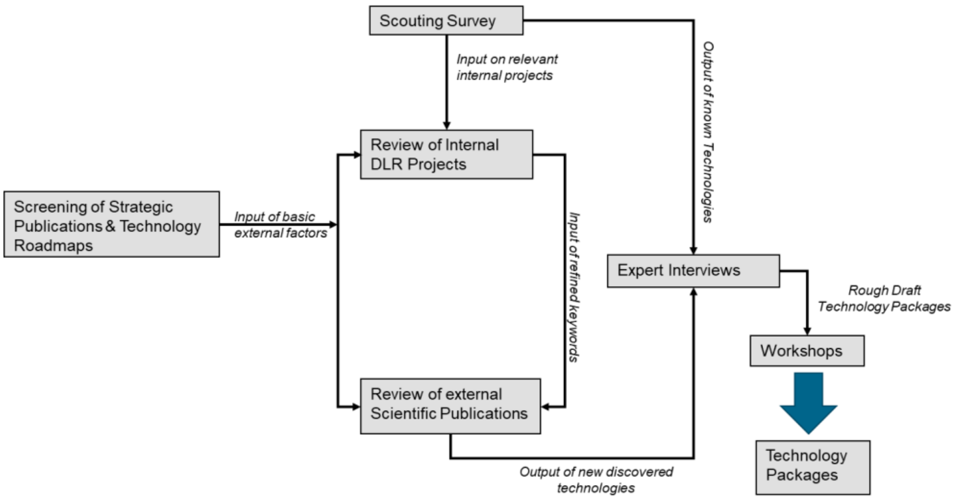


Figure 2: Technology Scouting Approach

Following 17 aviation roadmaps / transition strategies have been identified and analyzed with special regard towards considered technologies, their alignment and their respective benefits:

1) United States of America: United States 2021 Aviation Climate Action Plan, 2021 [7]

2) Netherlands Aerospace Centre (NLR): Destination 2050 – A Route to net zero European Aviation, February 2021 [8]

3) Clean Sky 2 Joint Undertaking: Clean Sky 2 – Technology Evaluator First Global Assessment 2020 Technical Report, May 2021 [9]

4) Air Transport Action Group (ATAG): Waypoint 2050, September 2021 [10]

5) German Aerospace Centre (DLR): Towards emission free aviation - DLR Strategy for European Green Deal, December 2021 [11]

6) Clean Aviation Joint Undertaking: Clean Aviation – Strategic Research and Innovation Agenda, December 2021 [12]

7) European Union Aviation Safety Agency (EASA): European Aviation Environmental Report 2022, 2022 [13]

8) ATI: Destination Zero - The Technology Journey to 2050, 2022 [14]

9) International Council on Clean Transportation (ICCT): Vision 2050 – Aligning Aviation with the Paris Agreement, 2022 [15]

10) International Civil Aviation Organization (ICAO): Report on the feasibility of a long-term aspirational goal (LTAG) for international civil aviation CO2 emission reductions, March 2022 [16]

11) European Federation for Transport and Environment AISBL: Roadmap to climate neutral aviation in Europe, March 2022 [17]

12) Mission Possible Partnership (MPP): Making Net-Zero Aviation Possible – An industry-backed 1.5°C-aligned transition strategy, July 2022 [18]

13) Roland Berger: Roadmap to True Zero – A path-breaking approach to bring down aviation's total climate impact, August 2022 [19]

14) NLR: TRANSCEND D3.2: Novel propulsion and alternative fuels for aviation towards 2050, September 2022 [20]

15) International Air Transport Association (IATA): Aircraft Technology – Net Zero Roadmap, 2023 [21]

16) House of Commons Environmental Audit Committee (United Kingdom): Net zero and the UK aviation sector, December 2023 [22]

17) Aerospace Technology Institute (ATI): Non-CO2 Technologies Roadmap, April 2024 [23]

## 3.2. Technology Explorer

In order to collect, analyze and compare existing and future aircraft technologies, architectures and concepts an interactive technology explorer is being developed. Following 16 classification criteria and taxonomy are used in the technology explorer:

1) Technology / Architecture / Concept Name

2) Category
a) Aerodynamics
b) Propulsion
c) Systems
d) Structural
e) Architecture: Geometric arrangement and location of aircraft components such as fuselage, wings, horizontal tail plane (HTP), vertical tail plan (VTP), landing gear, propulsion system.

f) Concept: A combination of technologies and possible architectures, usually combined to reach a certain (performance or emission) goal.
g) Air Traffic Management (ATM)
h) (Aero-) Acoustics

3) Short Description

4) Entry into Service (EIS) conservative and progressive

5) Lifetime (time from production to out of service)

6) Interdependencies (with other Technologies / Architectures / Concepts)

7) Technology Readiness Level (TRL):
The TRL can vary from 0 where technology research has not yet started to 9 where the technology is available and in service.

8) Market Segment:
Possible and usual market segments in civil aviation can be: Short and Medium Range Aircraft (SMR), Long Range Aircraft (LR), Ultra Long-Range Aircraft (LR+), Supersonic aircraft, Unmanned Air Vehicle (UAV), (Sub-)Regional Jets, Business Jets.

9) Literature Reference

10) Technology Reference:
The technology references determine against which (already existing) technology/architecture/concept the new technology is being measured or compared with.

