GLOWOPT

Global-Warming Optimized Aircraft Design

A Clean Sky 2 project to develop novel Climate functions for designing new "green" aircraft to reduce climate impact of aviation.

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Clean Sky 2
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Objectives

The GLOWOPT research and innovation action addresses the Thematic Topic *"Aircraft Design Optimisation providing optimum performance towards limiting aviation's contribution towards Global Warming".* The specific challenge associated to this topic is to address the issue of global warming minimization from a multi-parametric and multi-disciplinary design optimization approach.

GLOWOPT is set to directly contribute to this challenge by developing innovative Climate Cost Functions for design that allow for a minimization of the climate impact of next-generation aircraft within the MDO process.

In aircraft design optimization studies, fuel burn, maximum take-off mass or direct operation cost are used often used as cost functions. However, when an environmental-impact metric is used, such as equivalent CO_2 emissions, the optimal aircraft has different wing-loading and thrust-to-weight ratio and flies at a different cruise altitude compared to an aircraft designed for minimal fuel burn. It is therefore, important that if we wish to design aircraft for minimal global warming impact that a Climate Cost Function (CCF) is defined that is sensitive to aircraft/engine design parameters as well as operational parameters.

More than 50% of the climate impact from aviation arises from non-CO_2 effects. Therefore, complex climate-chemistry models were used in the past to evaluate the climate impact of aircraft cruise altitude and designs, which is far too computational demanding for a multi-disciplinary optimisation (MDO) process, requiring a multitude of climate impact evaluations. Instead, climate cost functions, as proposed in GLOWOPT, enable such an MDO process.

The high-level objective of the proposed GLOWOPT project is the development and validation of Climate Cost Functions with respect to minimizing global warming and their application to the multidisciplinary design optimization of next-generation aircraft for relevant market segments.

Several objectives are set in order to reach this target.

- **The first objective is to provide an overview of the state of the art on the scientific background** of the relation between aircraft design and operation and its climate impact (WP1).

- The second objective is to **derive characteristic aircraft design requirements**, primarily payload and range, based on statistical data analysis of the worldwide aircraft fleet and route structure for future entries into service (WP2).

- The third objective is to **develop climate cost functions for the use in the aircraft design optimisation**, which reliably represent the climate impact of CO_2, NO_x, H_2O emissions, as well as contrail-cirrus effects (WP3).

- The fourth objective is to **perform a Multidisciplinary Design Optimization with respect to the climate cost function** to find a set of operational parameters, design parameters and aircraft technologies that minimize the climate impact of the aircraft design (WP4).

- The fifth and final objective is to **perform an assessment of the aircraft designs chosen in order to quantify their impact on important metrics** such as landing and take-off noise, emissions and cash operating cost (WP5).

Motivation

The aviation sector must undergo a revolution as commercial air travel is growing at an impressive pace and of emissions on climate change at high altitude are deemed very relevant. The targets set by ACARE of 75% CO_2 and 90% NO_x emission reduction respectively by 2050 relative to a baseline aircraft from the year 2000 are pushing the aviation industry to rethink the way aircraft are designed and operated. Within the Clean Sky 2 framework a plethora of technologies are under investigation to enable the next generation of aircraft with new technologies to make them lighter, more aerodynamically efficient, quieter, and more fuel efficient. Aircraft operators use these aircraft to make a profit, which implies that they will fly these aircraft on multiple routes at a combination of speed and altitude that maximizes their revenue. This implies that most transport aircraft fly at altitudes where contrail-cirrus formation is high resulting in a negative impact on global warming. Also, to cater for network flexibility, most of the routes in the network have a mission range that is considerably below the maximum mission range, which implies that the aircraft is actually oversized in terms of weight, wing area, and engine power to fly these missions. This results in more emissions and global warming impact on such missions than would be the case for an aircraft that is specifically designed for these missions. The question is for what top-level aircraft requirements (TLARs) the next generation of aircraft should be designed such that their impact on global warming is minimized while network flexibility is still ensured.

The Clean Sky 2 programme has been set up to:

- accelerate the progress towards the ACARE SRIA goals for 2020-2050;
- enable a technological leap in the face of emerging competitors;
- justify the early replacement of aircraft that have yet to enter service and accelerate the adoption of new technology into the global fleet.

