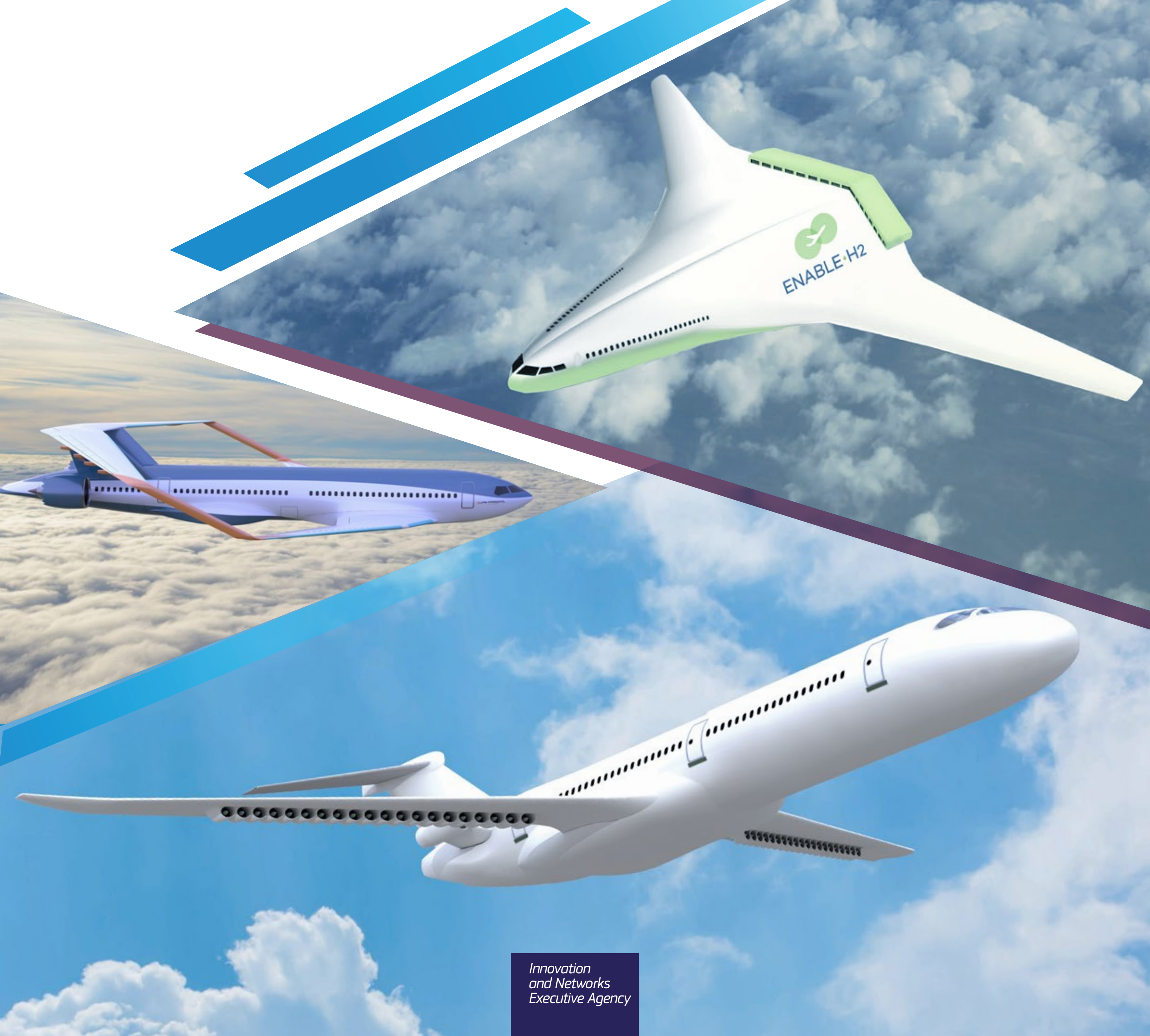
European Commission

# Towards Climate-Neutral Aviation

## Contributions from Horizon 2020 Projects Implemented by INEA




Innovation and Networks Executive Agency

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# FOREWORD

*I am delighted to introduce this publication presenting the European Union Innovation and Networks Executive Agency's (INEA) contribution to supporting research and technology development towards climate-neutral aviation.*

*Aviation is one of Europe's main industries of excellence and an important contributor to the European Union's economic prosperity: it maintains close to 5 million jobs and represents over 2% of European GDP. The continuous growth in demand for air transport worldwide will not only further increase the sector's economic and social impact, but it also calls for measures to mitigate its environmental footprint in terms of greenhouse gas (GHG) and air pollutant emissions and noise pollution.*

*INEA has been addressing this challenge through a growing number of collaborative aviation research and innovation projects supported by the Horizon 2020 programme. The projects featured in this publication are making an important contribution towards achieving the ambitious European Green Deal's objectives[1], namely a 55% reduction in greenhouse gas emissions by 2030 and a climate-neutral continent by 2050. They are developing technologies that will make aviation more environmentally friendly and safer, while improving citizens' quality of life. The aviation projects implemented by the Agency are delivering results that are not only further improving existing solutions but are also – and more importantly – developing the disruptive, game-changing technologies needed to further accelerate the path towards climate neutrality.*

*This publication presents key results and the impact of aviation research and innovation projects selected through competitive calls for proposals under the H2020 Transport and Energy Societal Challenges, i.e. "Smart, green and integrated transport" and "Secure, clean and efficient energy". The effective contribution made by the Agency towards supporting clean aviation in Europe is illustrated by highlights from completed and ongoing projects.*

*This publication was finalised during the COVID-19 outbreak, which is having an unexpectedly significant impact on the aviation sector and has introduced crucial challenges for the short-term future. The aviation industry in Europe is facing serious consequences, with a considerable reduction of passenger traffic and revenue losses for airlines expected in 2020. The European Commission is taking concrete actions and putting forward targeted initiatives to help ease the impact of the outbreak on the sector.*

*I hope you will enjoy your reading and appreciate the relevance of our work for a more sustainable European aviation sector.*

***Dirk Beckers***
***Director, INEA***

[1] The European Green Deal (https://ec.europa.eu/info/files/communication-european-green-deal_en)

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# INTRODUCTION

With worldwide air-traffic demand increasing at nearly 5% every year until 2019, aviation has been one of the most rapidly growing transport sectors: it moved more than 4.4 billion passengers in 2018, with a record of 120 thousand daily operated flights, and is expected to move more than 7.2 billion passengers in 2035[1].

The growth in air transport is accompanied by a growing demand for energy resources to "fuel" the sector[2], leading to an increase of greenhouse gas (GHG) and air pollutant emissions, as well as perceived noise levels. To date, global aviation accounts for approximately 2.1% of global carbon dioxide[3] ($CO_2$) emissions, and by 2050 emissions are expected to be seven to ten times higher than in 1990 due to the increase in air-traffic, according to International Civil Aviation Organisation (ICAO) projections. However, political instability in specific regions, wars or pandemic diseases which pose an on-going threat to global security can in turn influence either on a short-term or long-term the future of aviation growth and hence on the relevant emissions (Kousoulidou et al. 2016)[4].

Mitigating aviation impact on climate change, community noise and air quality is of primary importance in order to safeguard people's health and quality of life, and to protect the environment. The European aviation research community is currently addressing these challenges by leveraging on a growing number of dedicated research projects financed under the European Union's Horizon 2020 Framework Programme. As highlighted in the Flightpath 2050 – Europe's Vision for Aviation, research and technology developments for clean aviation should be further accelerated to effectively allow, by 2050, 75% reduction in $CO_2$ emissions per passenger kilometre, 90% reduction in NOx emissions and 65% reduction in perceived noise emissions (compared to the capabilities of typical aircraft of 2000).

To achieve the EU environmental goals by 2050, disruptive innovation in aircraft configuration and operations (including alternative energy sources) will be crucial for the EU aviation industry to stay globally competitive, as also indicated by the Advisory Council for Aeronautics Research in Europe (ACARE) Strategic Research and Innovation Agenda (SRIA). Future step changes in areas such as disruptive airframe configurations, low-emission propulsion systems (including hybrid-electric and hydrogen technologies), Sustainable Aviation Fuels (SAF), advanced lighter materials and more efficient manufacturing processes, on-board systems, as well as greener operations, will need to prove their value compared to evolutionary developments, whilst maintaining or improving the high levels of reliability, safety and usability that customers demand.

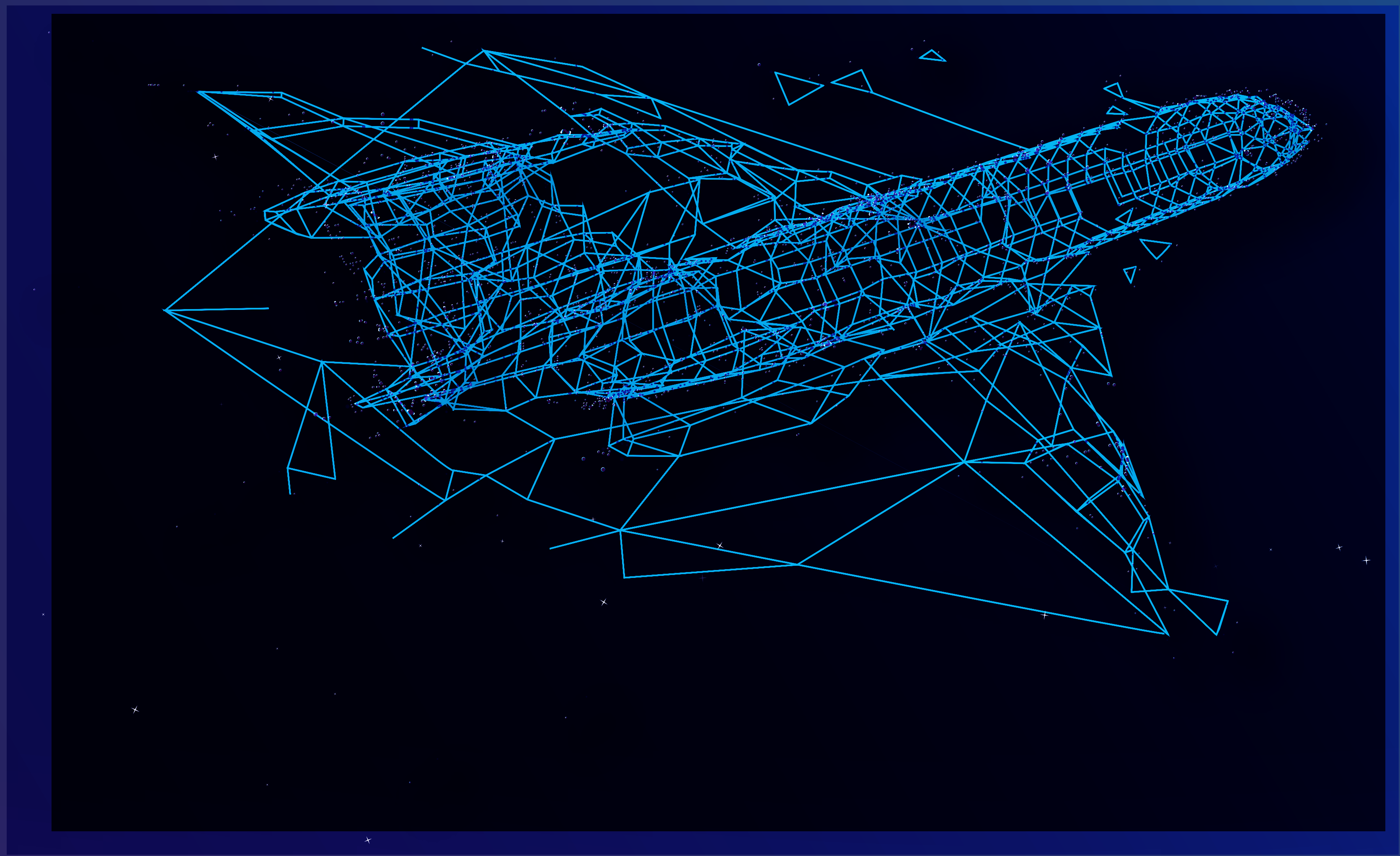
It is evident that the transformation towards climate-neutral aviation will be achieved by combining contributions from several novel technologies (and not by one single solution), thus highlighting the importance of accelerating research and technology development in all promising areas.

The EU research in clean aviation is not only producing excellent results, it is also strengthening the European aviation industry and fostering cooperation, even beyond EU borders. Several projects include partners from further afield, such as the USA, Canada, Japan, China, Russia and Brazil, helping to tackle the climate change challenge at a global level.

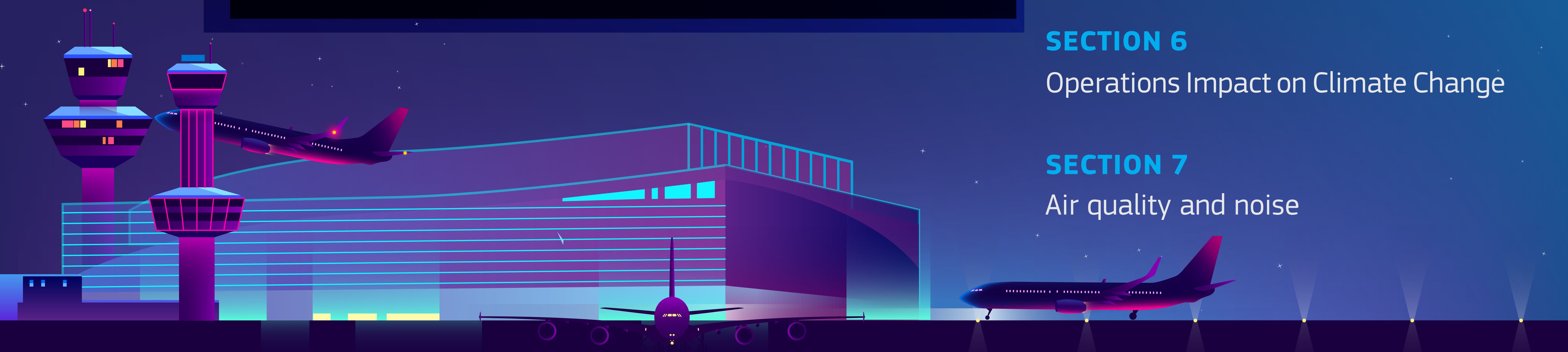
This publication presents the contribution of INEA-managed aviation research and innovation projects to the EU policy priority of reducing aviation's environmental footprint. It includes a concrete overview of project objectives, activities and results focused on decarbonising and increasing the sustainability of aviation by advancing the state of the art in various technology areas, such as disruptive airframe configurations (section 1), Sustainable Aviation Fuels (section 2), hybrid-electric propulsion (section 3), hydrogen (section 4), lightweight structures and advanced manufacturing processes (section 5), and green operations (section 6). Finally, this publication offers an overview of the contribution from INEA-managed aviation projects towards reducing the perceived levels of aircraft noise and ensuring healthy air quality[5] in and around airports, which are both issues of great public concern (section 7).