11) Estimated Market Penetration

12) Considered Benefits:
Possible climatological, environmental, social and economic benefits expressed in physical units can be:
a) Fuel burn or flow reductions and direct $CO_2$ emission reductions due to reduced drag, weight or improved lift characteristics, or increased efficiencies
b) Non-$CO_2$ emission reductions due to reduced fuel burn, or due to reductions in $NO_X$, particulate matter, water vapor emissions or reduced contrail formation. If given or used: Climate metrics for $CO_2$ equivalent estimations.
c) Noise reductions
d) Air quality, health and safety improvements
e) Connectivity, accessibility and effectiveness improvements
f) (Seat-) Capacity improvements
g) Propulsion improvements possible due to more fuel compatibilities, potential for new energy sources

13) Uncertainties of considered Benefits: Quantification of the uncertainties of the possible considered benefits mentioned above.

14) Scope of considered Benefits:
The scope of considered benefits in terms of Life Cycle Analysis (LCA): Tank to wake, well to wake.

15) Development of considered Benefits:
Evaluation of the benefit development during the scope and technology lifetime. Possibly dependencies of the considered benefits on local or temporal circumstances.

16) Location of Emission:
Estimation of flight phases or location (longitude, latitude, altitude) of the emissions or where the benefit effects can be expected.

In total a number of 117 technologies / architectures / concepts have been collected in the technology database. The technologies are grouped into 18 aerodynamic, 36 propulsion, 30 systems, 13 structural, 6 architectures, 7 concepts and 8 ATM and 6 aero-acoustics technologies (some technologies are applicable in more than one category, leading to a sum larger than 117).

All the technologies are collected and categorized in the technology explorer as described above. The technology explorer offers the option then to sort, filter and roadmap the technologies using interactive features for the user. Figure 3 gives an example how a technology can be explored in the database in a detailed view and how the roadmapping view is being visualized.

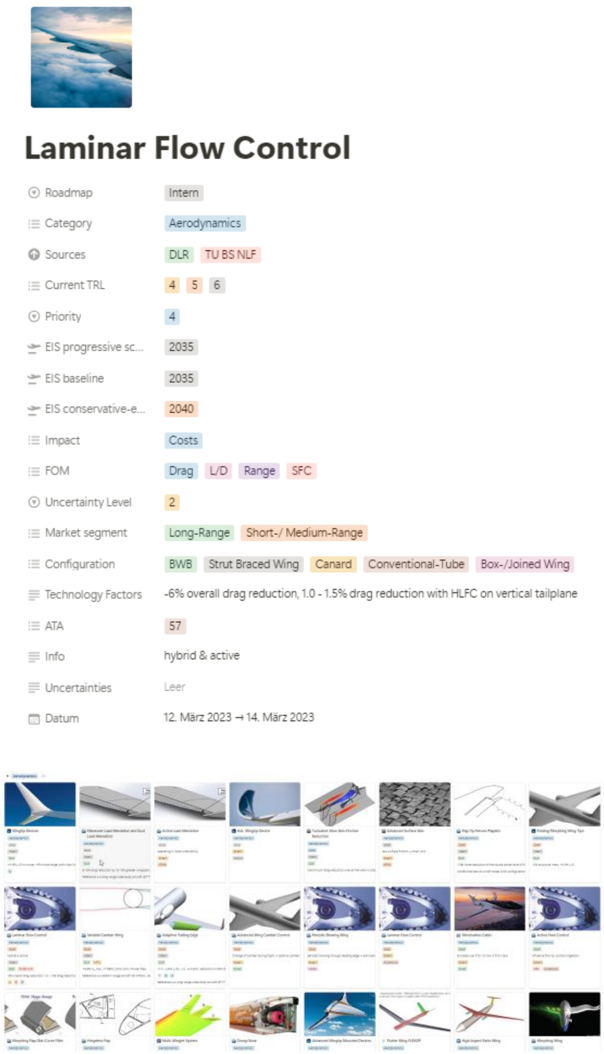


Figure 3: Technology Explorer Detailed View Layout (top) and Roadmapping View (bottom)

Table 1: Technology Roadmap Trends

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| USA [7] | x | | | x | | | | | | | x | | | | | x |
| NLR 2021 [8] | | | | | | | | | | | x | | | x | | x |
| Clean Sky 2 [9] | | | x | | | | | | | | | | | x | | x |
| ATAG [10] | x | | | x | | x | | | | | x | | | | | x |
| DLR [11] | x | | | | | | | | | | x | | | | | x |
| Clean Aviation [12] | | | x | | | | | | | | | | | x | | x |
| EASA [13] | x | | | | | x | | | | | x | | | | | x |
| ATI 2022 [14] | x | | | | | | | | x | | x | | | x | | x |
| ICCT [15] | x | | | | x | | x | x | | x | x | | | | | x |
| ICAO [16] | x | | | x | x | | | | x | x | x | | | | | x |
| EU TE [17] | x | | | | | x | | x | x | | x | | x | | | x |
| MPP [18] | x | | | | | x | | | x | x | x | | x | | | x |
| Roland Berger [19] | x | | | | | x | | | | | | x | | | | x |
| NLR 202022 [20] | x | | | x | | x | | | | | | x | | | | x |
| IATA [21] | | x | | x | | | | | | | | | | x | | x |
| HC UK [22] | x | | | | x | | x | | | | | x | x | | | x |
| ATI 2024 [23] | | x | | | | | | | | | | | | x | | x |
| Trend no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |

Throughout the technology collection and the collected roadmaps following technologies have frequently been mentioned:

Ultra-high bypass ratio engine, composite structures (wings & fuselage), riblets & shark skin paint, active load alleviation, laminar flow control (natural & hybrid), open rotor propulsion, (hybrid-) electric propulsion (including required systems and enablers), hydrogen combustion propulsion (including required systems and enablers), fuel cell propulsion (including required systems and enablers), blended wing body (and hybrid wing body), strut/truss-braced wing, emission & environmental management instrumentation and systems, water vapor release controls, distributed propulsion, high aspect ratio wing (highly flexible wing, increased span), dry wing , advanced turboprop engine, advanced wing tip devices & advanced winglets & morphing flaps, more electric aircraft (including required systems and enablers), advanced systems & ATM.