The Programme aims to accelerate the introduction of new technology in the 2025-2035 timeframe. It is assumed that by 2050, 75% of the world's fleet now in service (or on order) will be replaced by aircraft that can deploy Clean Sky 2 technologies. It is therefore of special importance that aircraft manufacturers are provided a technique as early as possible, which allows for the consideration of the aircraft's fleet level climate impact at design stage, to make sure that next-generation aircraft will have a considerably smaller impact on global warming.

Climate Cost Functions (CCF), sometimes also referred to as Climate Change Functions, represent mathematical objective functions to be used in single- or multi-objective optimization processes. The concept of such CCFs has been originally developed in the EU project REACT4C and extended to so-called algorithmic CCFs (aCCFs) in the SESAR Exploratory Research project ATM4E. In these projects, 3-dimensional (latitude, longitude, altitude) CCFs were used to determine the optimum route or trajectory of an aircraft, as they allow for the computation of the climate impact of a unit emission of the relevant species (CO_2, H_2O, NO_x), which is released at a specific location.

While the REACT4C-CCFs have been designed to specific weather situations and required a lot of computational effort, the aCCFs provide a means to quickly calculate CCFs for any given weather situation based on formulas using a limited number of meteorological parameters.

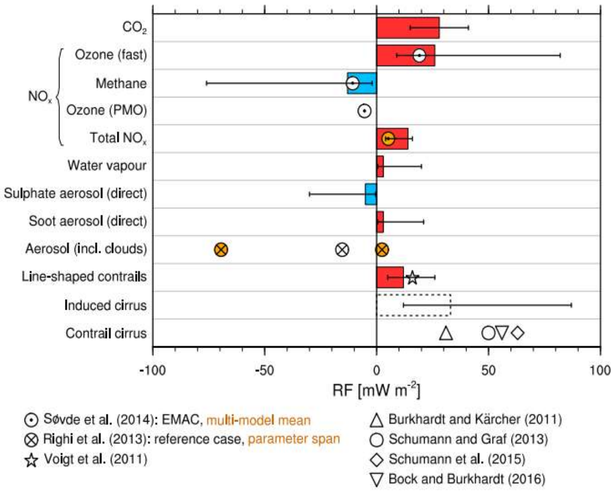
However, the CCFs that GLOWOPT will develop address the aircraft design process and therefore will look substantially different. These novel CCFs for aircraft design will not be a function of the location any more, but need to include the effect of the route network the aircraft will be operated in implicitly.

For the first time, GLOWOPT will create such aircraft design-related CCFs.

Work Packages

WP 1: Review of State-of-the-Art

The objective of this work package is to provide an overview of the state of the art on the scientific background of the relation between aircraft design and its climate impact. In order to achieve this overall objective, the following more detailed objectives have to be accomplished:



Measure of Climate impact of aviation

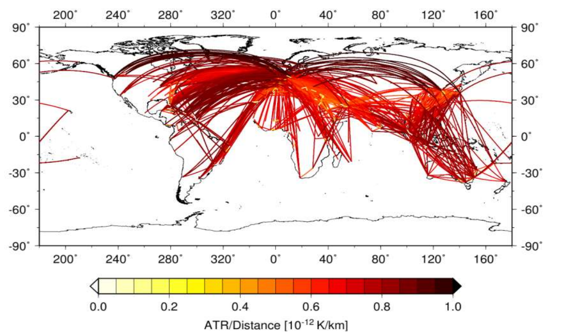
- Analysis of previous research related to the overall climate impact of aviation.
- Analysis of previous research on climate impact metrics, corresponding temporal scales and their application to different problems.
- Analysis of previous research on the sensitivity of the overall climate impact with regard to operating parameters such as cruise speed and altitude, as well as on the analysis of the interaction between atmospheric conditions and operating parameters.
- Analysis of previous research on aircraft design optimization studies regarding climate impact reduction.

The description of the state of the art on the relation between aircraft design and climate impact is split into four tasks, which represent four key areas in atmospheric and aircraft design research and reflect both the individual competences of the consortium and the four detailed objectives.