[1] IATA, https://www.iata.org, 2019. Projections refer to a pre-COVID scenario.
[2] Alonso, G., Benito, A., Lonza, L., Kousoulidou, M. "Investigations on the distribution of air transport traffic and $CO_2$ emissions within the European Union", Journal of Air Transport Management, 36, p. 85-93, 2014.
[3] Aviation in the EU ETS, March 2020, https://www.emissions-euets.com/carbon-market-glossary.
[4] Marina Kousoulidou and Laura Lonza. "Biofuels in Aviation: Fuel and $CO_2$ Projections in Europe, Implications and new trends to 2030", Journal of Transportation Research, Part D: Transport and Environment, 46, p. 166–181, 2016.
[5] Ambient Air Quality Directive (2008/50/EC).

# THEMATIC AREAS ADDRESSED BY THE FUNDED PROJECTS







*Click on title to go to page.*

# SECTION 1 – DISRUPTIVE AIRFRAME CONFIGURATIONS

Developing more performing aerodynamic airframe is key to reduce aircraft emissions. Over the past decades, aeronautical engineers have achieved significant improvements in aircraft aerodynamic performance by developing more efficient wings, control surfaces and high-lift devices, as well as technologies such as the "winglet", a modification of wingtips to reduce aerodynamic drag that is now seen on many civil aircraft.

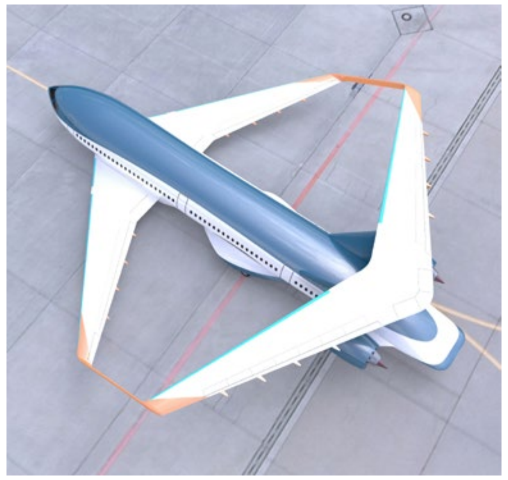
While research and technology development remains of paramount importance to further decrease aerodynamic drag of civil aircraft, continuous improvements on current airframe configurations – i.e. the "fuselage-wing" – are expected to be insufficient to achieve the ambitious EU aviation environmental goals, as set out in the Flightpath 2050's vision.

To fully meet the EU environmental goals, revolutionary airframe configurations maximizing flight efficiency will be necessary. Research and development focusing on disruptive airframe designs, such as blended wing or box-wing structures and morphing wings, is therefore strategic for the EU to accelerate technology development towards a future civil aviation that is climate-neutral. Future airframe architectures, which will be realizable thanks to breakthrough advancements in lightweight structures and advanced manufacturing processes (section 5), will fully integrate high-efficiency alternative propulsion systems (e.g. hybrid-electric propulsion, section 3) and will accommodate novel designs for passenger cabins.

This section presents the main objectives, activities and results of projects focusing on the development of future disruptive airframe architectures: i) a box-wing aircraft, called the "PrandtlPlane" minimizing the induced drag; ii) a bio-inspired hybrid electroactive morphing wing increasing aircraft aerodynamic performance; iii) and a fuselage integrating a wake-filling propulsion system, which directly compensates the viscous drag effects in the fuselage wake field by ingesting and re-energising the fuselage boundary layer.

# PARSIFAL

## PRANDTLPLANE ARCHITECTURE FOR THE SUSTAINABLE IMPROVEMENT OF FUTURE AIRPLANES



ALL IMAGES © PARSIFAL

The PARSIFAL project is designing a disruptive box-wing aircraft, called the "PrandtlPlane". The novel design of the PrandtlPlane demonstrated notable aerodynamic advantages since it is capable of minimizing the induced drag for a given total lift and wingspan.

PARSIFAL successfully delivered the design and performance analysis of the PrandtlPlane aircraft. According to the proposed design, this aircraft is fully compatible with present ICAO reference C airports, has a maximum of 308 seats, overall dimensions and turnaround time that are similar to its direct competitors (the A320/B737 family of aircraft). The double-aisle cabin allows to accommodate more than one luggage per passenger, a longer cargo bay capable of transporting more containers compared to competitor aircraft and also a front and rear door, for simultaneous loading and unloading operations. PARSIFAL also investigated the adoption of innovative design tools and procedures for the PrandtlPlane design, including the integration of engines with ultra-high bypass ratio (18 and above), landing gear and built-in air stairs.

Most notably, the project has directly contributed to the Flightpath 2050 goals by demonstrating that the PrandtlPlane can achieve reduced fuel consumption and emissions compared to its direct competitors. In particular, $CO_2$ and other pollutants are reduced by more than 15% (per passenger-kilometre). Also, the novel design allows to reduce direct operating costs by more than 10%. The project successfully performed flight tests on a radio-controlled 1:38 scaled model in order to assess the flight behaviour at low speed conditions. The Technology Readiness Levels (TRL) achieved towards the end of the project is above 4.

### PROJECT DURATION

Start date: 01/05/2017 ⇢ End date: 31/07/2020

### COORDINATOR

University of Pisa

### PROJECT NUMBER

723149

### EU FUNDING

€2,955,706.25

### WEBSITE

www.parsifalproject.eu

### VIDEOS

Aircraft engineering of the future

https://youtu.be/MVEXRx9ixOg

Euronews (October 2018) – "Futuris" reaches for the sky with the wings of the future

https://youtu.be/TXyaKl3-dTE



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# SMS

## SMART MORPHING AND SENSING FOR AERONAUTICAL CONFIGURATIONS

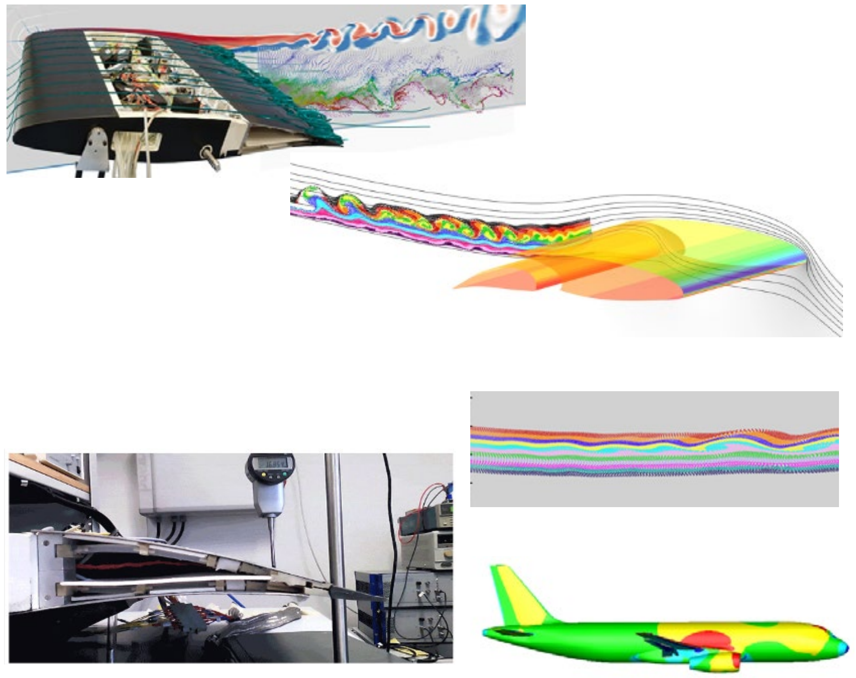
The SMS project used morphing disruptive configurations to increase aircraft aerodynamic performance. SMS employed intelligent electro-active actuators to modify the lifting structure of an aircraft and to obtain the optimum shape and vibrations, with respect to aerodynamic performance. This was accomplished by morphing actuators coupled to highly efficient sensing devices, able to be embedded in real flight. A new generation of fiber-optics-based sensors allows distributed pressure measurements and in-situ real-time optimisation of the aerodynamic characteristics of the aircraft's wings.

SMS demonstrated significant aerodynamic performance increase by developing partly bio-inspired hybrid electroactive morphing, associating novel smart actuators at different time and length scales: Shape memory alloys operate at low frequencies and at high deformations, whereas piezoactuators are employed at higher frequencies and low deformations.

The wing prototypes developed by SMS increase lift by 10% and reduce drag by 3% compared to conventional systems.

A 5% lift-to-drag ratio increase is expected in cruise phases of flight. Moreover, the SMS wing prototypes are able to reduce aerodynamic noise by 8%. The project demonstrated its results by wind-tunnel experiments and near full-scale wing prototypes, in synergy with high-fidelity numerical simulations.

Overall, the concepts designed in the project considerably increase performance in all flight phases, thus contributing to the EU Flightpath 2050 goals by reducing gas and noise emissions, as well as by increasing safety in manoeuvring.



ALL IMAGES © SMS

Top: The A320 morphing wing of the H2020 SMS European project N° 723402 illustrating the electroactive materials ability to camber and the modification of the turbulence structures around the morphing A320 wing prototype in order to increase the aerodynamic performance and reduce noise. Destruction of the coherent turbulence in the wake thus reducing drag and noise in the Large Scale morphing wing in high-lift configuration. Numerical design of the morphing full A320 airplane.

### PROJECT DURATION

Start date: 01/05/2017 ⇢ End date: 30/04/2020

### COORDINATOR

INSTITUT NATIONAL POLYTECHNIQUE DE TOULOUSE

### PROJECT NUMBER

723402

### EU FUNDING

€3,991,687.50

### WEBSITE

www.smartwing.org/SMS/EU

### VIDEO

Participation of the SMS project in Aerodays, Bucharest 27-30 May 2019

https://youtu.be/Pwzu7KFE_Go



References under "SMS" on page 62.

# CENTRELINE

## CONCEPT VALIDATION STUDY FOR FUSELAGE WAKE-FILLING PROPULSION INTEGRATION

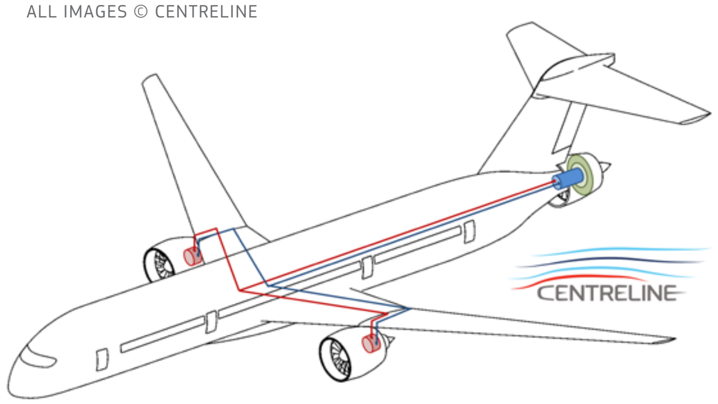
The CENTRELINE project is maximising the benefits of fuselage wake-filling propulsion integration (i.e. the ingestion and re-energisation of the fuselage boundary layer by the propulsion system in order to directly compensate the viscous drag effects in the fuselage wake field) under realistic systems design and operating conditions, in a turbo-electric propulsive fuselage concept (PFC) aircraft.

The project developed a thorough understanding of the aerodynamic effects of 360° fuselage BLI through extensive aero-numerical simulations and low-speed experimental testing. It produced optimised aerodynamic predesigns for the fuselage fan as well as for the fuselage and nacelle bodies. It elaborated conceptual solutions for the aero-structural integration of the BLI propulsive device and the turbo-electric powertrain. Also, CENTRELINE developed important heuristics for PFC aircraft design by using multi-disciplinary design optimisation.

The consortium verified the developed design solutions analytically or experimentally, to demonstrate TRL 3 for the PFC technology, and has taken the initial steps towards experimental validation in a laboratory environment. An additional notable outcome of the project was a technology roadmap towards TRL 6 by 2030.

Specifically targeting the long-range market segment, CENTRELINE aims to maximise the PFC technology's impact on aviation's overall emission reduction. By its improved vehicular efficiency and excellent compatibility with other advanced technologies, the CENTRELINE concept may contribute significantly to achieving the Flightpath 2050 emission goals. CENTRELINE has formed a strong team of leading research and industrial stakeholders supporting Europe's leading position in aviation.

ALL IMAGES © CENTRELINE




### PROJECT DURATION

Start date: 01/06/2017 → End date: 01/11/2020

### COORDINATOR

BAUHAUS LUFTFAHRT

### PROJECT NUMBER

723242

### EU FUNDING

€3,680,520.78

### WEBSITE

www.centreline.eu

### VIDEOS

Euronews (May 2019) - Is this the future of aircraft design? We investigate Centreline's rear-mounted electric fan
https://youtu.be/1rK_1bUqqTQ
CENTRELINE EU Project – How are we going to fly in 2035?
https://youtu.be/Ik3EHO_Kldk



References under "Centreline" on page 62

# SECTION 2 - SUSTAINABLE AVIATION FUELS

With the rapid growth of air-transport traffic and consequent increase in energy demand, the aviation industry is currently pursuing Sustainable Aviation Fuels in order to reduce aviation oil dependency and greenhouse gas emissions, and to improve environmental performance[1]. Sustainable Aviation Fuels can also contribute towards the updated Renewable Energy Directive's targets[2] in all Member States, on the condition that they comply with specific sustainability criteria.