## 4. TECHNOLOGY ROADMAP COMPARISON

The collected technology sources can generally be grouped into two different types: Emission Scenario models [8, 7, 10, 11, 13, 14, 15, 16, 17, 18, 19, 22]. And Technology Roadmaps [14, 21, 23].

Additionally following 16 trends across roadmaps have been identified and are illustrated in Table 1:

1) Goal to explore pathways or show scenarios for aviation towards net-zero emissions or meeting Paris Agreement [7, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 22]

2) Goal to make a Technology Roadmap for net-zero aviation [21, 23]

3) Goal to drive research towards net zero [9, 12]

4) SAF employment named as one of the largest potentials for climate effect mitigation [7, 10, 16, 20, 21]

5) In aviation sector net-zero is usually not achieved by 2050 [15, 16, 22]

6) Carbon offsetting is usually needed to reach net zero by 2050 [10, 13, 17, 18, 19, 20]

7) Fulfilling 2°C goal is still possible ($CO_2$ emissions only [15], Equivalents also [22])

8) Stressing demand management importance [15, 17]

9) Stressing costs of alternative fuels & importance of energy demand management [14, 16, 17, 18]

10) Technological improvements yearly modelled with values between 0.2% and 2.2% [7, 8, 10, 15, 16, 18]

11) Scenario model for $CO_2$ emissions only [7, 8, 10, 11, 13, 14, 15, 16, 17, 18]

12) Scenario model for CO2 equivalent emissions [19, 22] ([20] CO2 and H2O emissions)

13) Larger sections on cost effectiveness and policy alignment [17, 18, 22]

14) Larger technology and their alignment sections [8, 9, 12, 14, 21, 23]

15) “Act now” or “accelerate” developments for multiple mitigation measures [7, 9, 11, 12, 14, 15, 17, 19]

16) Time Horizon 2050 [7-23]

Overall, specific goals, assumptions and reference scenarios can differ across the roadmaps. Main levers are commonly identified as: SAF employment, demand management, technology advances (in both fuel efficiency increase and the shift towards zero carbon technologies) and operational measures. In the roadmap modelling approaches, net zero emissions (mostly $CO_2$ emissions only) are usually not reached within the aviation sector by 2050. Incorporating non-$CO_2$ emissions is a commonly recognized future goal, resulting in the need for even further mitigation acceleration measures to potentially reach net zero by 2050 with the additional non-$CO_2$ emissions. Some roadmaps stress the urgency to act now (regardless of the current scientific uncertainties) and have aviation emissions peak before 2030 (ideally even 2025) [15, 19].

Some sources already incorporate non-$CO_2$ emissions in their future emission scenarios [16, 19]. Due to currently ongoing research activities especially regarding the understanding, quantification and considerations of uncertainties of non-$CO_2$ emissions the number of publications in the upcoming years including these effects in their scenarios is expected to increase.

## 5. VEHICLE ASSESSMENT

For the vehicle assessment an aircraft design workflow is applied which compares the reference design mission to the modeling of the concept aircraft and their new payload-range characteristics. The workflow starts with the selection of the reference vehicles which are ATR72, A320neo, A321neo, A350-900 or A350-1000. The related digital models are the D70, D180, D239, D325 and D366 which directly include the seating capacity within their respective names. The digital models are structured in CPACS (Common Parametric Aircraft Configuration Schema) format which allows the manipulation of several factors of the aircraft [24]. OpenAD is the aircraft design tool used in the workflow to model the new aircraft concept by using technology factors to change engine, weight, geometry and drag parameters. All the technology factors applied are described in more detail in chapter 5.1.1. and 5.1.2. OpenAD then models the new concept aircraft with their regarded aerodynamic and engine performance. OpenAD is also capable of calculating the payload-range characteristics of the new concept aircraft and gives a basis for comparisons [25]. To compare the fuel burn and emission results of the new vehicle to the reference vehicles, a design mission is defined which suits the regarding use case. For the technology assessment on mission level technology trendlines are retrieved from the OpenAD mission inventory by comparing the fuel burn or emission metrices to a constant design mission. Different mission points with different payload and range characteristics are calculated in OpenAD, generating the payload range diagram of the new concept vehicle