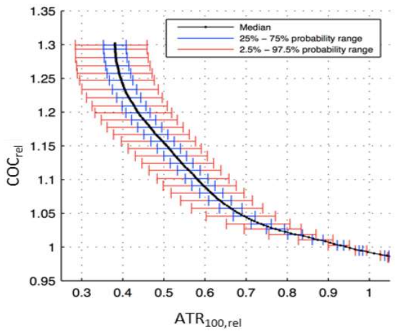
Task 1.1: Overall climate impact of aviation
A literature review will be performed to analyse and summarise previous research related to the overall climate impact of aviation. Special emphasis is given on non-CO_2 effects, such as stemming from emissions of nitrogen oxides, water vapour, particulate matters, as well as contrail, and contrail-cirrus effects.

Task 1.2 Climate metrics
Previous research on climate metrics will be analysed, identifying the range of metrics, the impact of a metrics choice on the results and on how to use the climate metrics, linking climate metrics to specific climate targets.

Task 1.3: Climate-optimized aircraft operation
A literature review will be performed in order to analyse the sensitivity of the overall climate impact with with regard to operating parameters such as cruise altitude and speed. Additionally, previous research focusing on the interaction between atmospheric conditions, resulting climate sensitivities and potential operational strategies avoiding climate sensitive regions is considered (e.g. lateral rerouting, altitude adaptions). The literature review will contain the findings from previous projects such as CATS, REACT4C, ATM4E, and WeCare.



Specific climate imapct (ATR_100) per route (K/Km)

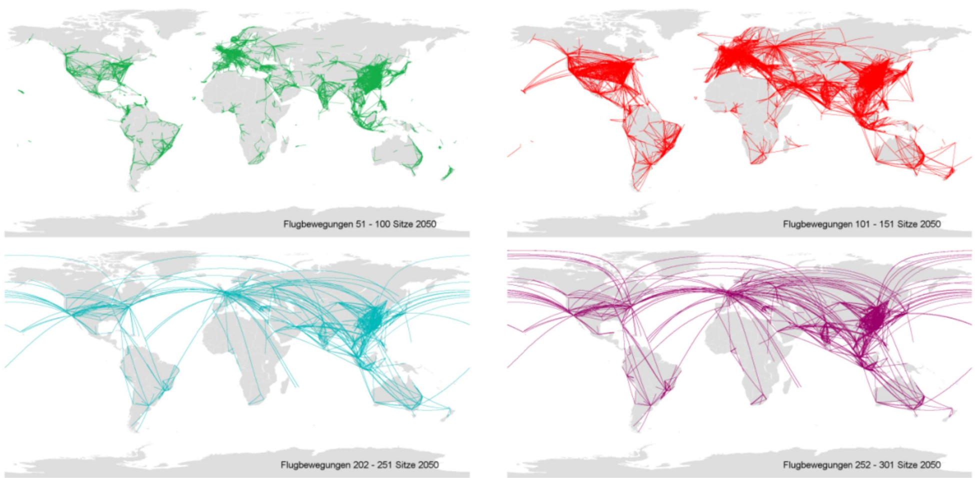


Optimal relation between cost and climate

Task 1.4: Climate-optimized aircraft design
A literature review will be performed on research focussing on aircraft design studies, which include climate impact assessments or even optimisations.

WP 2: Representative Route Network and Fleet

This work package aims at deriving characteristic aircraft design requirements, primarily payload and range. These requirements are determined based on a analysis of the worldwide aircraft fleet and route structure for future entries into service (EIS).



Project specific adaptation of future air traffic prediction

The work to be carried out in WP2 is subdivided into four tasks contributing to the sub-objectives:

Task 2.1: Adaptation and preparation of air traffic forecast model
An existing model chain for the prediction of future aircraft movements will be extended and updated. The applied air traffic forecast model consists of three network layers: (1) the passenger origin-destination demand network, (2) the routes network and (3) the aircraft movements network. The included passenger air traffic demand model (layer 1) is updated and calibrated with respect to latest passenger demand figures. Additionally, a frequency-capacity-model calculating flight frequencies and aircraft size is adapted and a fleet renewal model is updated using up-to-date order book data (layer 3).