In the last decade, there has been significant progress in developing Sustainable Aviation Fuels produced from bio-based feedstocks which have lower carbon intensity (i.e lignocellulosic biomass, hydrotreated oils, recycled waste or other renewable sources), and through dedicated processes (thermochemical and biochemical conversion, electrocatalytic conversion of $CO_2$ using renewable electricity, etc.). In order for these fuels to be used in aircraft operations, they must have 'drop-in' characteristics, meet strict fuel specifications and have comparable behaviour to fossil fuel during the combustion process. The American Society for Testing and Materials (ASTM) has developed standards[3], to approve new aviation fuels, with six production pathways already certified for blending (at various ratios) with conventional aviation fuel and more pathways currently under review for approval[4].

The main advantage of Sustainable Aviation Fuels is their significant well-to-wake $CO_2$ emissions reduction compared to conventional jet fuels, although results demonstrate that this reduction depends on the feedstock and production pathway selected[5]. In addition to the reduction of well-to-walk $CO_2$ emissions, Sustainable Aviation Fuels can also reduce direct emissions of particulate matter (PM) and sulphur (SOx), compared to conventional jet fuel. The main challenge for Sustainable Aviation Fuels is their limited uptake due to various factors, including the cost relative to conventional aviation fuel. When comparing demand and supply volumes projections to 2030 for Sustainable Aviation Fuels available in Europe[1], it is evident that dedicated Sustainable Aviation Fuels production will not be sufficient to meet demand. This stems mainly from the fuel price considerations and the competition between road and aviation sectors in terms of absorbing hydrotreated fuels, which is the main sustainable fuel used at large scales in aviation[1,5].

This section presents the main objectives, activities and results of projects contributing to a competitive and sustainable future for Sustainable Aviation Fuels. In particular, the following issues are addressed: i) the promotion of technological maturity of the individual process steps in the production of Sustainable Aviation Fuels; ii) the update and optimization of all screening processes related to Sustainable Aviation Fuels; iii) and, finally, the development of tools and methods to screen and assess Sustainable Aviation Fuels candidates, in order to reduce the substantial investment needed to seek approval under the ASTM international standardisation process.

[1] Kousoulidou Marina and Laura Lonza. "Biofuels in Aviation: Fuel and $CO_2$ Projections in Europe, Implications and new trends to 2030", Journal of Transportation Research, Part D: Transport and Environment, 46, p. 166–181, 2016.
[2] RED 2018/2001/EU https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN
[3] ASTM D4054, 2017 and ASTM D7566, 2018.
[4] European Aviation Environmental Report 2019, https://www.easa.europa.eu/eaer/.
[5] O'Connell, A, Kousoulidou, M., Lonza, L, Weindorf, W. "Considerations on GHG emissions and energy balances of promising aviation biofuel pathways", Renewable and Sustainable Energy Reviews, 101, p. 504-515, 2019.

# BECOOL

## BRAZIL-EU COOPERATION FOR THE DEVELOPMENT OF ADVANCED LIGNOCELLULOSIC BIOFUELS

References under "BECOOL" on page 62

The project BECOOL is developing advanced lignocellulosic biofuels produced from sustainable agricultural value chains. The project is based on three pillars: production and harvesting of non-food crops and crop residues, efficient biomass logistics and the conversion processes.

BECOOL successfully assessed the feasibility of growing annual lignocellulosic crops integrated in traditional agricultural rotations with food crops. Preliminary results indicate that integrated food-energy-crop schemes can be a sustainable solution to achieve more efficient use of agricultural land in time and in space, thus increasing biomass production and improving soil conditions, without any negative effects on cereal grain yields.

The project is developing novel biomass logistics concepts to provide a cost-effective supply of biomass from a range of diverse feedstocks, including agricultural residues.

BECOOL is also working towards the optimization and integration of different thermochemical and biochemical conversion processes for advanced lignocellulosic biofuels. In this regard, the project develops solutions for the valorisation of the lignin-rich residue derived from cellulosic ethanol facilities through fast pyrolysis bio-oil, a promising intermediate energy carrier for further upgrading into additional advanced biofuels.

International cooperation for the development of advanced lignocellulosic biofuels is one of the main features of BECOOL, whose activities are aligned with those of BioVALUE, a twin project funded by Brazilian state foundations and industries. The two projects adopt a synergistic work program. The cooperation between Europe and Brazil on advanced biofuels brings mutual benefits and has created synergies at a scientific level. This will help to exploit the full economic potential of advanced biofuel value chains while creating unique opportunities for both Brazilian and European companies.

BECOOL contributes to the Flightpath 2050 goals by assessing the limitations and logistics of advanced biofuel value chains, thus enhancing environmental benefits, creating new jobs, and reducing land pressure.



### PROJECT DURATION

Start date: 01/06/2017 ⇢ End date: 31/05/2022

### COORDINATOR

UNIVERSITY OF BOLOGNA

### PROJECT NUMBER

744821

### EU FUNDING

€4,999,955.00

### WEBSITE

www.becoolproject.eu

### VIDEO

BECOOL project video

https://youtu.be/ibpPdTyaL48





# BioMates

## RELIABLE BIO-BASED REFINERY INTERMEDIATES

The BioMates project is producing jet fuel from 2nd generation (2G)-biomass (i.e. straw and Miscanthus) by turning it into an intermediate, to be co-processed within conventional refineries.

The project has introduced an approach where ablative fast pyrolysis (AFP) and single-stage mild catalytic hydro-processing (mild-HDT) turn 2G-biomass into an intermediate, i.e. BioMates, which is then co-processed within conventional refineries into jet fuel. Along with the proposed approach, the project developed supplementary innovations like tailor-made catalysts and high performance electrochemical H2 compression and purification. The project identified suitable BioMates refinery entry points, and plants have been prepared to validate the process at TRL 5 in 2021.

The project achieved AFP of TRL4. The latter delivered one-phase bio-oil yield of up to 31 % weight by weight (w/w), and produced the first 230 kg of straw-based TRL 5-AFP bio-oil. The project also demonstrated the production of BioMates in the subsequent mild-HDT step for both straw and Miscanthus. Co-processing the intermediate with a light cycle oil (LCO) in a lab-scale refinery hydrotreating unit reduced the hydrogen demand by more than 8 %.

BioMates contributes to the Flightpath 2050 goals by providing a technology to turn 2G-biomass into jet fuel. Moreover, BioMates relies on products common throughout the EU and due to European refineries being supported by the produced intermediate, it can also lead to creation of qualified jobs.

### PROJECT DURATION

Start date: 01/10/2016 ⇢ End date: 30/11/2021

### COORDINATOR

FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.

### PROJECT NUMBER

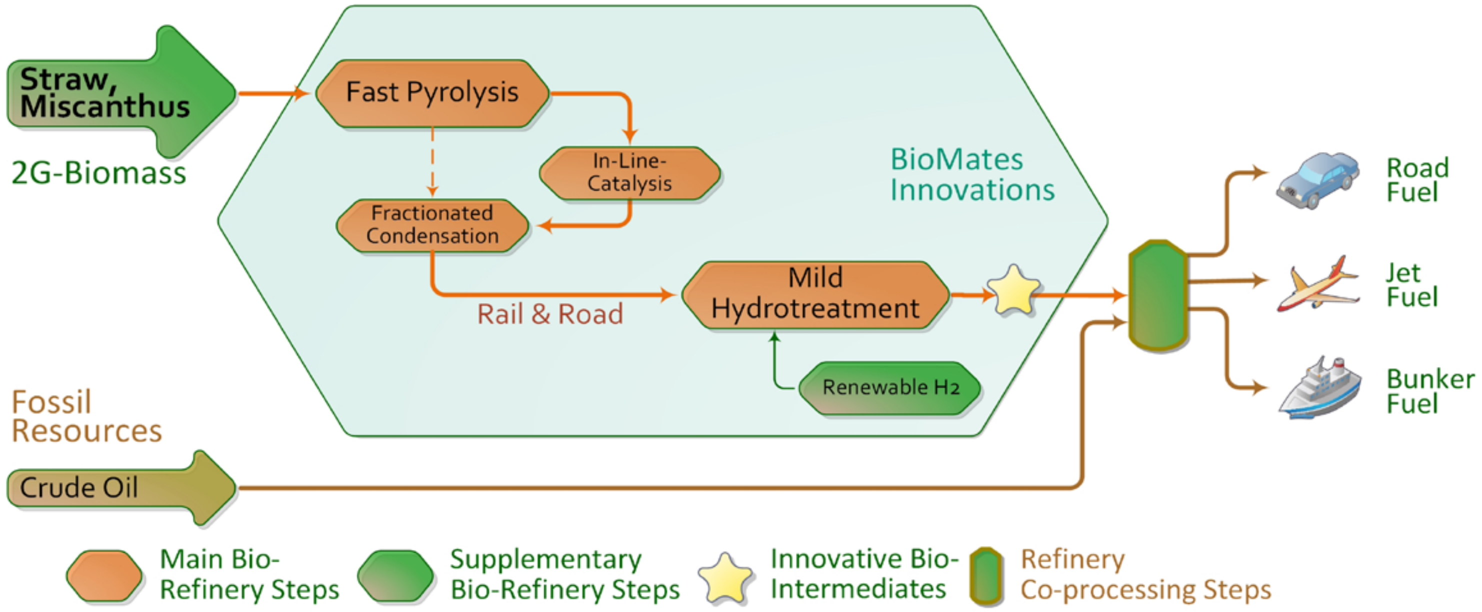
727463

### EU FUNDING

€5,923,316.25

### WEBSITE

www.biomates.eu



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# ABC-Salt

## ADVANCED BIOMASS CATALYTIC CONVERSION TO MIDDLE DISTILLATES IN MOLTEN SALTS

The ABC-Salt project is developing an innovative cost-effective technical solution for the production of sustainable liquid biofuels (middle distillate hydrocarbons) from biomass waste streams. The proposed technology concerns an advanced, integrated thermochemical conversion process for lignocellulosic waste streams, as these are abundantly available at low costs. The process of ABC-Salt involves biomass liquefaction, catalytic hydro-pyrolysis, followed by a catalytic hydro-deoxygenation to the desired middle distillate hydrocarbons.

The ground-breaking advance beyond the state of the art of ABC-Salt is to use molten salt to solubilize the biomass source and to act as an excellent heat transfer medium, which is expected to achieve higher overall biomass to hydrocarbon yields compared to existing processes. ABC-Salt will demonstrate the integrated concept at lab scale in a dedicated bench scale unit (TRL 4), which will be the prototype for a future fuel production system in an industrial environment. The project will address and investigate major technological barriers, the techno-economic viability of the technology, as well as the socio-economic impact.

ABC-Salt has performed extensive experimental studies on the individual steps of the integrated concept on small laboratory scale, paving the way for the design, construction, and operation of the integrated pilot unit. For instance, the consortium has demonstrated that molten salts are suitable for the liquefaction and processing of some types of biomass, with good carbon efficiencies.

Liquid fuels from biomass resources (2nd generation fuels) are expected to form the backbone of the energy system by 2030 and 2050. The ABC-Salt project will contribute to the ambition of the EU to be a leader in bio-based jet fuels and transportation fuels for shipping and heavy transport.

© ABC-SALT

### PROJECT DURATION

Start date: 01/04/2018 ⇢ End date: 31/03/2022

### COORDINATOR

RIJKSUNIVERSITEIT GRONINGEN

### PROJECT NUMBER

764089

### EU FUNDING

€3,998,025.50

### WEBSITE

www.abc-salt.eu





# BIO4A

## ADVANCED SUSTAINABLE BIOFUELS FOR AVIATION

The BIO4A project is developing a viable large-scale industrial approach for pre-commercial production of ASTM-certified SAF from used cooking oils and residual lipids, while investigating the alternative supply of sustainable feedstocks. The objective is to produce 5,000 tons of hydrotreated esters and fatty Acids (HEFA) in the biorefinery plant of Total in La Mède, France. BIO4A has also implemented a dedicated R&D plan to recover marginal land in areas prone to desertification, by adding co-composted biochar so that sustainable drought resistant oleaginous crops (such as Camelina sativa) can be cultivated while sequestering carbon in soil.

The plant in La Mède has already started testing and its full operation is expected during 2020. Moreover, the project has carried out an analysis of the BIO4A supply chain. On the R&D component, BIO4A has collected data to provide information on how to increase soil fertility and resilience to climate change in EU Mediterranean countries, while storing fixed carbon into the soil for producing low-ILUC (indirect land use change) biofuels based on Camelina sativa.

Latest results on agronomic work obtained by the consortium involve field trials with soil, biochar/compost and Camelina sativa. BIO4A has collected soil samples for analysis, while initiating geographic information system (GIS) mapping of these soils. It has also elaborated an overview of 6 selected ASTM-certified SAF routes, in order to evaluate the BIO4A key performance indicators and to assess the sustainability of the full BIO4A value chain. The validation of the described technology for TRL5 will also generate valuable research data.

BIO4A is contributing to the FlighPath2050 priorities as the project aims to set up a complete flight program and supply chain, reaching SAF end-users in several airports across Europe. It will demonstrate that Europe can be a centre of excellence on SAF in the very near future.

ALL IMAGES © BIO4A

### PROJECT DURATION

Start date: 01/05/2018 ⇢ End date: 30/04/2022

### COORDINATOR

CONSORZIO PER LA RICERCA E LA DIMOSTRAZIONE SULLE ENERGIE RINNOVABILI

### PROJECT NUMBER

789562

### EU FUNDING

€10,002,520.13

### WEBSITE

www.bio4a.eu

### VIDEO

'BIO4A Project' YouTube channel:
https://www.youtube.com/channel/UC8TO8hZorPcs44TGbkdC59w/videos



References under "BioMates" on page 62

# HYFLEXFUEL

## HYDROTHERMAL LIQUEFACTION: ENHANCED PERFORMANCE AND FEEDSTOCK FLEXIBILITY FOR EFFICIENT BIOFUEL PRODUCTION

The HyFlexFuel project is developing scalable next-generation conversion technologies, capable of processing abundantly available biomass into Sustainable Aviation Fuels. The project is demonstrating all individual steps along a hydrothermal liquefaction (HTL) pathway to produce liquid transportation fuels from various types of organic feedstock, including residue and waste streams. HyFlexFuel promotes the technological maturity of the individual process steps from TRL 2-4 to TRL 5.