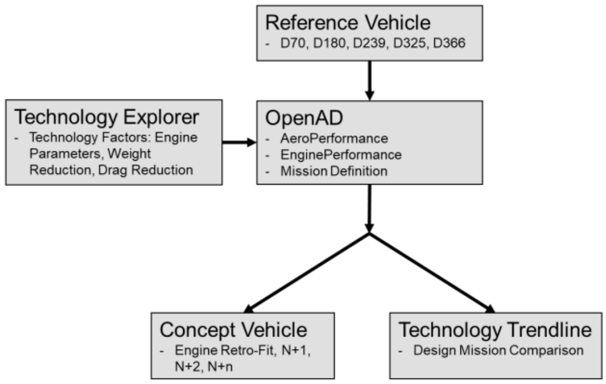


Figure 4: Aircraft Design Schematic Workflow

For the technology integration process using OpenAD all the files structured by the CPACS schema. To apply adjustments to the reference aircraft, the process parameters or toolspecifics (TS) of OpenAD must be manipulated using RCE. In order to align the factors from the literature with the corresponding factors in the OpenAD TS, first the adjustable values for each component must be identified. These values are described in chapter 5.1.1. and 5.1.2. CPACS organizes OpenAD's TS by component and further subdivides them into disciplines such as Geometry, Aerodynamic, and Masses, in which parameters such as drag coefficient, mass, wing span, or lift coefficient can be adjusted. In Figure 6 two examples for geometry factor manipulation are displayed compared to their reference aircraft. The applied RCE workflow which also includes the set-up of a reference aircraft for an EIS of 2030 is shown in Figure 5. In the subsequent analysis the reference aircraft model for a state-of-the-art aircraft is used.

As a result of the technology assessment the technology trendlines are generated. These trendlines already represent the technology roadmap and show the impact on fuel burn by comparing the fuel burn of the design mission for the reference vehicle and the new concepts. These discrete timestamps then refer to the vehicle concept and the included technology portfolio. This paper uses concept vehicles from the DLR project DEPA 2070 [26], for the timestamps 2035 and 2050 are modeled. The fuel burn reduction on different timestamps can be interpolated ween today and 2035 and in between 2035 and 2050.

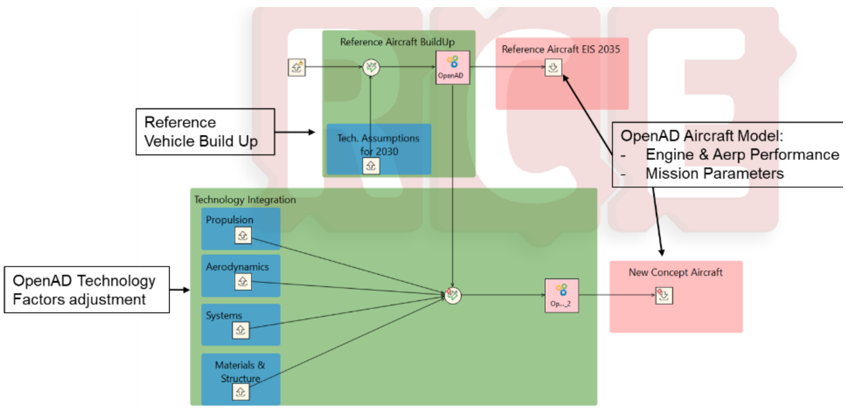


Figure 5: RCE Design Workflow

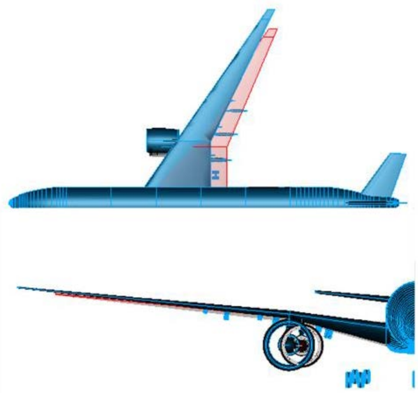

Figure 6: High Aspect Ratio Wing (top) and Ultra High Bypass Ratio Engine (bottom) Technology Changes

### 5.1. Technology Trendline

The assessment framework needs a technology introduction scenario to model technological progresses. In the DLR project DEPA 2070 two different scenarios where conducted. A conservative Scenario in which the technological progress is low and a progressive Scenario which considers a more advanced technological development. For both of these Scenarios different Technology Portfolios where selected and applied to the reference vehicle. This technology selection bases on a simple methodology which uses a compatibility matrix of the most promising future aircraft technologies. Figure 7 shows the technology portfolios for the conservative and progressive scenario.

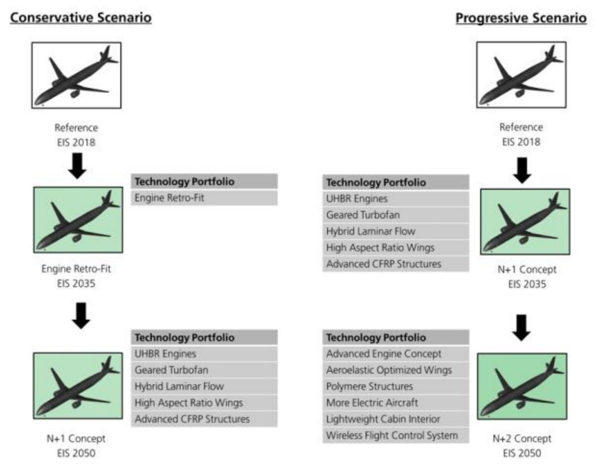


Figure 7: Technology Portfolios for Conservative and Progressive Scenario

3 different concept aircraft with different technology portfolios were derived from the technology explorer. These concepts include technology portfolios based on the regarded EIS of the single technologies in the both scenarios. The entry into service of the concept aircraft and the regarded technology portfolios is listed in Table 2.