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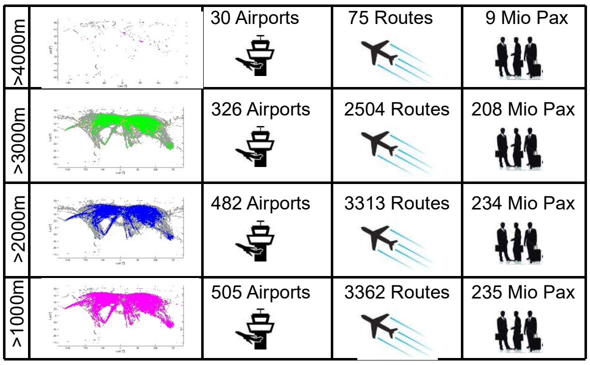
Task 2.2: Identification of relevant TLARs and aircraft design constraints
Within this task, TLARs which are considered to be relevant in the course of this project, are identified (e.g. payload and range). Moreover, additional aircraft design constraints which limit the aircraft design envelope (e.g. airport gate constraints, take off field length) are listed.



Task 2.3: Prediction of future air traffic
The updated air traffic forecast model will be applied in order to predict today's and future global air traffic flows. Therefore, the number of passengers transported between city-pairs as well as the specific itineraries which are chosen are computed. The resulting forecast is compared with relevant market forecasts from other institutions.

Task 2.4: Analysis of fleet composition, TLAR and design constraint definition
The resulting quantities constitute the basis for a statistical overview of the required transport capacities on any flight segment. In conjunction with the fleet renewal model and the frequency-capacity model, the analysis of the market's composition as well as the derivation of the conceptual aircraft's design TLARs and design constraints for selected market segments and corresponding route networks are conducted.

WP 3: Climate Cost Functions

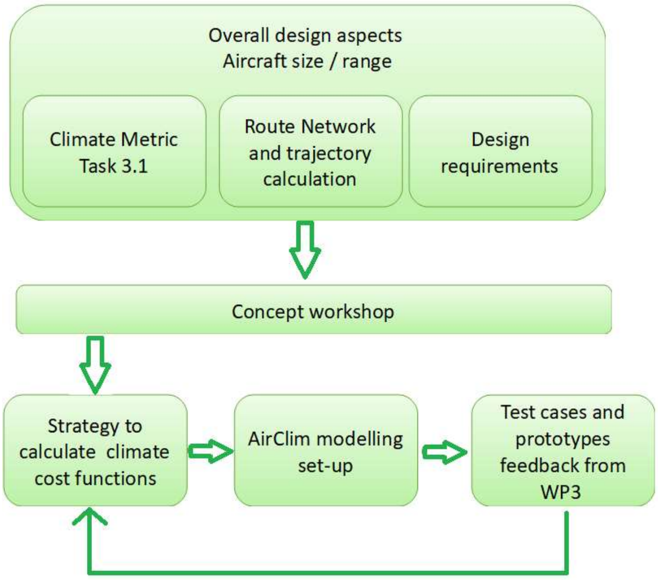
The overall objective of this work package is to develop climate cost functions for the use in the aircraft design optimisation in WP4, which reliably represent the climate impact of CO_2, NO_x, H_2O emissions, as well as contrailcirrus effects. To reach this overall objective some more detailed objectives have to be achieved:

- Determination of a climate metric adequately addressing the climate impact of a new aircraft design
- Set up of a strategy how to calculate the climate-cost functions
- Calculation of the climate cost functions

For the calculation of the climate-cost functions three steps have to be taken, which relate to the three more detailed objectives:

Task 3.1: Determination of an adequate climate metric
Based on findings from WP 1 a set suitable climate metrics, including an emission scenario and time horizon, will be determined and the sensitivity to choices made will be tested based on an emission data base, such as TRADEOFF or REACT4C. Based on the findings an adequate climate metric will be selected.