The HyFlexFuel project successfully produced major biocrude volumes via continuous hydrothermal liquefaction of sewage sludge, algae and Miscanthus, a lignocellulosic model feedstock which represents cultivated energy crops with high biomass yield. The intermediate biocrude was successfully converted into upgraded hydrocarbon fuels via hydrotreatment in continuous operational mode. These achievements reach well beyond the state of art of the HTL pathway. The consortium provided the jet fuel range fractional cuts of the upgraded fuel product to the H2020 JETSCREEN project for further analysis. HyFlexFuel will use the results of this analysis to adapt the upgrading procedures for HTL biocrudes to meet specifications for jet fuel blend components. The collaboration between HyFlexFuel and JETSCREEN prepares a future fuel approval process to promote the HTL pathway from a SAF candidate towards an approved biofuel blend component for civil aviation.

The biofuel technology developed in HyFlexFuel can provide major volumes of Sustainable Aviation Fuel with low greenhouse gas impact and low risk of land-use change. HyFlexFuel contributes to the Flightpath 2050 target to develop technologies that allow a 75% reduction in $CO_2$ emissions per passenger kilometre. Hydrothermal liquefaction can process residual waste streams to transportation fuels and basic chemical commodities; the project also investigates nutrient recovery from by-products of the fuel conversion process. HyFlexFuel thereby supports the EU ambition to establish a circular economy.



ALL IMAGES © HYFLEXFUEL

Top: Hydrothermal liquefaction plant for biocrude-production from various organic feedstock.
Bottom: Hydrotreatment unit for biocrude upgrading to liquid transportation fuel products.

### PROJECT DURATION

Start date: 01/10/2017 ⇢ End date: 30/09/2021

### COORDINATOR

BAUHAUS LUFTFAHRT EV

### PROJECT NUMBER

764734

### EU FUNDING

€5,038,343.75

### WEBSITE

www.hyflexfuel.eu

### VIDEO

HyFlexFuel project video
www.hyflexfuel.eu/project-video



References under 'HyFlexFuel' on page 62



# JETSCREEN

## JET FUEL SCREENING AND OPTIMIZATION

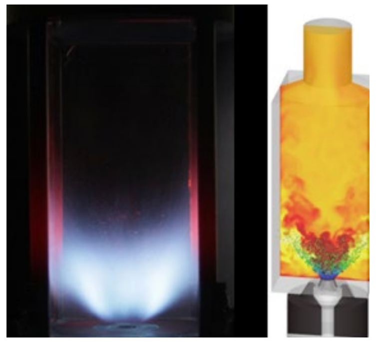
The JETSCREEN project is developing tools and methods to screen and assess alternative fuel candidates using small-scale, low-cost experimental testing, combined with advanced computer-modelling techniques. The goal is to reduce the substantial investment needed to seek approval for a new alternative fuel under the ASTM D4054 international standardisation process, a rigorous procedure that complies with the aviation industry's very high safety requirements.

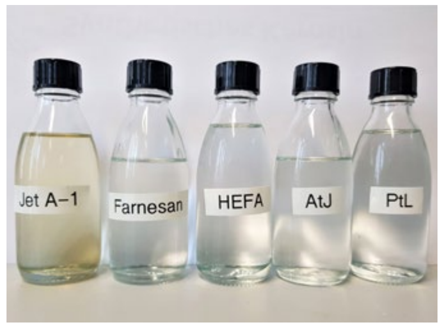
In 34 different experiments, the JETSCREEN consortium investigated 31 different fuels and identified fuel effects on the aircraft fuel system, the engine performance and its emissions. The consortium predicted fuel effects using empirical, physical-based and machine learning models. These models and experiments can be used as fuel screening tools, as well as a design tool for future fuel-flexible aircraft. JETSCREEN developed a unified approach that combines a newly created fuel property database and distributed models into an effective fuel screening workflow incorporating internal and external partner's expertise.

The project demonstrated the benefit of de-risking and cost reduction for the development of new aviation fuels by providing early feedback to innovative fuel producers. JETSCREEN is collaborating with the HyFlexFuel project, project, which is developing the HTL pathway to produce aviation fuels from a wide set of organic feedstocks. The detailed analysis report within JETSCREEN enables the HyFlexFuel project to adapt the upgrading procedures for HTL biocrudes to meet aviation fuel requirements.

JETSCREEN has contributed to achieve one of the EU's environmental goals set in Flightpath 2050, which is to establish Europe as a centre of excellence on Sustainable Aviation Fuels. JETSCREEN provides fuel producers with the required feedback and tools for the development of future fuel-flexible aircraft.

JETSCREEN activities are deeply linked to partners in the USA working on fuel pre-screening and streamlining of the fuel approval process. JETSCREEN has also built a strong collaboration with the National Jet Fuels Combustion Program (NJFCP), with the mission to help streamline the current ASTM fuel approval process.






ALL IMAGES © JETSCREEN

Left: Generic spray burner test rig (first photo) and numerical simulation (second photo) to assess fuel influence on flame stabilization and lean blow out.
Middle: Jet A-1 probe and four approved Sustainable Aviation Fuels.
Right: Pump endurance test rig to measure the influence of low-sulfur fuels on fuel system performances and material wear.

### PROJECT DURATION

Start date: 01/06/2017 ⇢ End date: 31/10/2020

### COORDINATOR

DLR

### PROJECT NUMBER

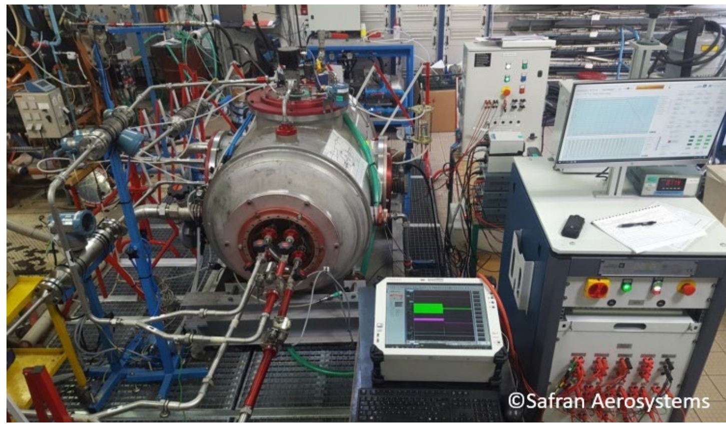
723525

### EU FUNDING

€7,498,105.00

### WEBSITE

www.jetscreen-h2020.eu






References under 'Jetscreen' on page 63

# ALTERNATE

## ASSESSMENT ON ALTERNATIVE AVIATION FUELS DEVELOPMENT

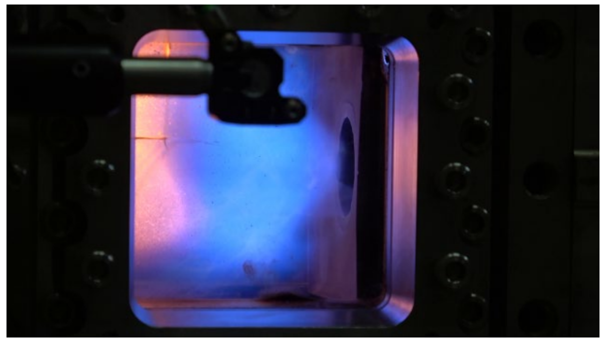
The ALTERNATE project aims to assess wider SAF utilization, by considering both technical and economic aspects, including the use of novel feedstocks and sustainable production pathways in addition to the existing one. The consortium's ambition is to reduce the unknowns with regard to SAF's actual environmental and economic viability, in order to leverage SAF utilization.

One of the main obstacles for quantifying the climate impact of air transport is the development of a reliable and globally harmonized life cycle analysis (LCA) for the calculation of greenhouse gas emissions from a potential SAF supply chain. ALTERNATE will evaluate new fuel candidates using improved modelling methods, while considering LCA optimization, climate change effects and the technical, economic, and environmental consequences of their use.

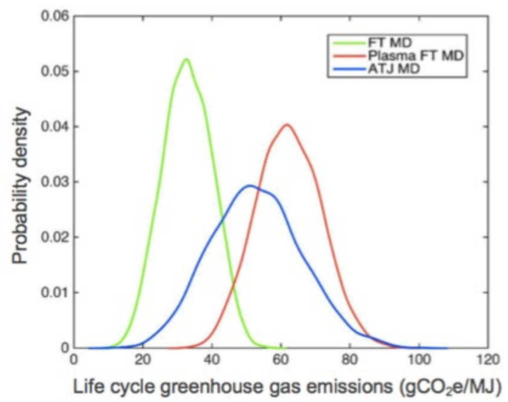
Drop-in sustainable fuels need to undergo a complicated certification process, and uncertainties govern the escape emissions composition, as well as the potential effects on engines and climate change. The project will propose advanced modifications in the engines and fuel certification procedures to properly reflect the consequences of using different fuels, by taking into account the properties of new fuels. All these will be quantified by advanced testing methods.

ALTERNATE will provide novel data on the per-unit and cumulative contribution of different alternative jet fuel pathways to the goal of carbon-neutral growth for aviation, in line with the Flightpath 2050 goals. The project will help to estimate the credits to be given under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to the different sustainable fuels that airlines may introduce. A similar application could also be used in different national and international emission trading systems. Additionally, new feedstocks and pathways can accelerate SAF introduction, suggesting new regulatory techniques to facilitate intensive use of these new fuels.

ALTERNATE is a Research and Innovation Action 'Open to the World' bringing together international partners from the EU and China.








### PROJECT DURATION

Start date: 01/01/2020 ⇢ End date: 31/12/2022

### COORDINATOR

UNIVERSIDAD POLITECNICA DE MADRID

### PROJECT NUMBER

875538

### EU FUNDING

€2,748,243.75

### WEBSITE

https://www.alternateproject.com/





# SUN-TO-LIQUID

## SUNLIGHT-TO-LIQUID: INTEGRATED SOLAR-THERMOCHEMICAL SYNTHESIS OF LIQUID HYDROCARBON FUELS

The SUN-to-LIQUID project designed, fabricated and experimentally validated a large-scale, complete solar fuel production plant. The project achieved the scale-up from the laboratory to the field at a pre-commercial scale, of the complete production chain from H2O, $CO_2$, and solar energy to solar liquid hydrocarbon fuels.

The core conversion technology of SUN-to-LIQUID is a thermochemical redox cycle driven by concentrated solar radiation. Following the lab-scale predecessor SOLAR-JET project that demonstrated the first-ever production of solar jet fuel, SUN-to-LIQUID advanced this technology with an approximately 10-fold increase of radiative power and 3-fold improvement in energy conversion efficiency. The design and operation of the SUN-to-LIQUID plant demonstrated the successful development of key innovations, such as an advanced high-flux ultra-modular solar heliostat field, a 50-kW solar reactor and optimized redox materials.

The unique solar fuel research facility of SUN-to-LIQUID achieved a new record of more than 5% solar-to-syngas energy conversion efficiency and a long-term routine operation on a daily basis of more than 100 cycles. A field of 169 sun-tracking heliostats delivered 50 kW of concentrated solar radiative power, driving the thermochemical syngas production (at temperatures up to 1500°C), which was further processed to kerosene. The system performance under realistic conditions represents a pioneering achievement and demonstrates the technical feasibility of solar technology for producing drop-in fuels at industrial scales.

Estimated production costs of future commercial plants are 2.0 €/L for the baseline and 1.2 €/L under favourable conditions, with a life-cycle emission reduction potential of 80% compared to conventional jet fuel. As the fuel is produced on arid non-arable land, positive impacts on energy supply security and economic development of economically challenged regions are expected.

This project received funding from the European Union's Horizon 2020 research and innovation programme and by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 15.0330.



### PROJECT DURATION

Start date: 01/01/2016 ⇢ End date: 31/12/2019

### COORDINATOR

BAUHAUS LUFTFAHRT

### PROJECT NUMBER

654408

### EU FUNDING

€4,450,618.00

### WEBSITE

www.sun-to-liquid.eu

### VIDEO

SUN-to-LIQUID project video
https://youtu.be/IaUe23OhHXgt

Photo caption: Integrated plant in operation including solar heliostat field, thermochemical reactor (on top of tower), and Fischer-Tropsch conversion (in container to the right).



References under "SUN-to-LIQUID" on page 63

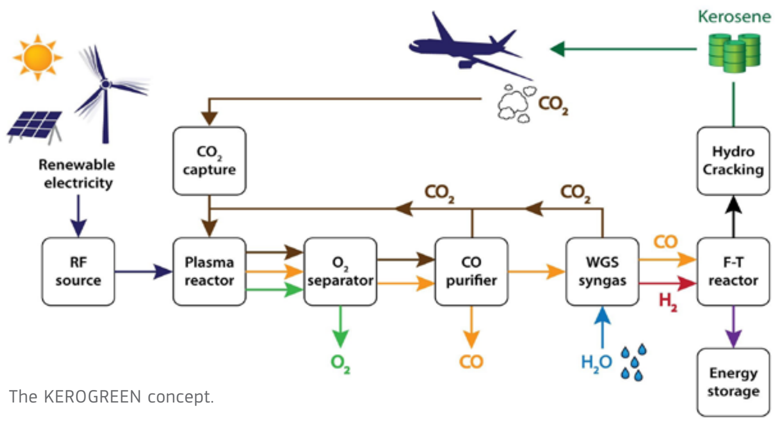
# KEROGREEN

## PRODUCTION OF SUSTAINABLE AIRCRAFT GRADE KEROSENE FROM WATER AND AIR POWERED BY RENEWABLE ELECTRICITY, THROUGH THE SPLITTING OF $CO_2$, SYNGAS FORMATION AND FISCHER-TROPSCH SYNTHESIS

The KEROGREEN project is producing green synthetic jet-grade fuel in a closed carbon cycle; the kerosene is synthesised from air and water, powered by renewable electricity and the emitted $CO_2$ is recaptured directly from the atmosphere.