Table 2: Entry into Service (EIS) Concepts

| Aircraft | EIS cons. | EIS prog. |
|---|---|---|
| Reference | 2018 | 2018 |
| Engine Retro-Fit | 2035 | - |
| N+1 Concept | 2050 | 2035 |
| N+2 Concept | - | 2050 |

As described in chapter 5 the aircraft design process conducts the comparison of the design mission of the new concept aircraft with the reference aircraft, which includes state-of-the-art technologies. This leads to a technology trendline by regarding the fuel or emission reduction for the referred EIS of the concept vehicle. In the project DEPA 2070 concept aircraft for the timestamps 2035 and 2050 were modeled, which are then represented in the trendlines. In this paper 2 different use cases are presented for the narrow body and wide body segment. As the narrow body and the wide body aircraft lead to the major share of today's emissions in the aviation sector. Therefore, they are considered relevant use cases to apply the technology assessment on a mission level. Due to the rather small shares of regional aircraft flights, the comparison of the regional aircraft is not considered in this paper, but can be considered in further studies and is implemented in the project DEPA 2070.

#### 5.1.1. Narrow Body Aircraft

The reference aircraft for the narrow body use case is the D239 model which is a representative model for the Airbus A321neo based on public available data. Figure 8 shows the geometry of the model derived from the TiGL-Viewer. In the Table 3 the top-level aircraft requirements for the narrow body use case are listed. These values are constant in the technology comparison in order to compare different technology impacts to conduct the trendline on mission level.

Figure 8: Isometric view of the D239 Model

Table 3: Top Level Aircraft Requirements Narrow Body Use Case

| Parameter | Unit | Value |
|---|---|---|
| Number of Passenger | [-] | 239 |
| Design Range | [km] | 4630 |
| Design Payload | [kg] | 25000 |
| Mach Cruise | [-] | 0.78 |
| Cruise Altitude | [m] | 9447 |

For the technology integration process OpenAD is utilized by changing several technology factors based on the technology portfolio. The D239 model offers to manipulate technology factors for the engine, structure and aerodynamic behaviors of the aircraft. In Table 4 all the factors adjusted in the framework are listed including the values for the reference aircraft. These values are adjusted based on the technology portfolio. The different impacts from the portfolios are also listed in Table 4. This technological impact on the vehicle are based on the results of the extensive literature study as described in chapter 3.

Table 4: Technology Factors applied D239

| Parameter | Unit | Value | Eng. RetroFit | N+1 | N+2 |
|---|---|---|---|---|---|
| Eff. Gas Turbine | [-] | 0.5099 | +4,25% | +4,25% | +15% |
| Bypass Ratio | [-] | 12.05 | 16 | 16 | 16 |
| Engine Mass | [kg] | 8955.2 | +18% | +18% | +18% |
| Fuselage Mass | [kg] | 10877 | - | -5% | -10% |
| Wing Mass | [kg] | 10121 | - | -10% | -15% |
| VTP Mass | [kg] | 502.31 | - | -3% | -10% |
| HTP Mass | [kg] | 775.87 | - | -3% | -10% |
| Cabin Mass | [kg] | 3667.6 | - | - | -15% |
| System Mass | [kg] | 5643 | - | - | -2% |
| Wing span | [m] | 35.8 | - | +17% | +17% |
| Lift to Drag Ratio Cruise | [-] | 18.366 | - | +5% | +8% |

By applying these factors to all the concepts the results of the mission calculation provides the fuel burn for the design mission. Investigating the fuel burn of all concepts following trendlines are derived as results. In Figure 9 the trendlines for the narrow body aircraft segment is shown. In the conservative scenario there is a reduction in mission fuel burn of 17,1% until 2050 by applying the DEPA 2070 technology portfolio. In the progressive scenario including the more advanced N+2 concept a reduction in fuel burn of 21,8% is possible due to the openAD calculations. These reductions in fuel burn are based on the impact from the new aricraft technologies not including alternative fuels, ATM or air transport system (ATS) technologies.

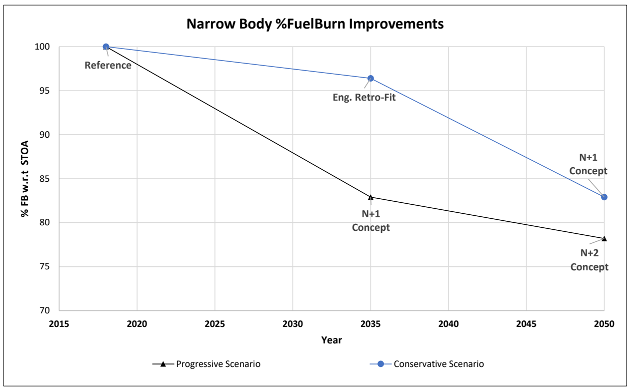


Figure 9: Technology Trendline Narrow Body Aircraft

### 5.1.2. Wide Body Aircraft

The reference model for the wide body aircraft assessment is the D366 which is a representative digital model for the Airbus A350-1000. Figure 10 shows the geometry of the model derived from the TiGL-Viewer. In Table 5 the top-level aircraft requirements for the wide body aircraft are collected. Similarly, to the narrow body study, these values are constant for the whole technology assessment.