Task 3.2: Development of a strategy to calculate climate-cost function



Based on the WP 5 workshop results and in cooperation with WP 2 a strategy to calculate the climate cost functions will be developed. The WP 5 workshop identifies the parameters which are addressed at aircraft design level and which are key input parameters to both the calculation of the climate cost function and its application. Those parameters might be cruise altitude, NO_x-Emission Index, fuel consumption, etc. Parameter ranges of these key input parameters and common interfaces for the climate-cost function will be defined in cooperation with the partners. A set-up for the AirClim modelling environment will be developed and tested for this specific application. Based on the tests, a prototype climate-cost function is derived and exchanged with WP 3 to ensure common interfaces and allow early testing of subsequent tasks.

Task 3.3: Calculation of climate-cost functions

The set-up of the AirClim modelling environment, which is developed and tested in Task 3.2, will be employed to calculate large look-up tables, which will serve as the basis for the climate cost function. Cross-checks, e.g. based on the sensitivity calculation performed in Task 3.1, will be performed to guarantee the validity of the calculation procedure. Based on these massive calculations climate cost functions will be derived and delivered to WP 4 and the work summarized for publication.

WP 4: Aircraft Design Optimization

The goal of this work package is to find which set of operational parameters, design parameters and aircraft technologies minimize the climate cost function of WP3. More specifically, the following questions need to be answered in this work package:

- Which combination of range, speed and altitude should be selected for the optimal design?
- Which combination of design parameters should be selected for the optimal design?
- Which technologies should be included in the optimal design?

Task 4.1: Design reference aircraft

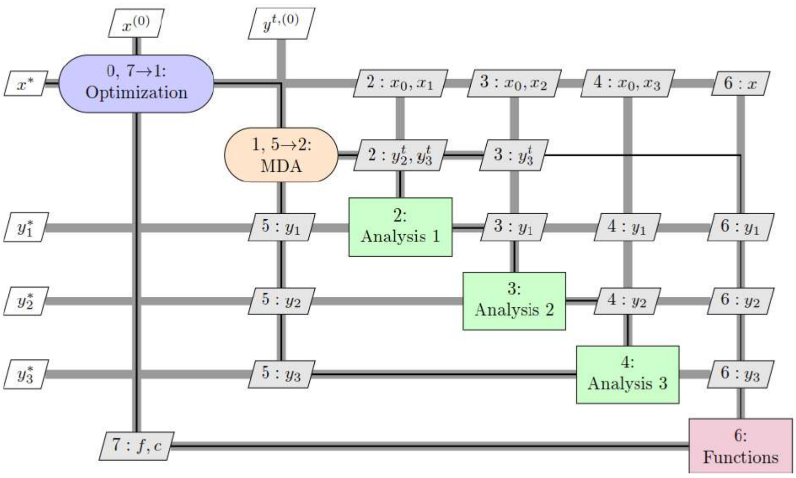
The reference aircraft serves as a baseline for comparison of the global-warming optimized design. The reference aircraft can be used to compare the proper functioning of the aircraft design methodology that is employed in this project (verification) as well as to compare the resulting performance, weight, and geometric characteristics to an existing aircraft (validation). Once the climate cost function of WP3 is established, the global warming impact of the reference aircraft can also be quantified.

Task 4.2: Create envelope of operational parameters and engine/airframe parameters
Based on the fleet analysis of WP2, an envelope of operational parameters is established. This includes variation in harmonic range, cruise altitude, cruise speed, as well as airport-related parameters such as gate-constraints, take-off field length, and landing distance. Furthermore, a range of engine and airframe parameters are established, which have an impact on aircraft performance such as engine bypass ratio, wing aspect ratio or the type of high-lift devices that are installed.