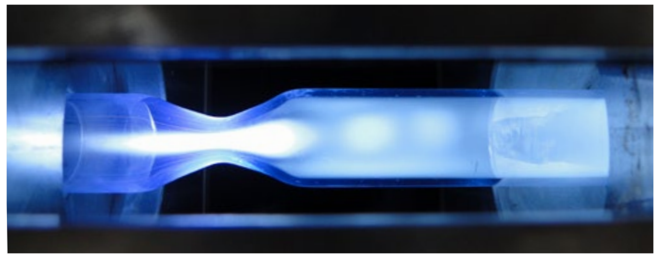
The KEROGREEN approach is based on plasma-driven dissociation of air-captured $CO_2$, on solid-oxide membranes for oxygen separation and advanced Fischer-Tropsch (FT) synthesis to yield kerosene. Synergy between plasma-activated species and novel perovskite electrodes of the oxygen separator is expected to raise $CO_2$ productivity, an important intermediate in the full synthesis scheme. High heat transfer FT technology and heat integration raise energy efficiency. Hydrocracking tunes the kerosene yield to ASTM qualified aviation fuel. The KEROGREEN technology is designed for modular scaling and envisioned for decentralised, remote production plants, like off-shore wind parks or desert solar farms. It relies on the existing infrastructure for fuel storage and distribution, and it fuels current aircraft engine technology.

KEROGREEN will deliver a container-sized plant able to produce up to 0.1 kg/hr kerosene at TRL 4, enabled by a compact integrated system of all technologies. The project has identified optimal integration scenarios of the individual elements and module sizes and has defined system interfaces for all sub-systems. The project showed through a chemical pathway analysis that over 90% conversion of $CO_2$ to liquid fuels can be achieved in the integrated KEROGREEN system.




The KEROGREEN concept.

The KEROGREEN approach meets the ICAO CORSIA emission reduction objectives and the Flightpath 2050 environmental objectives, as this fuel contains no sulphur, produces no soot and reduces NOx emissions. This $CO_2$-neutral Power-to-X technology strengthens the EU energy security by creating a long-term, large-scale storage capacity, and is generic in coupling the power sector to other fuel and chemical driven sectors.



$CO_2$ plasmolysis reactor
ALL IMAGES © DIFFER

### PROJECT DURATION

Start date: 01/04/2018 ⇢ End date: 31/03/2022

### COORDINATOR

STICHTING NEDERLANDSE WETENSCHAPPELIJK ONDERZOEK INSTITUTEN

### PROJECT NUMBER

763909

### EU FUNDING

€4,951,958.75

### WEBSITE

http://www.kerogreen.eu/

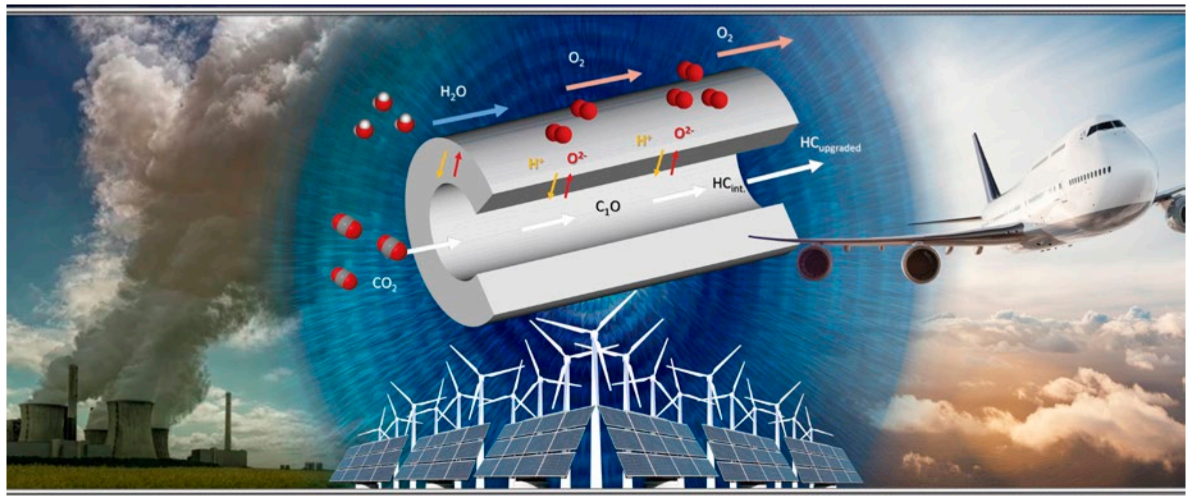


References under 'Kerogreen' on page 63



# e$COCO_2$

## DIRECT ELECTROCATALYTIC CONVERSION OF $CO_2$ INTO CHEMICAL ENERGY CARRIERS IN A CO-IONIC MEMBRANE REACTOR






The e$COCO_2$ project is combining smart molecular catalysis and process intensification to develop a novel efficient, flexible and scalable carbon capture and utilization (CCU) technology.

The $CO_2$ converter consists of a tailor-made multifunctional catalyst integrated in a co-ionic electrochemical cell that enables to realise in-situ electrolysis and water removal from a hydrocarbon synthesis reaction. An important aspect of the project is the design of a dense electrolyte with adequate co-ionic $H^+/O2^-$ conductivity to adjust the hydrogen injection and the extraction of oxygen to/from the reaction chamber at the required proportions. The e$COCO_2$ project will develop new electrodes by adjusting composition and microstructure, in order to reach the active and selective operation required for the electrochemical reactor.

The project aims to demonstrate the technology at TRL5 by producing > 250 g of jet fuel per day in an existing modular prototype rig that integrates 18 tubular intensified electrochemical reactors. As a result, the technology developed by e$COCO_2$ will enable the storage of more energy per processed $CO_2$ molecule and therefore to reduce greenhouse gas emissions per jet fuel ton produced from electricity, at a substantially higher level.

The e$COCO_2$ project will contribute to achieve the EU environmental and energy goals set by Flightpath 2050 by the production of carbon-neutral synthetic liquid fuels for use in aviation. Additionally, the project addresses societal perception by modelling and predicting the acceptance of the technology and the products obtained from its application.

The project is a Research and Innovation Action bringing together international partners from the EU, Japan and China, with three major actors from the most $CO_2$-emitting industrial sectors.

### PROJECT DURATION

Start date: 01/05/2019 ⇢ End date: 30/04/2023

### COORDINATOR

Direct electrocatalytic conversion of $CO_2$ into chemical energy carriers in a co-ionic membrane reactor

### PROJECT NUMBER

838077

### EU FUNDING

€3,949,978.75

### WEBSITE

https://ecocoo.eu/

### VIDEO

e$COCO_2$ project video
https://youtu.be/Y2DUMJMba2E

# SECTION 3 - HYBRID-ELECTRIC PROPULSION

Hybrid-electric/fully electric propulsion technologies are seen to have a high potential in reducing the environmental impact of air transport and in supporting the EU to become the world's first major economy to go climate-neutral by 2050. As private investments in this sector have risen significantly, hybrid-electric propulsion is expected to become a reality for general aviation, regional and short-medium range aircraft.

The introduction of more electric power for propulsive (and non-propulsive) energy will require to redesign aircraft architectures, at both system and sub-system level. In this context, more research and development is needed to develop future hybrid-electric aircraft that are safe and, at the same time, highly efficient. In particular, the use of integrated, multi-domain modelling tools will be key to conduct preliminary architecture studies.

Research and development is needed to focus on new aircraft design tools and methods, novel propulsion architectures (e.g. distributed propulsion), system integration, as well as on challenges related to energy/power density and recharge/discharge rates. A multidisciplinary approach is required to advance further and eliminate technological barriers towards electric and hybrid-electric aviation. Viable R&I roadmaps will need to address relevant issues concerning regulatory framework, airport infrastructure upgrades and energy storage.

This section presents the main objectives, activities and results of EU-funded projects focusing on the development of future low-emission hybrid-electric aircraft (from 4 to 180 PAX), including i) superconducting motor prototype with the power densities and efficiency needed for hybrid-electric distributed propulsion of future large civil aircraft; ii) serial and parallel hybrid-electric propulsion architectures for General Aviation; iii) and disruptive technology development and roadmap preparation for hybrid-electric regional aircraft including in-depth investigation of electric technologies focusing on advanced aircraft configurations.

# ASuMED

## ADVANCED SUPERCONDUCTING MOTOR EXPERIMENTAL DEMONSTRATOR

The ASuMED project is developing a fully superconducting motor prototype with the power densities and efficiency needed for hybrid-electric distributed propulsion of future large civil aircrafts. The ASuMED project has developed the first fully superconductive high-power (1 MW) motor having a superconductive rotor and stator with integrated magnetization system.

The project's outstanding achievements include the development of an innovative motor topology, a light and highly efficient airborne cryogenic cooling system design for the motor, and a modular inverter topology which allows highly-dynamic, fail-safe and robust control of superconducting machines. In addition, ASuMED developed novel numerical simulation and design tools for superconducting motors. The project will demonstrate the technology´s benefits by full-scale test, in order to allow its integration into designs of future distributed propulsion systems.

ASuMED contributes to achieve the EU environmental goals outlined in Flightpath 2050 by demonstrating the technology readiness of the propulsor in a drive chain of future hybrid or fully electrically-driven airplane generations. The project's results will strengthen the competitiveness of the European aviation industry by creating new market opportunities and by enabling European companies to establish early leadership in distributed electric propulsion.

ASuMED is a Research and Innovation Action 'Open to the World' bringing together international partners from the EU and Russia.




### PROJECT DURATION

Start date: 01/05/2017 → End date: 31/08/2020

### COORDINATOR

OSWALD ELEKTROMOTOREN GMBH

### PROJECT NUMBER

723119

### EU FUNDING

€4,007,476.25

### WEBSITE

http://www.asumed.oswald.de/



References under "ASUMED" on page 63



# MAHEPA

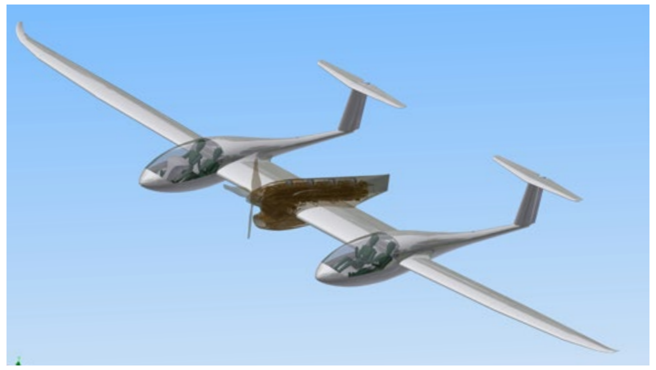
## MODULAR APPROACH TO HYBRID ELECTRIC PROPULSION ARCHITECTURE

The MAHEPA project is advancing two variants of a low emission, highly efficient, serial hybrid-electric propulsion architecture to TRL 6. One hybrid-electric powertrain is based on an internal combustion engine, while the second one is based on hydrogen fuel cells. In order to showcase the flexibility of the new powertrains, the project will conduct in-flight demonstrations on two 4-seater hybrid-electric aircraft. A scalability study will be performed to conceptualise the scale-up of the developed technologies and components to regional distributed electric propulsion aircraft of 19 and 70 seats.

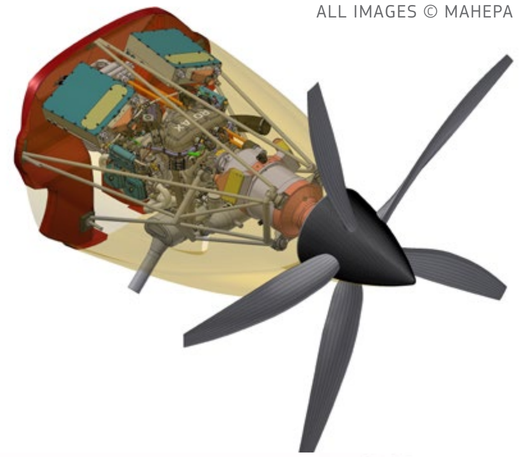
MAHEPA has developed a revolutionary modular design approach, by identifying all common blocks of any hybrid-electric powertrain architecture and later utilizing them for the design of the two propulsion units. In parallel to the component design phase, MAHEPA developed tools to estimate the future needs of hybrid-electric aviation. From battery charging concepts to micro-feeder market analyses, MAHEPA built the basis to explore the most efficient and environmentally friendly ways to operate novel hybrid aircraft.

Nevertheless, the project's biggest achievements reside in the components. From an extremely powerful (300 kW) and light (less than 35 kg) electric motor, to lithium batteries capable of withstanding a double cell thermal runaway, MAHEPA components have shown incredible performance with the most powerful hydrogen fuel cell system ever mounted on an aircraft now ready to fly.

The technology developed by MAHEPA is clearly offering solutions for the future of aviation. In fact, design methods and components now tested within MAHEPA can easily be re-utilized on bigger platforms, paving the way to EU environmental goals set in Flightpath 2050.







### PROJECT DURATION

Start date: 01/05/2017 → End date: 30/04/2021

### COORDINATOR

PIPISTREL VERTICAL SOLUTIONS

### PROJECT NUMBER

723368

### EU FUNDING

€8,979,928.75

### WEBSITE

https://mahepa.eu/

### VIDEO

Overview of MAHEPA project
https://www.facebook.com/mahepa4/videos/221973535500728/
About MAHEPA project
https://youtu.be/m9QCHuenElw

References under "Mahepa" on page 63

# H3PS

## HIGH POWER HIGH SCALABILITY AIRCRAFT HYBRID POWERTRAIN

The H3PS project is developing the first parallel hybrid powertrain for General Aviation, in a 4-seater aircraft. H3PS will power the Tecnam P2010 in order to demonstrate the benefits and high scalability of the hybrid powertrain for up to 11-seater airplanes. The project will introduce a marketable solution, that will allow superior performance, fuel savings and greener operations, at comparable installation weights.

H3PS completed the design phase of the hybrid powertrain and physically manufactured all the key components. This includes the dedicated Rotax 915iS combustion engine, Genset (electric motor/generator), batteries, battery container, wiring looms, and control boxes. The consortium weighted all aforementioned components and validated that, for the first time in aviation, the global installation weight of a hybrid solution is equivalent to the weight of the standard configuration.