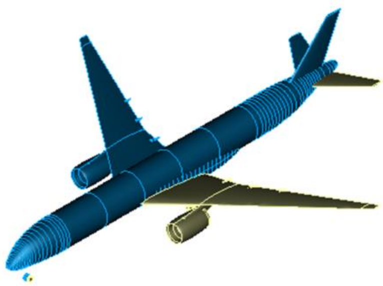

Figure 10: Isometric View of the D366 Model

Table 5: Top Level Aircraft Requirements Wide Body Use Case

| Parameter | Unit | Value |
|---|---|---|
| Number of Passenger | [-] | 366 |
| Design Range | [km] | 15446 |
| Design Payload | [kg] | 34770 |
| Mach Cruise | [-] | 0.85 |
| Cruise Altitude | [m] | 10058 |

To compare the mission level results also for the wide body segment, the same methodology is applied as for the narrow body aircraft assessment. The top-level aircraft requirements based on the reference vehicle are kept constant in the aircraft design process. For the concepts the technology factors are adjusted in OpenAD based on the technological impact from the technology portfolio. As for the narrow body segment the wide body model D366 is used to adjust the factors in CPACS and running OpenAD to model 3 different concepts. The technology factors adjusted in the D366 model are listed in Table 6. The wing span only changes by 12% for the wide body model, because of the higher wingspan in general. 12% more wing span is needed here to change the aspect ratio similarly to the narrow body model where the wing span is changed by 17%.

Table 6: Technology Factors applied D366

| Parameter | Unit | Value | Eng. RetroFit | N+1 | N+2 |
|---|---|---|---|---|---|
| Eff. Gas Turbine | [-] | 0.53943 | +4,25% | +4,25% | +15% |
| Bypass Ratio | [-] | 9.01 | 16 | 16 | 16 |
| Engine Mass | [kg] | 19835 | +18% | +18% | +18% |
| Fuselage Mass | [kg] | 28050 | - | -5% | -10% |
| Wing Mass | [kg] | 33837 | - | -10% | -15% |
| VTP Mass | [kg] | 1383 | - | -3% | -10% |
| HTP Mass | [kg] | 2532.9 | - | -3% | -10% |
| Cabin Mass | [kg] | 10104 | - | - | -15% |
| System Mass | [kg] | 11798 | - | - | -2% |
| Wing span | [m] | 64.75 | - | +12% | +12% |
| Lift to Drag Ratio Cruise | [-] | 21.055 | - | +5% | +8% |

By applying these facotrs to the CPACS file of the model, OpenAD then sizes the new aircraft concepts including the refered technology factors. OpenAD then calculates the fuel burn for the required design mission and by post processing the data from CPACS the technology trendline derived. As for the narrow body concepts the trendlines have the timesstamp 2035 and 2050 which represent the introduction of the concepts with included technology portfolios. For the wide body aircraft concepts in the conservative scenario the fuel burn for the design mission can be reduced until 2050 by 17,2%. For the N+2 concept in the progressive scenario for 2050 a fuel burn reduction of 25,8% is calculated by this mission level study. The trendline is shown in Figure 11.

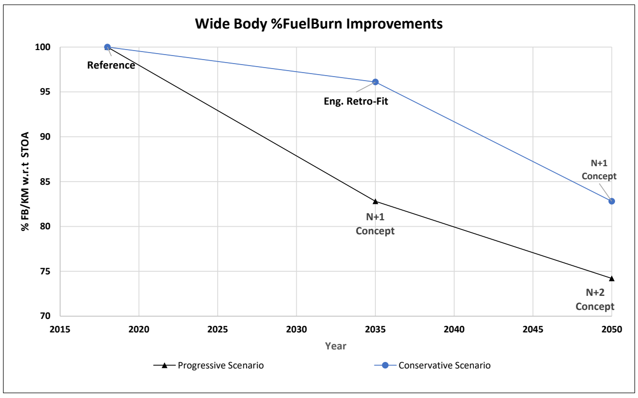


Figure 11: Technology Trendline Wide Body Aircraft

## 6. FLEET LEVEL INTERFACE

The vehicle assessment as described before compares the technology portfolios and their derived concepts only on one specific design mission. However, normally an aircraft does not only operate on a design mission when it is operating in an airline business. The aircraft is used for different routes with different payloads, depending on the demand of the operator. This perspective represents the fleet level which involves more global factors and behaviors of the aviation system. Different models to show the evolution of the fleet level of the aviation sector are used in DLR, for example the FORMO model [27]. These models are used in forecasting of flight schedules of civil aviation transport until 2050 or even further in the future. In this flight schedules different aircraft parameter and their technology developments can be implemented. Required aircraft data from new concepts to include in this flight schedules are: Entry into service, out of production date, fuel burn reduction vs. state of the art, range, seat capacity and energy carrier.

For the vehicle assessment only, a design mission with constant range and payload is calculated and compared. By calculating the payload-range characteristics using OpenAD the new concepts will show their capabilities on three different payload-range configurations. As displayed in Figure 12 the payload-range diagrams for the concepts differ from the reference aircraft. Here the payload-range characteristics of the narrow body concepts are displayed.