Windows Server 2008 R2 Network Optimizations compatibility matrix						
	TCP Chimney Offload	VMQ	RSS	Jumbo Frames	Teaming	VLANs
TCP Chimney Offload	N/A	VMQ have precedence	Yes	Yes	Depends on vendor NIC and drivers	Yes
VMQ	VMQ have precedence	N/A	No	Depends on NIC and drivers	Intel requires Proset 15.0 or higher	Yes
RSS	Yes	No	N/A	Yes	Yes	Yes
Jumbo Frames	Yes	Depends on NIC and drivers	Yes	N/A	iSCSI traffic does not support teaming. MPIO must be used for fault tolerance	Yes
Teaming	Depends on vendor NIC and drivers	Intel requires Proset 15.0 or higher	Yes	iSCSI traffic does not support teaming. MPIO must be used for fault tolerance	N/A	yes
VLANs	Yes	Yes	Yes	Yes	Yes	N/A

Task 4.3: Create technology portfolio and establish boundary conditions
Based on the literature survey in WP1, a technology portfolio is created that could potentially improve the climate cost function of WP3. For each technology, its impact on system mass, drag, and/or power consumption is quantified such that it can be used in the overall aircraft synthesis process. Moreover, a technology compatibility matrix is established. Furthermore, boundary conditions stemming from operational conditions (i.e. SESAR) that affect the aircraft performance are also established.

Task 4.4: Perform multi-disciplinary design optimization
Using the results of the two previous tasks, a multi-disciplinary aircraft design synthesis method is employed to assess the climate cost function of WP3. Given the large design space in terms of possible technology combinations, operational parameters, airframe parameters and engine parameters a search strategy for finding the optimum will be employed. The search algorithm is to be define in this work package and could be (a combination of) a response-surface method, a global optimization scheme or a gradient-based optimization scheme.



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WP 5: Assessment

The main objective of this work package is to perform a higher-fidelity assessment of the aircraft designs chosen in WP4 in order to assess the effectiveness and validity of the climate cost functions for aircraft design developed in WP3. Therefore, the following more detailed objectives have to be accomplished:

- Creation of global emission inventories for reference and climate optimized aircraft designs
- Estimation of the global climate impact and associated direct operating costs for reference and climate optimized aircraft designs
- Analysis of the compliance with additional regulations (e. g. noise, local air quality)

Task 5.1: Global emission inventories for reference and climate optimized aircraft designs
Within this task, detailed trajectory calculations are performed for both, the reference as well as the climate optimized aircraft design from WP4 for the market segment(s) and the corresponding route network(s) selected in WP2. The resulting emission distributions along each route of the route network are aggregated as emission inventories.

Task 5.2: Assessment of climate impact and direct operating costs for reference and climate optimized aircraft designs
Based on the detailed trajectory calculations and the emission inventories generated in Task 5.1, the resulting climate impact for both, the reference and the climate optimized aircraft design is estimated using a higher fidelity climate impact assessment model in order to validate the climate cost functions derived in WP3. Moreover, direct operating costs resulting from the operation of the reference and the climate optimized aircraft on the regarded market segment's/ segments' route network(s) are estimated and compared against each other.

Task 5.3: Compliance of the climate optimized aircraft design with additional regulations
Within this task, the compliance of the climate optimized aircraft design from WP4 with additional current and future regulations including noise and local air quality is investigated.

Related Research and Innovation Activties

GLOWOPT makes use of pre-existing knowledge that has been generated in course of national and European projects. The objectives of GLOWOPT do not rely on pending results of any other project. Results from the following projects relate to GLOWOPT:

CATS: The DLR-internal project CATS (Climate-compatible Air Transport System) developed a multi-disciplinary simulation and analysis approach to study the climate impact of aviation with respect to changes in the operating conditions as well as the aircraft design parameters. First, the climate impact mitigation potential and cash operating cost changes of altered cruise altitudes and speeds for all flights globally operated by the Airbus A330-200 fleet in the year 2006 was analysed. Then, based on the results new design requirements were derived and with the aircraft design optimization software PrADO a new conceptual design was elaborated that was optimized for cruise conditions with reduced climate impact. It was found that replacing the entire A330-200 fleet by an aircraft redesigned for a cruise Mach number of . 72 and an initial cruise altitude of 8000 m could reduce the climate impact by 32% without any increase of cash operating cost.