Upcoming activities of H3PS involve field testing that will make the results of the project even more tangible. More specifically, once the P2010 equipped with the H3PS power plant is ready to fly, the consortium will perform a direct comparative test against the Tecnam P2010 from the production line, equipped with a standard Lycoming IO-360-M1A engine. H3PS will realize tests during the same day, in the same ambient conditions, following an identical ground and flight mission profile. It will then measure and directly compare the fuel consumption, along with noise, $CO_2$, and lead emissions. The expectation of H3PS is to achieve 10% reduction in fuel consumption.

The H3PS project contributes to the goals outlined by Flightpath 2050 by reducing aircraft emissions and enabling carbon-neutral growth of aviation.

### PROJECT DURATION

Start date: 01/05/2018 ⇢ End date: 30/04/2021

### COORDINATOR

COSTRUZIONI AERONAUTICHE TECNAM SPA

### PROJECT NUMBER

769392

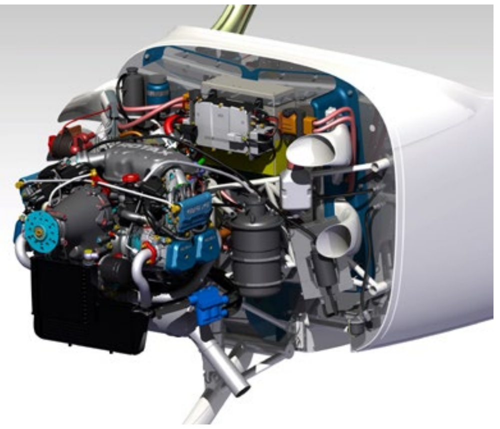
### EU FUNDING

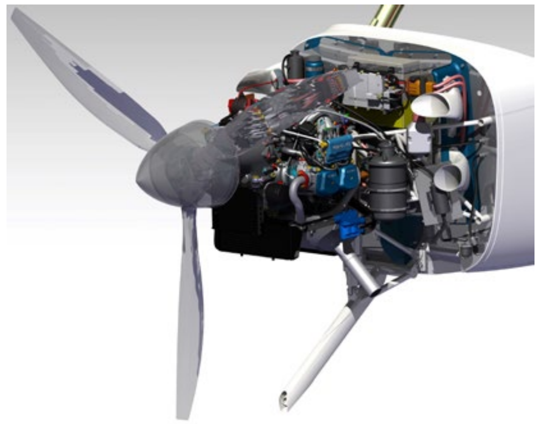
€4,000,000.00

### WEBSITE

https://www.h3ps.eu/project/





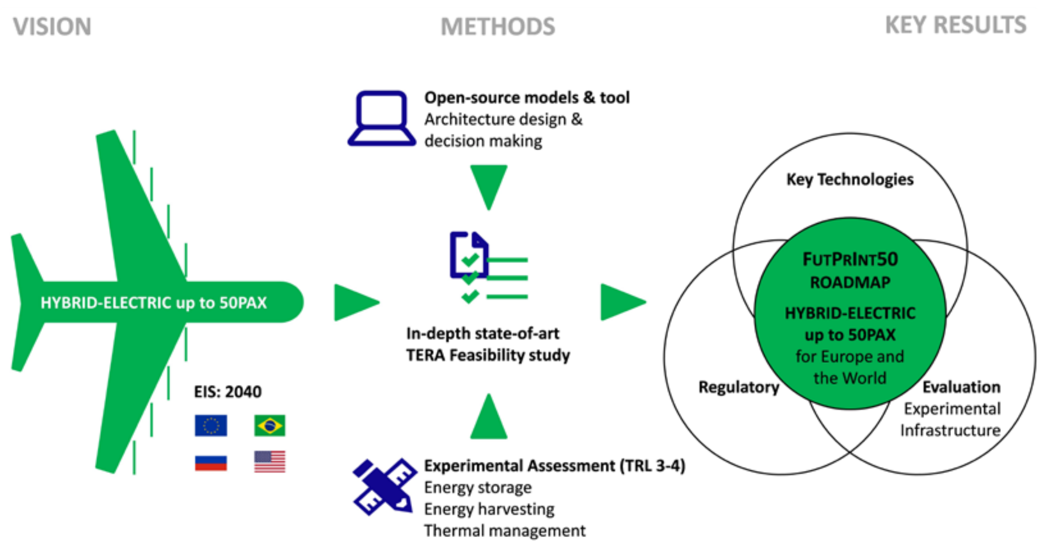






# FUTPRINT50

## FUTURE PROPULSION AND INTEGRATION: TOWARDS A HYBRID-ELECTRIC 50-SEAT REGIONAL AIRCRAFT




The FUTPRINT50 project aims to accelerate the entry-into-service of a commercial hybrid-electric aircraft of up to 50 seats by 2035-2040. The project's ambition is to establish a common roadmap for technology and regulatory aspects for this class of hybrid-electric aircraft, while prioritizing the key enabling technologies for future hybrid-electric demonstrators.

FUTPRINT50 will accelerate advanced aircraft technologies for hybrid-electric powertrains and their integration in a disruptive aircraft configuration with a particular focus on energy storage up to TRL 3, energy harvesting up to TRL 4, and thermal management up to TRL 3-4. FUTPRINT50 will provide an open reference for a 50-seat hybrid-electric aircraft configuration, including top level aircraft requirements, mission specifications and figures of merit. Moreover, the project will develop an open source tool for system and aircraft level integration, as well as technological and economic risk assessment.

The project will contribute to the EU environmental goals set in Flightpath 2050, by preparing the roadmap for a hybrid-electric regioliner with distributed propulsion and a synergetic configuration design that will surpass the efficiency and environmental performance of the current generation of regional aircraft. This will be an important element in a new sustainable air transport system, opening new flexible routes to link smaller cities, and enabling air mobility for European citizens at zero emissions on thin routes. The focused research will help ensure the leadership and competitiveness of the European aircraft industry.

As a flagship Research and Innovation Action 'Open to the World' for international cooperation, the FUTPRINT50 consortium comprises partners from the EU, Russia, Brazil and the US.

### PROJECT DURATION

Start date: 01/01/2020 ⇢ End date: 31/12/2022

### COORDINATOR

Universitaet Stuttgart

### PROJECT NUMBER

875551

### EU FUNDING

€4,727,797.50

### WEBSITE

futprint50.eu

# IMOTHEP

## INVESTIGATION AND MATURATION OF TECHNOLOGIES FOR HYBRID ELECTRIC PROPULSION

The IMOTHEP project aims to assess the potential offered by hybrid-electric propulsion (HEP) to reduce aviation $CO_2$ emissions and also to build the European aviation roadmap for the maturation of electric technologies and hybrid power architectures. The ultimate goal is to support the EU industry in its future strategical choices and to orientate research and technology efforts in this direction.

IMOTHEP will perform an in-depth investigation of electric technologies for hybrid-electric aircraft focusing on advanced aircraft configurations and innovative propulsion architectures. The project will cover the whole energy chain from power generation to propulsion actuators. IMOTHEP will explore potential technologies and technical issues at the scale of commercial aircraft, which compose the bulk of current airlines' fleets and aviation's emissions, thus targeting regional (50 PAX) and short/medium range (150-180 PAX) aircraft. The project aims to target TRL 4 by the end of the proposed activities.

The project's main ambition is to achieve a step beyond (>10%) the highest emissions reduction targets for conventional technologies in 2035. This requires going beyond the conceptual research performed to date in Europe, by closely coupling the study of aircraft configuration and propulsion architecture, with a detailed investigation of electric technologies and the use of high-fidelity approaches. To this end, tremendous progress on the power density of electric machines and power electronics is required, as well as on electric architecture design. Safety and optimal use of energy should be ensured, while mitigating thermal, arcing, and electromagnetic issues.

Based on the project's findings, IMOTHEP will develop an EU roadmap, which will include the main priorities for research on key enablers, as well as the specific needs for tools, infrastructure and regulatory adaptations. The project will also deliver a proposal of key demonstrators for operational development.

IMOTHEP is a Research and Innovation Action 'Open to the World', bringing together partners from the EU, Canada, and the US.




**PROJECT DURATION**

Start date: 01/01/2020 → End date: 31/12/2023

**COORDINATOR**

ONERA

**PROJECT NUMBER**

875006

**EU FUNDING**

€10,392,845.00

**WEBSITE**

https://imothep-project.eu/


# SECTION 4 – HYDROGEN PROPULSION

Flightpath 2050 has set ambitious environmental targets for aviation. Despite the continuous advancement in jet-propulsion technologies, these targets cannot be met if aviation remains fuelled by conventional fossil-based fuels (e.g. Jet-A1 fuel), or even by Sustainable Aviation Fuels used at the maximum blending ratios.

In general, it is evident that the transformation towards climate-neutral aviation will not be achieved with one sole novel technology, but it will more probably be achieved by the eclectic contribution of different technologies, such as hybrid-electric / fully electric (section 3), drop-in biofuels (section 2), and also hydrogen ($H_2$), which is expected to play a significant role in aviation as an energy carrier. More specifically, while hybrid-electric and fully electric technologies will more likely serve the development of future low-emissions regional aircraft, liquid hydrogen (LH2)[1] is seen to offer viable opportunities to fuel aircraft for longer hauls.

Hydrogen has the great advantage of delivering ultra-low NOx emissions[2] and zero $CO_2$ emissions, as its combustion is carbon-free. However, besides the environmental benefits, there are several key challenges, i.e. safety, airport infrastructure, economic sustainability, and community acceptance, that still require research and innovation efforts, as well as tailored certification, regulation and standardization methodologies.

This section presents the main objectives, activities and results of projects that are investigating LH2 technologies, as well as how these projects are exploring key opportunities through i) integration of innovative propulsion systems based on liquid hydrogen, unconventional structural configurations and systems for thermal and energy management (for short-medium and long range); ii) and improvement of combustor design and fuel system heat management, to further minimize NOx emissions.

[1] Baroutaji, A., Wilberforce, T., Ramadan, M., Olabi, A. "Comprehensive investigation on hydrogen and fuel cell technology in the aviation and aerospace sectors", Renewable and Sustainable Energy Reviews, 106, p. 31–40, 2019.
[2] Sefain, M. "Hydrogen aircraft concepts and ground support", Cranfield University, 2005.

# STRATOFLY

## STRATOSPHERIC FLYING OPPORTUNITIES FOR HIGH-SPEED PROPULSION CONCEPTS

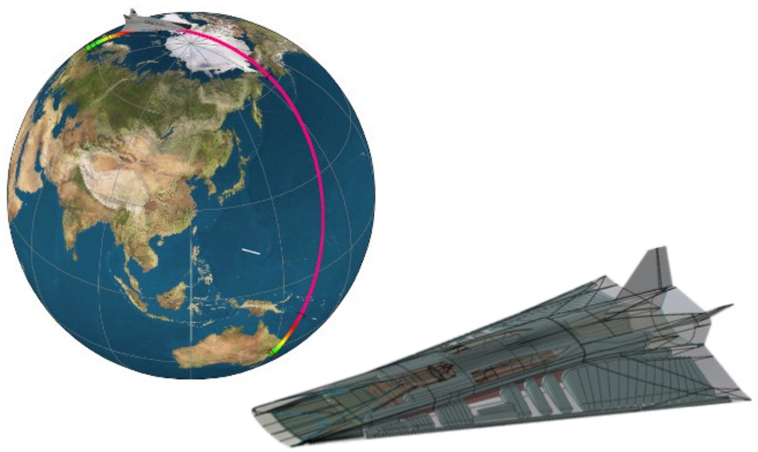
The STRATOFLY project is assessing the potential of high-speed stratospheric transport to reach TRL6 by 2035, with respect to key technological, societal and economical aspects. STRATOFLY tackles the integration of an innovative propulsion system based on liquid hydrogen, unconventional structural configurations and systems for thermal and energy management. The project addresses fundamental operative issues such as emissions and noise reduction, sustainability of unexplored trajectories and flight safety.

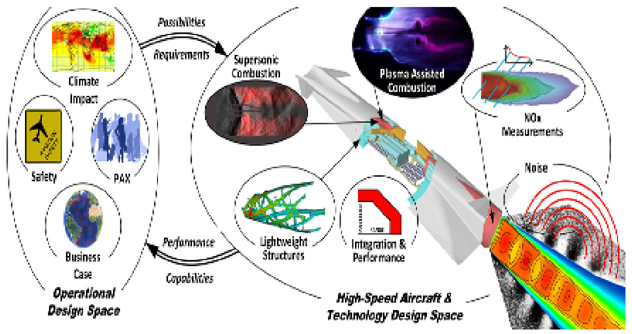
STRATOFLY started from the promising results of LAPCAT II. A new vehicle concept, STRATOFLY MR3, was defined, which has a waverider configuration and is able to take off and land from/to conventional aerodromes. STRATOFLY MR3 integrates 6 air turbo rocket (ATR) engines that operate up to Mach 4.5 and a dual mode ramjet (DMR) that operates from Mach 4.5 up to Mach 8. Liquid hydrogen was selected as propellant to allow the vehicle to cover antipodal routes, without emitting any $CO_2$.

The STRATOFLY project has achieved so far the following: development of a multidisciplinary design framework for a non-conventional air transportation system and assessment of its economic viability; design and integration of a complex cryogenic propellant subsystem for liquid hydrogen; assessment of the thermal and energy management subsystem's capability to increase global thermodynamic cycle efficiency up to 75%; proof of concept of the ATR's high efficiency expander cycle combined with a novel plasma-assisted combustion system, to reduce aeroengine emissions.

The consortium is currently conducting analysis and tests to assess and reduce noise, NOx, and water vapour emissions, in order to limit environmental impact. It is also considering sonic-boom carpet minimization to this end. STRATOFLY additionally performs trajectory optimization analysis to investigate higher cruise altitudes that will guarantee the minimum life-cycle of particles emitted into the stratosphere.

STRATOFLY contributes to the Flightpath 2050 goals by addressing environmental, social, and economical aspects of commercial high-speed stratospheric flight.