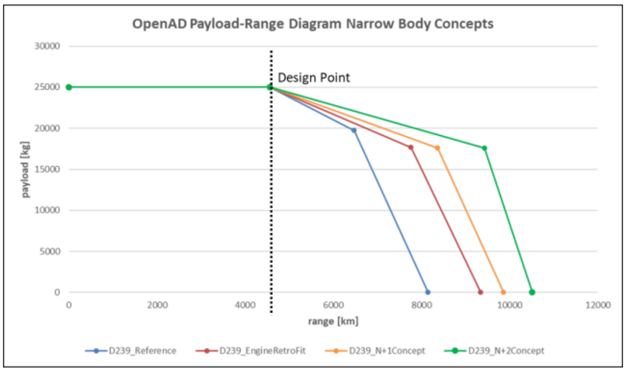


Figure 12: Payload-Range Diagram D239 Concepts

Due to the better fuel efficiency of the concepts their maximum range is larger than the range of the reference aircraft. In the narrow body use case the maximum range of the engine retro-fit concepts increases by 12,9%, for the N+1 concept by 17,4% and for the N+2 an increase of the maximum range by 22,5% is reached.

## 7. CONCLUSION AND OUTLOOK

This paper describes an aggregated methodology to access technology impact on mission level for representative aircraft models. Firstly, a systematic technology scouting approach is applied, generating a technology explorer with relevant future aircraft technologies and their impacts. A simple methodology is used to derive technology portfolios to model concept vehicles, based on the scenario definition from the DLR project DEPA 2070. These concepts are linked to an entry into service year to fulfill the technology roadmapping through the trendlines until 2050. Subsequently the aircraft design process is started which includes OpenAD as an aircraft design tool. By adjusting the technology factors, the new aircraft concepts are derived. For the comparison on vehicle level this paper demonstrates how the design mission of the aircraft is compared and how the technology trendlines are derived for the respective mission. Furthermore, the generated new concept aircraft can be used in a global assessment by implementing them into a given demand forecast and flight schedules. The concept aircraft payload-range characteristics are calculated using OpenAD and the new characteristics then can lead to new routes and airline use cases for these concept vehicles.

The technology taxonomy and the technology assessment and selection methodology are based on an extensive literature study to conduct aircraft technologies for the technology explorer. The application of a literature study usually holds a lot of uncertainties which are not further investigated in this framework. In future work additional expertise in the scouting of technologies is needed. For the project DEPA 2070 for example the technology scouting process is combined with several expert interviews for technologies with very uncertain impacts. Nevertheless, the taxonomy in the technology explorer opens a lot of possibilities to describe these uncertainties and other information uncertainties. This enables the framework for more detailed studies also for example on non-$CO_2$ effects of technologies. For an environmental impact assessment including non-$CO_2$ emissions and effects an additional assessment step will be required in order to estimate and calculate climate impacts (e.g. a temperature change) due to the combination of $CO_2$ and non-$CO_2$ emissions. This assessment step would have to include an approach on handling the uncertainties of the reductions for future emissions. Generally climatological models such as DLRs AirClim [28] could be used for this kind of assessment. The same framework presented in this paper can be also used for the estimation of technology impact factors by applying them to more detailed CPACS models which include all emission data for the engines of the model. In future work not only fuel burn as a metric can be applied to the technology trendlines, but the complete emission ($CO_2$ and non-$CO_2$) reduction could be presented.

In the future the framework can be used for more detailed studies on mission level. Therefore, more use cases can be applied, for example the investigation of the technology impact of regional aircraft. The D70 model could be regarded the reference model for this use case. In addition to the technology trendlines this framework opens also the possibility to calculate sensitivity studies on selected aircraft technology factors (see chapter 5.1.1. and 5.1.2.). These sensitivities could then lead to a broader investigation of different technology factors and the investigation on a single technology impact.

Furthermore, the investigation of technology combinations, a more detailed methodology of selecting the technology portfolio is in development. New publications propose utilizing their methodology by using model-based system engineering (MBSE) tools for technology identification and their combination potentials. In future such a methodology could be implemented in the framework presented in this paper to attain more reliable results.

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## REFERENCES

[1] Grewe, V., Rao, A. G., Grönstedt, T., Xisto, C., Linke, F., Melkert, J., Middel, J., Ohlenforst, B., Blakey, S., Christie, S., Matthes, S., and Dahlmann, K., Evaluating the climate impact of aviation emission scenarios towards the Paris agreement including COVID-19 effects. Nature Communications, (2021), DOI: https://doi.org/10.1038/s41467-021-24091-y

[2] The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, D.S. Lee, Atmospheric Environment Vol. 244, 2021, DOI: https://doi.org/10.1016/j.atmosenv.2020.117834

[3] Airbus, Global Market Forecast 2024, retrieved online on 13th September 2024, URL: https://www.airbus.com/sites/g/files/jlcbta136/files/2024-07/GMF%202024-2043%20Presentation_4DTS.pdf

[4] IPCC, Intergovernmental Panel on Climate Change (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, 2021, URL: https://www.ipcc.ch/report/ar6/wg1/

[5] European Commission 2019 – A European Green Deal – Striving to be the first climate-neutral continent, retrieved online on 19th March 2024, URL: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[6] Clean Aviation, Clean Aviation Joint Undertaking, retrieved online on 12th, September 2024, URL: https://www.clean-aviation.eu/who-we-are and https://www.clean-aviation.eu/mission-and-values

[7] Federal Aviation Administration, United States of America: United States 2021 Aviation Climate Action Plan, 2021. Retrieved online on July 30th 2024, URL: https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