WeCare: The DLR-internal project WeCare (Utilizing Weather information for Climate efficient and ecoefficient future aviation) aimed at finding solutions for reducing the climate impact of aviation based on an improved understanding of the atmospheric impact from aviation by making use of measurements and modelling approaches. WeCare gave a revised view on the total radiative forcing of aviation. The assessment of a fleet of strut-braced wing aircraft with an open rotor showed a significantly reduction in climate impact. Intermediate stop operations can reduce fuel consumption substantially. However, if only optimized for fuel use, they will have an increased climate impact, since non-CO_2 effects compensate the reduced warming from CO_2 savings. Avoiding climate sensitive regions has a large mitigation at relatively low costs. Thus, climate optimal routing is not cost-optimal. This conflict of objectives can be resolved, if regulatory or market-based measures are in place that include these non-CO_2 effects. An alternative measure to foster climate-optimal routing is the closing of air spaces, which are very climate-sensitive.

REACT4C: In the EU FP7 project REACT4C (Reducing Emissions from Aviation by Changing Trajectories for the benefit of Climate) a complex simulation framework was set up to optimize air traffic flow with respect to its climate impact . Based on a detailed weather classification 5 representative days for winter and 3 days for summer were selected to calculate Climate-Cost-functions for these individual days. They comprise the impact of local emissions on climate change and are used in a traffic simulator to optimize the traffic flow with respect to climate impact. The results from REACT4C indicate, in a case study, a large mitigation potential with a reduction of the climate impact of around 25% at a cost increase of about 0.5% for westbound trans-Atlantic flight and less for eastbound flights.

ATM4E: The SESAR2020 ER project ATM4E (Air Traffic Management for Environment) explored the feasibility of integrating environmental cost functions covering climate impact, local air quality and noise issues into the process of trajectory planning. Instead of computing high fidelity CCFs (see REACT4C), the concept of algorithmic environmental cost functions (aECFs) was evolved. These aECFs were estimated based on available meteorological forecast parameters (e.g. temperature) and integrated into a trajectory calculation framework in order to establish a multi-criteria environmental impact assessment allowing for the optimisation of air traffic with regard to environmental aspects. Results for a European air traffic sample indicate large climate impact reduction potentials in the order of 10's of percents going along with fuel penalties in the order of a few percents. Additionally, it was found that optimised aircraft routing may cause demand-capacity imbalances especially since flights are shifted to reduced cruise altitudes.

NOVAIR: The CSII project NOVAIR (Novel Aircraft Configurations and Scaled Flight Testing Instrumentation) investigates the impact of hybrid-electric propulsion on aircraft performance metrics (fuel burn, maximum take-off weight, etc.). This also includes the aero-propulsive interaction of integrated propulsion systems such as distributed propulsion or using a tail-cone thruster (relying on boundary-layer ingestion). It was found that electrification of the powertrain is only justified if sufficient aero-propulsive benefits can be realized, i.e. an increase in aerodynamic performance and/or an increase in propulsive efficiency. This is dependent on the integration of the propulsive system and the penalty in terms of system weight.

Expected Impact

GLOWOPT correlates with the complete list of expected outcomes mentioned under the Thematic Topic JTICS2- 2018-CFP09-THT-04. The following table provides an overview on how the project contributes to the single outcomes/impacts:

Expected Impact	GLOWOPT contribution
Analysis of previous research into the overall climate impact of aviation and in particular for the sensitivity of this impact to aircraft operating parameters such as cruise speed and altitude, as well as the SoA of understanding the interaction between atmospheric conditions and operating parameters [projects such as REACT4C et. al.]	**A comprehensive analysis of previous research and the SoA is provided by GLOWOPT through WP1**: • Task 1.1 will give a full overview on the overall climate impact of aviation. • Task 1.3 will give a full overview on previous research on the interaction between operating parameters and atmospheric impact.
SoA of previous optimization studies, and metrics used for global warming metrics	**A comprehensive analysis of previous research and the SoA is provided by GLOWOPT through WP1:** • Task 1.2. will give an overview on climate metrics and its usage • Task 1.4 will give an overview on research on climate optimised aircraft design
Analysis, selection and development of the most suited climate cost function	**The sound development of the aircraft design-related CCFs is one of the core activities in GLOWOPT and carried out within WP3:** • Based on the review in Task 1.2 a most suited climate metric will be selected in Task 3.1. • Based on the WP5 workshop an analysis of the most suited climate-cost function will be developed in Task 3.2, which is then calculated in Task 3.3.
Emissions (CO2 / NOx / Particulates / Aromatics / Water Vapour and Noise) prediction models and sensitivity to operating parameters such as flight altitude, Mach number)	**Where applicable GLOWOPT integrates and extends available emission models:** • Based on the selected propulsion technology and the performance of the aircraft engine emissions are calculated in the MDO process in WP4 to allow for an evaluation of the CCFs. • In the course of the assessment in WP5 with higher fidelity models engine emission distributions are calculated more in detail.
Aircraft/Engine Design and Performance Models including the effect of engine parameters such as OPR/BPR on the emissions 'species' and in particular on contrail formation with flight altitude.	**Aircraft and Engine performance models are inherent in the GLOWOPT MDO environment.** • They will be adapted in such way that all parameters for the evaluation of the CCFs