ALL IMAGES © STRATOFLY

### PROJECT DURATION

Start date: 01/06/2018 ⇢ End date: 30/11/2020

### COORDINATOR

Politecnico di Torino

### PROJECT NUMBER

769246

### EU FUNDING

€4,000,000.00

### WEBSITE

https://www.h2020-stratofly.eu

### VIDEO

H2020 STRATOFLY project video
https://youtu.be/kBz6aRJaAwA



References under "Stratofly" on page 63



# ENABLEH2

## ENABLING CRYOGENIC HYDROGEN-BASED $CO_2$-FREE AIR TRANSPORT

The ENABLEH2 project is investigating novel technologies that will enable the utilisation of LH2 in civil aviation. The project comprises of experimental and numerical work for two key enabling technologies: H2 micro mix combustion for ultra-low NOx emissions (TRL4) and fuel system heat management, to exploit the heat sink potential of LH2 in order to facilitate advanced turboelectric propulsion technologies (TRL4).

ENABLEH2 will evaluate and analyse these technologies for a number of novel aircraft propulsion system configurations and utilisation scenarios. The project has down-selected four aircraft configurations, two for short-medium range and two for long range, for more detailed study. These studies will include mission energy efficiency and NOx emissions assessments, $CO_2$ life cycle and economic viability studies of the technologies under various fuel prices and emissions taxation scenarios. Moreover, ENABLEH2 will deliver a comprehensive safety audit characterising and mitigating hazards in order to support integration and acceptance of LH2.

In collaboration with industry partners and stakeholders, the project will also provide a roadmap for development of key enabling technologies and the integrated aircraft and propulsion systems in the 2050 timeframe.

ENABLEH2 contributes to the goals of Flightpath 2050 in that it will demonstrate that liquid hydrogen combined with advanced airframes, propulsion systems and air transport operations can meet the ambitious long-term environmental and sustainability targets for civil aviation.

ENABLEH2 is already widely recognised as a key project in the initiative for decarbonising civil aviation through the adoption of LH2. This is apparent by the commitment of several senior individuals from key EU civil aviation stakeholders to the ENABLEH2 advisory board. ENABLEH2 is also featured in the 2019 ICAO Environmental Report.


© ENABLEH2

### PROJECT DURATION

Start date: 01/09/2018 ⇢ End date: 31/08/2021

### COORDINATOR

Cranfield University

### PROJECT NUMBER

769241

### EU FUNDING

€3,995,430.00

### WEBSITE

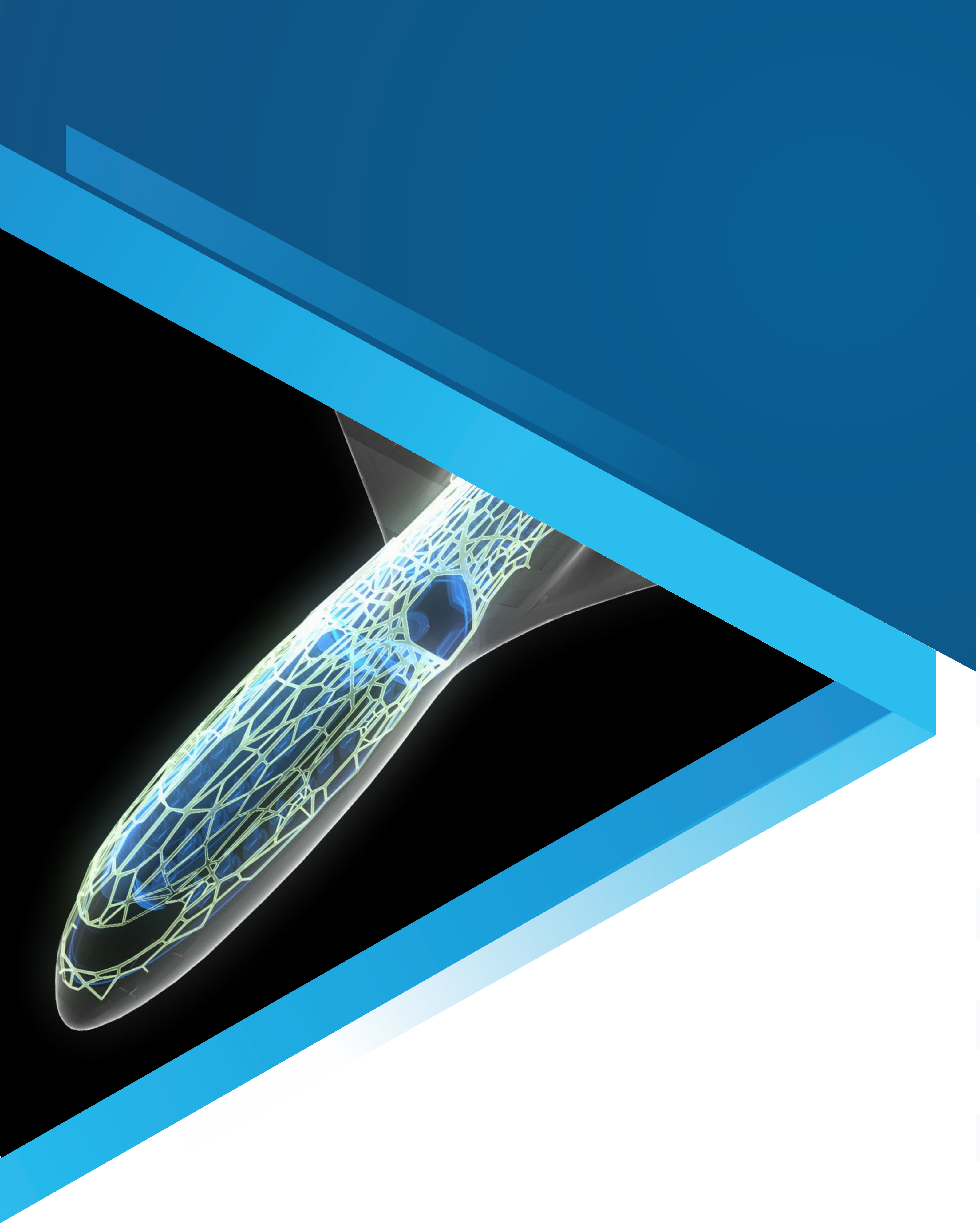
https://www.enableh2.eu/

### VIDEO

Just Have a Think - Liquid Hydrogen Jet Aircraft : A Carbon-Free Flying Future (7:50)
https://youtu.be/WukX4O-hraY



References under "ENABLEH2" on page 63



# SECTION 5 - LIGHTWEIGHT STRUCTURES AND ADVANCED MANUFACTURING PROCESSES

Lightweight structures and materials are of paramount importance to reduce aircraft fuel consumption and, therefore, pollutant emissions. While novel structures and materials should demonstrate full compliance with the required safety standards, reduced emissions can be achieved by the aviation industry also by increasing the efficiency of design methods and manufacturing processes, as well as by developing aircraft systems and subsystems requiring less energy resources for monitoring, repairing and maintenance.

Advancing technologies of weight-saving structures and materials (including composites), along with new approaches and techniques for designing and manufacturing, will play a key role to achieve safe, reliable and low-emissions disruptive aircraft configurations (section 1), fully integrating future propulsion systems (e.g. powered by electricity, see section 3 or by liquid-hydrogen, see section 4). More performing composite materials and alloys, and more efficient additive manufacturing processes, are examples of strategic areas of research, including health monitoring to enable prognostics and connectivity for increasing system safety and reliability.

Important environmental benefits can be achieved by implementing aircraft design-for-environment and design-for-recycling methods. These include the development of easily-recyclable polymers, such as thermoplastics or bio-derived and naturally biodegradable polymers for structural applications. While, on the one hand, these advanced methods will lead to reduced dismantling costs and higher recovery rates for the materials, they will, on the other hand, lead to lowering the demand of energy and compound resources. Future innovations in aeronautical materials and processes will be more integrated and supported by life-cycle assessments, to increase component life-time and improve reuse and recyclability.

This section presents the main objectives, activities and results of projects focusing on developing advanced and sustainable lightweight materials for aircraft structures. The projects include research on efficient design and manufacturing methods, aiming to improve all stages of the aircraft's life cycle and to optimize component design. The research was complemented by the development of novel experimental and numerical methods, and in-situ measurement techniques.

# ECO-COMPASS

## ECOLOGICAL AND MULTIFUNCTIONAL COMPOSITES FOR APPLICATION IN AIRCRAFT INTERIOR AND SECONDARY STRUCTURES

The ECO-COMPASS project developed and assessed multifunctional and ecologically improved composites from bio-sourced and recycled materials for application in aircraft secondary structures and interior. The project helped mature ecologically improved composites and addressed environmental challenges such as material sustainability and waste treatment.

Natural fibres such as flax and ramie were used for different types of reinforcements, including fabric and nonwoven. Honeycomb sandwich cores with wood fibres substituting a part of the aramid fibres were successfully tested. Substitution of bisphenol-A based epoxy resins in secondary structures by partly bio-based epoxy resins was investigated with promising results. Material protection technologies were studied to reduce environmental influence and improve fire resistance. Modelling and simulation of chosen eco-composites optimised the use of materials while a life cycle assessment assessed the ecological advantages compared to synthetic state-of-the-art materials.

ECO-COMPASS investigated different approaches, concepts, and technologies. In terms of eco-reinforcements, the project reached generally TRL 3-4. An example is the hybrid combination of flax fibres with recycled carbon fibres in a hybrid nonwoven with TRL 3. Partly rosin-based epoxy resins and the Green Honeycomb sandwich core have achieved a TRL 4. Generic demonstrator parts for interior and secondary structures were manufactured.

ECO-COMPASS has contributed to the goals of Flightpath 2050 by demonstrating that some aircraft components can include new, eco-efficient and competitive materials.

The project reinforced the cooperation between European and Chinese participants to improve the ecological balance of materials currently used in aviation. It enabled a unique leverage of resources and allowed mitigation of risks in the eco-composites development and production. Two open access special issues in scientific journals have been published by the consortium. In 2018, ECO-COMPASS was featured in Euronews' Futuris programme, which is broadcast in 158 countries and 12 languages.


© ECO-COMPASS

### PROJECT DURATION

Start date: 01/04/2016 ⇢ End date: 30/06/2019

### COORDINATOR

DLR

### PROJECT NUMBER

690638

### EU FUNDING

€1,893,685.00

### WEBSITE

www.eco-compass.eu

### VIDEO

Euronews (April 2018) - Airplanes and material gains
https://youtu.be/xwgl5hzGH2I

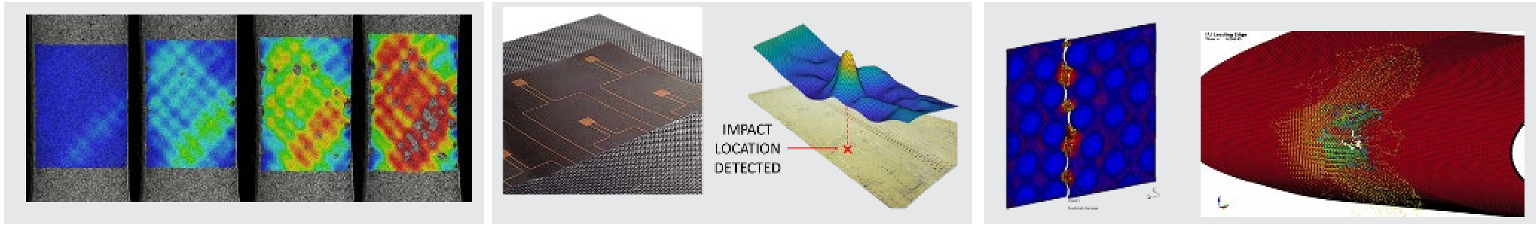


References under 'ECO-COMPASS' on page 63



# EXTREME

## EXTREME DYNAMIC LOADING - PUSHING THE BOUNDARIES OF AEROSPACE COMPOSITE MATERIAL STRUCTURES




ALL IMAGES © EXTREME

The EXTREME project pioneered experimental and numerical tools for the accurate and reliable design and manufacturing of aircraft composite structures under extreme dynamic loadings. EXTREME delivered novel material characterisation and in-situ measurement techniques, and advanced multiscale simulation methods for aircraft composite structure design.

The project demonstrated novel composite manufacturing procedures which allows significant reduction of weight, design and certification costs, and environmental signature. More specifically, the EXTREME project developed simulation tools that enable reduced physical testing by improving the accuracy of the predictions by 20%, while also contributing to the reduction of development costs by 10%. It also researched and proposed advanced dynamic testing and sensing methodologies, for accurate damage detection and structural health monitoring. Finally, the consortium introduced advanced modelling algorithms in industrial software and successfully commercialised novel optoelectronic devices (TRL9).

EXTREME's findings will allow lighter design of aeronautical structures in line with EU environmental goals set in Flightpath 2050 by seeking a new "right at first time" design philosophy. The competitive supply chain enabled by the developments of EXTREME will help the aviation industry to rapidly introduce more environmentally friendly products, reduce development costs and provide a safer air-transport system. EXTREME's key outcomes also support EU competitiveness by satisfying the demand for highly skilled jobs and enabling economic growth with lighter and safer aircraft structures.