[8] Netherlands Aerospace Centre (NLR), Netherlands Aerospace Centre: Destination 2050 - A Route to net zero European Aviation, February 2021. Retrieved online on July 30th 2024, URL: https://www.destination2050.eu/

[9] Clean Aviation, Clean Sky 2 Joint Undertaking: Clean Aviation - Strategic Research and Innovation Agenda, December 2021. Retrieved online on July 30th 2024, URL: https://www.clean-aviation.eu/clean-sky-2/technology-evaluator

[10] Air Transport Action Group: WAYPOINT 2050 – Balancing growth in connectivity with a comprehensive global air transport response to the climate emergency: a vision of net-zero aviation by mid-century, September 2021. Retrieved online on July 30th 2024, URL: https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf

[11] German Aerospace Center (DLR), Aerospace Technology Institute: Auf dem Weg zu einer emissionsfreien Luftfahrt - Towards emission free aviation - DLR Strategy for European Green Deal, December 202. Retrieved online on July 30th 2024, URL: https://www.dlr.de/de/aktuelles/nachrichten/2021/04/20211215_auf-dem-weg-zu-einer-emissionsfreien-luftfahrt

[12] Clean Aviation, Clean Aviation Joint Undertaking: Clean Sky 2 - Technology Evaluator First Global Assessment 2020 Technical Report, May 2021. Retrieved online on July 30th 2024, URL: https://clean-aviation.eu/sites/default/files/2022-01/CAJU-GB-2021-12-16-SRIA_en.pdf

[13] European Union Aviation Safety Agency: European Aviation Environmental Report 2022, 2022. Retrieved online on July 30th 2024, URL: https://www.easa.europa.eu/eco/eaer

[14] Aerospace Technology Institute: Destination Zero - The Technology Journey to 2050, 2022. Retrieved online on July 30th 2024, URL: https://www.ati.org.uk/wp-content/uploads/2022/04/ATI-Tech-Strategy-2022-Destination-Zero.pdf

[15] International Council on Clean Transportation: Vision 2050 - Aligning Aviation with the Paris Agreement, 2022. Retrieved online on July 30th 2024, URL: https://theicct.org/insight-analysis/publications/

[16] International Civil Aviation Organisation: Report on the feasibility of a long-term aspirational goal (LTAG) for international civil aviation CO2 emission reductions, March 2022. Retrieved online on July 30th 2024 , URL https://www.icao.int/environmental-protection/Pages/LTAG.aspx

[17] European Federation for Transport and Environment AISBL: Roadmap to climate neutral aviation in Europe, March 2022. Retrieved online on July 30th 2024, URL: https://www.transportenvironment.org/articles/2050roadmap

[18] Mission Possible Partnership: Making Net-Zero Aviation Possible - An industry-backed, 1.5°C-aligned transition strategy, July 2022. Retrieved online on July 30th 2024, URL: https://3stepsolutions.s3-accelerate.amazonaws.com/assets/custom/010856/downloads/Making-Net-Zero-Aviation-possible.pdf

[19] Roland Berger Holding GmbH & Co. KGaA: Roadmap to True Zero. A path-breaking approach to bring down aviaiton's total climate impact, August 2022. Retrieved online on July 30th 2024, URL: https://www.rolandberger.com/en/Insights/Publications/Aviation-s-Roadmap-to-True-Zero.html

[20] Netherlands Aerospace Centre (NLR), Netherlands Aerospace Centre: TRANSCEND D3.2: Novel propulsion and alternative fuels for aviation towards 2050, September 2022. Retrieved online on July 30th 2024, URL: https://cordis.europa.eu/project/id/864089/results

[21] International Air Transport Association (IATA): Aircraft Technology - Net Zero Roadmap, 2023. Retrieved online on July 30th 2024, URL: https://www.iata.org/en/programs/environment/roadmaps/

[22] House of Commons Environmental Audit Commitee (UK): Net zero and the UK aviation sector, December 2023. Retrieved online on July 30th 2024, URL: https://publications.parliament.uk/pa/cm5804/cmselect/cmenvaud/404/report.html

[23] Aerospace Technology Institute: Non-Co2 Technologies Roadmap, April 2024. Retrieved online on July 30th 2024 from https://www.ati.org.uk/funding/non-co2programme/

[24] Alder, M., Moerland, E., Jepsen, J., and Nagel, B., "Recent advances in establishing a common language for aircraft design with CPACS," Aerospace Europe Conference 2020, 2020, URL: https://elib.dlr.de/134341/

[25] Sebastian Wöhler, Georgi Atanasov, Daniel Silberhorn, Benjamin Föhler, Thomas Zill: Preliminary Aircraft Design with a multidisciplinary multifidelity design environment OpenAD, 2020, URL: https://elib.dlr.de/185515/1/AE2020_032_woehler.pdf

[26] German Aerospace Center (DLR): Development Pathways for Aviation up to 2070 (DEPA 2070), DLR Project, 2021-2024, URL: https://www.dlr.de/de/lv/forschung-transfer/projekte/laufende-projekte/depa-2070

[27] Markus Kühlen, Klaus Lütjens, Florian Linke, Volker Gollnick: An explanatory approach to modeling the fleet assignment in the global air transportation system, CEAS Journal, 2023, DOI: https://doi.org/10.1007/s13272-022-00622-1

[28] V. Grewe and A. Stenke: AirClim: an efficient tool for climate evaluation of aircraft technology, 2008, DOI: https://doi.org/10.5194/acp-8-4621-2008