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	are calculated. • The conditions for contrail formation as well as their climate impact will be captured by the CCFs by design.
Selection of an appropriate predictive model of air traffic flows that allows statistically relevant selection of the overall market's composition and a selection of the conceptual aircraft's design payload and range	**GLOWOPT will incorporate an air traffic forecast model, which is the key element of WP2**. This will be the basis for • the analysis of future flight networks for different market segments, as well as • the selection of representative design payload and range
Presentation of one or more conceptual aircraft designs that allow to understand what the optimum aircraft/engine design combination (for both short medium and long range market segments) is, that would yield the minimum climate.	**GLOWOPT will deliver at least one reference aircraft design as well as one conceptual aircraft design with minimum climate impact as a result of the MDO process in WP4.**
The related impact of these selected designs on operating cost, block times, LTO emissions and noise should be provided as comparative performance estimates against current state of the art aircraft in service.	**In GLOWOPT a number of key performance indicators such as operating cost, block times, LTO emissions and noise will be determined as part of the assessment in WP5 and used to compare the performance of the next-generation aircraft to the reference.**

Consortium

To achieve its goals, GLOWOPT has assembled an international team with necessary multi-disciplinary expertise, and with experience of previously having worked successfully together in topics relevant to GLOWOPT (for example in the ATM4E project). The consortium is composed of two main participants, being those universities with the most relevant expertise in Europe to address the respective Thematic Topic. TUHH is involved with the Institute of Air Transportation Systems (ILT) and coordinates the Research and Innovation Action. TUD is contributing both with the Flight Performance and Propulsion (FPP) department and the Aircraft Noise and Climate Effects (ANCE) department.

Due to the fundamental character of Climate Cost Functions, the involvement of universities is predestined to address this Thematic Topic adequately. The three departments mentioned above bring in complementary expertise to achieve the GLOWOPT objectives spanning climate science (TUD-ANCE), aircraft design/MDO (TUD-FPP), aircraft technologies (TUD-FPP), aircraft operations on fleet/global level (TUHH-ILT), aircraft emissions modelling (TUHH-ILT) as well as air traffic scenarios and forecasts (TUHH-ILT). These are vital to understand the relationship between the aircraft design process, the service of aircraft within a global fleet and the climate impact of emissions as well as the sensitivity of the climate impact to changes in the aircraft design. In addition, the Consortium also have access to models (e.g. EMAC/AirTraf, TOM, AIRCAST, GRIDLAB) and data (e.g. climate cost functions, aircraft emissions) that will be used to assess the environmental impacts of different aircraft designs. Key personnel at TUHH and TUD has also collaborated with DLR in the context of the highly relevant CATS and WeCare projects and co-authored many of the respective publications.

An effective collaboration of the project partners is guaranteed by a clear work package and task structure and the overlapping membership of the WP teams. In each technical WP there all consortium members are involved. This is an ideal situation for promoting a cross-fertilisation between the different WPs and an exchange of expertise between different consortium members. Also regular communication by phone and online meetings as well as face-to-face meetings in Hamburg and Delft with the benefit of those places being not more than 500 km away from each other will support the effective collaboration of the partners. For effective exploitation of the results an Advisory Board will be established with representatives from all relevant stakeholders, e.g. aircraft manufacturers, which are in the position to provide market-oriented recommendations.