Left: Material Characterisation.
Middle: In-Situ Smart Sensing.
Right: Multiscale Modelling

### PROJECT DURATION

Start date: 01/09/2015 ⇢ End date: 31/08/2019

### COORDINATOR

UNIVERSITY OF BATH

### PROJECT NUMBER

636549

### EU FUNDING

€5,277,597.50

### WEBSITE

https://www.extreme-h2020.eu/

### VIDEO

EXTREME D8 5 impact movie
https://youtu.be/iK6OJBHjing



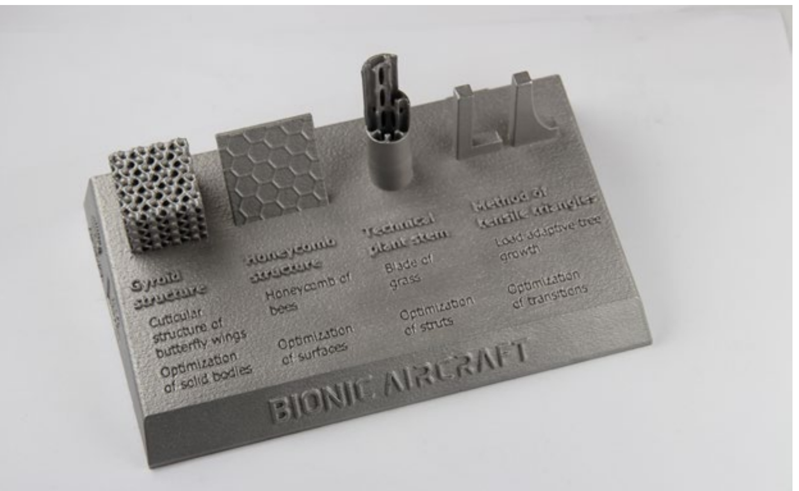
References under 'EXTREME' on page 63

# BIONIC AIRCRAFT

## INCREASING RESOURCE EFFICIENCY OF AVIATION THROUGH IMPLEMENTATION OF ALM TECHNOLOGY AND BIONIC DESIGN IN ALL STAGES OF AN AIRCRAFT LIFE CYCLE

The Bionic Aircraft project enhanced the resource efficiency of aviation by the development and implementation of additive layer manufacturing (ALM) technologies and bionic design in all stages of the aircraft life cycle, as part of a design-to-manufacturing process. With ALM as a tool-less production technology, highly developed geometries and internal structures can be produced, which could be only done otherwise by conventional manufacturing processes at a high material, time and cost consumption, if at all.

The project's main achievement was the optimization and automation of the design process of ALM part design with bionic features, while developing advanced numerical methods and parameterization tools. More specifically, the design of the demonstrator parts for ALM including topology optimization and introduction of bionic design features showed weight savings of up to 28% compared to the standard parts currently used in conventional aircraft. The consortium also developed a new high-strength AlSiSc alloy for use in ALM manufacturing and a new powder production process which can achieve cost savings of up to 15%. The Bionic Aircraft project also enhanced the productivity of the ALM process for the AlSiSc alloy by 30%, which results in 25% reduction of overall manufacturing costs, due to the reduction of machine runtimes.






The Bionic Aircraft project contributed to the Flightpath 2050 goals by improving the whole design-to-manufacturing chain and thus allowing reduced lead time and cost of the process, with a tangible likelihood of weight reduction, hence resulting in a high-potential environmental and societal impact. The project also contributed to policy-making by targeting new rules, processes and standards for the development of materials, processes, design methodologies, in-process, in-line and in-service inspections, repair and recycling methodologies and a new paradigm for the supply chain of aerospace structures, by the introduction of ALM materials.

### PROJECT DURATION

Start date: 01/09/2016 ⇢ End date: 31/08/2019

### COORDINATOR

FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.

### PROJECT NUMBER

690689

### EU FUNDING

€6,441,062.00

### WEBSITE

https://bionic-aircraft.eu/

### VIDEO

BIONIC AIRCRAFT // BIONIC DESIGN OF NEW ULTRA-LIGHTWEIGHT STRUCTURES
https://youtu.be/Zzg6TS-_yLI



References under 'Bionic Aircraft' on page 64



# NHYTE

## NEW HYBRID THERMOPLASTIC COMPOSITE AEROSTRUCTURES MANUFACTURED BY OUT OF AUTOCLAVE CONTINUOUS AUTOMATED TECHNOLOGIES


The NHYTE project is taking the use of composite materials to the next level, by developing new efficient concepts and methodologies that will enable the production of innovative and green integrated aero-structures by a novel recyclable hybrid thermoplastic composite material with multifunctional capabilities.

The project has developed and implemented a continuous automated process for the production of typical aero-structures (part of the wing and fuselage) by an innovative robotic machine. The novel material proposed by NHYTE delivers toughness improvement and process simplification, since it does not require autoclave consolidation, thus optimizing energy consumption and lowering production cycle times.

More specifically, NHYTE has developed an innovative multifunctional thermoplastic prepreg material, based on a hybrid semi-crystalline-amorphous polymer concept. The consortium has applied this multifunctional material to achieve an integrated aero-structure by using advanced out of autoclave joining methods for reducing the number of fasteners, and manufacturing and operational parts. The project has also developed a pre-industrial continuous automated process for fabrication of hybrid thermoplastic prepreg materials suitable to be processed by the automated fibre placement (AFP) machine. The AFP technology and the continuous forming process have enabled to manufacture complex shaped aero-structures by means of in-situ consolidation. Moreover, the consortium has performed an environmental and life cycle assessment, according to ECO-quotation procedures, and weight and cost savings.

The NHYTE project has designed and installed a unique automated pilot plant for the fabrication of the new thermoplastic composite material, by the developed industrial continuous automated process. The project will demonstrate the readiness of the pre-industrial process for manufacturing recyclable aero-structures by producing a structure representative of a fuselage section.

The contribution of the NHYTE project to the goals of Flightpath 2050 is outlined by its target of more than 5% weight saving for primary structures and more than 8% for narrow body fuselages, which translates into lower fuel consumptions and consequently lower emissions. Further reduction of full life-cycle cost is expected from recycling of scrap materials and end-of-life structures.




### PROJECT DURATION

Start date: 01/05/2017 ⇢ End date: 31/10/2020

### COORDINATOR

NOVOTECH s.r.l

### PROJECT NUMBER

723309

### EU FUNDING

€5,250,356.25

### WEBSITE

https://www.nhyte-h2020.eu/

### VIDEO

Interview with Leonardo Lecce and Marco Barile-Novotech S.r.L.
https://youtu.be/Xz4-q1p_He8



References under 'NHYTE' on page 64

# SECTION 6 - OPERATIONS IMPACT ON CLIMATE CHANGE

Aviation is altering the composition of the atmosphere globally, thus contributing to anthropogenic climate change and ozone depletion. In this context, a better scientific understanding of the impact of aviation emissions on the atmosphere is key to develop tailored mitigation strategies and novel low-emissions technologies. Particular focus is required not only on $CO_2$ emissions, but also on NOx, particulate matter and contrail-forming water vapour[1]. Research suggests that climate impacts from non-$CO_2$ emissions (e.g. NOx, particles) cannot be ignored as they contribute to climate change. However, further scientific understanding is still necessary in order to capture the real magnitude of the effects.

According to the data reported to the United Nations Framework Convention on Climate Change (UNFCCC), the $CO_2$ emissions of all flights departing from EU28 and EFTA countries increased from 88 to 171 million tonnes (+95%) between 1990 and 2016 (European Aviation Environmental Report, 2019). Similarly, for the same period, according to the Convention on Long-Range Transboundary Air Pollution (CLRTAP) data from the UN Economic Commission for Europe, NOx emissions have increased from 313 to 700 thousand tonnes. According to a JRC study (Kousoulidou et al. 2016), results regarding $CO_2$ emission projections to 2030 reveal a steady annual increase in the order of 3%, 1% and 4% on average, for three different scenarios (business as usual, pessimistic and optimistic), providing also a good correlation compared to the annual traffic growth rates that are indicated in the corresponding scenarios. According to Kousoulidou et al. (2016), any political instability in specific regions, wars or pandemic diseases which can pose an on-going threat to global security, could in turn influence the future of aviation growth and hence have an impact on the relevant emissions.

Regarding NOx emissions, by 2040, these are predicted to increase by at least 16% (reference: aviation environmental report). According to the same study (European Aviation Environmental Report, 2019), the fleet renewal has contributed in relatively stable particulate matter emissions between 2005 and 2014. However, these are expected to increase over the next twenty years, if there are no improvements on engine technology.

The development, analysis, and assessment of more sustainable flight trajectories and operations, including aircraft ground operations, are areas of research of paramount importance in the strive towards a more sustainable and clean aviation. They will in fact enable aircraft operators, manufacturers, air navigation service providers, and public authorities to identify best options in order to mitigate the air transport's environmental impact, by adopting best practices and by developing more accurate standards for aircraft operations. They will also provide the basis for the establishment of global environmental standards based on agreed and harmonized scientific principles. This section presents the main objectives and activities of projects focusing on investigating aviation operations' impact on climate change. In particular, the showcased projects aim to i) gain better scientific understanding of aviation emissions with high degree of uncertainty and high estimated impact on climate change; ii) propose and evaluate mitigation strategies towards operational improvements and greener flight trajectories; and iii) create a knowledge basis that will support informed decision-making and regulations in the field of greener flight operations.

[1] Kärcher, B., "Formation and radiative forcing of contrail cirrus", Nature Communications, 9, 1828, 2018.

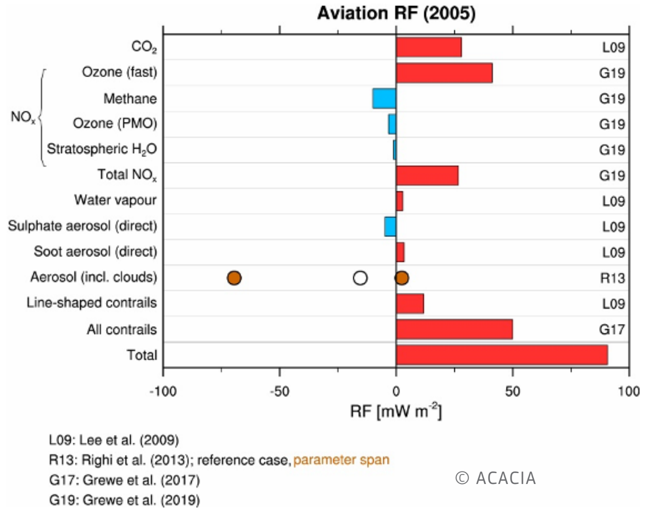
# ACACIA

## ADVANCING THE SCIENCE FOR AVIATION AND CLIMATE

The ACACIA project is improving the understanding of the climate impact of non-CO2 effects and particularly of indirect aerosol effects which have the largest uncertainty.

ACACIA will formulate concepts for international measurement campaigns with the goal to constrain numerical models and theories with data. Putting all aviation effects on a common scale will allow to provide an updated climate impact assessment. The project will treat uncertainties in a transparent way, such that trade-offs between different mitigation strategies can be evaluated explicitly. Finally, the project strives for the knowledge basis necessary to allow strategic guidance for future implementation of mitigation options, that is, to give robust recommendations of no-regret strategies for achieving reduced climate impact of aviation.

ACACIA will explore how changes to aviation can help bring emissions and impacts in line with the goals of Flightpath 2050. Thanks to a better understanding of aviation's non-CO2 climate effects, the project will deliver necessary input for an eco-efficient planning of flight trajectories, which will allow a substantial reduction of the aviation-induced climate change at the same transport capacity. The project will also deliver guidelines for the design of future aircraft, which are more adapted to a climate friendly transport.




### PROJECT DURATION

Start date: 01/01/2020 ⇢ End date: 30/06/2023

### COORDINATOR

DLR

### PROJECT NUMBER

875036

### EU FUNDING

€2,999,500.00

### WEBSITE

www.acacia-project.eu

Photo caption: Radiative forcing (RF) from aviation. RF is a proxy for the expected equilibrium climate change.





# CLIMOP

## CLIMATE ASSESSMENT OF INNOVATIVE MITIGATION STRATEGIES TOWARDS OPERATIONAL IMPROVEMENTS IN AVIATION

The ClimOP project aims to identify, evaluate, and support the implementation of mitigation strategies to initiate and foster operational improvements which reduce the climate impact of the aviation sector. The overall objective of ClimOP is to define actions and advice for policymakers by proposing a set of most promising and harmonized mitigation strategies.

The project will create a preliminary list of promising operational improvements including, for example, electric taxiing, flexible runway usage, intelligent runways lights, intermediate stops and formation flights. Subsequently, ClimOP will assess the impact these improvements have on climate and stakeholders. The consortium will develop harmonised mitigation strategies, together with a series of recommendations for policymakers, to support measures and foster the implementation. It will also stimulate international cooperation-building network partnerships with non-EU aviation stakeholders and with communication activities at worldwide level.

ClimOP will contribute to the goals of Flightpath 2050 by achieving operational gains in fuel consumption and emissions, while providing feedback to policymakers for the development of standards for future air operations.

### PROJECT DURATION

Start date: 01/01/2020 ⇢ End date: 30/06/2023

### COORDINATOR

Deep Blue SRL

### PROJECT NUMBER

875503

### EU FUNDING

€3,064,272.50

### WEBSITE

www.climop-h2020.eu

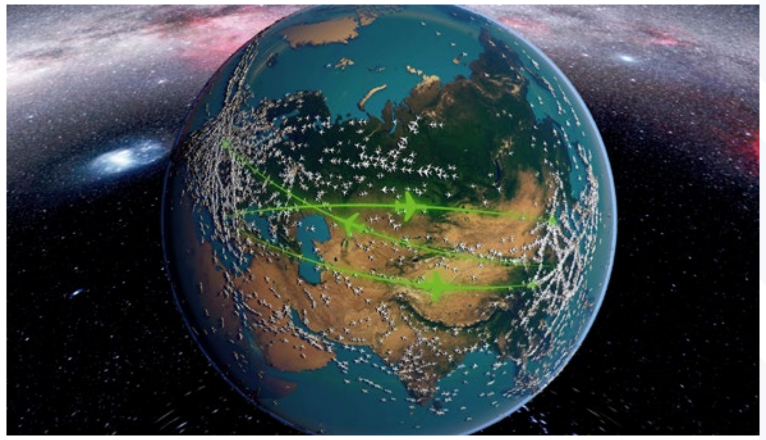
# GReAT

## GREEN AIR TRAFFIC OPERATIONS

The GreAT project is investigating new strategies towards greener flight trajectories, by innovative air traffic guidance methods and optimized routings on airports, in the terminal control area as well as during cruise flight.

The project will firstly detail and describe the overall concept to achieve greener flight trajectories, building a framework covering all thinkable improvements on a local and global level and put them into a context. Subsequently, GreAT will develop supporting algorithms and prototypes for trajectory negotiation, de-conflicting and optimization at TRL 2-4. In contrast to former research activities, the project will not only focus optimization processes on the highest possible airspace and airport capacity but also on the lowest environmental impact of air traffic. It will also use fast-time and real-time human-in-the-loop simulations to comprehensively validate the feasibility of the new methods, as well as to assess their potential and their limits in terms of saved fuel and emissions.

The GreAT project will contribute to Flightpath 2050 by paving the way to an optimized airspace structure as well as highly efficient flight procedures and trajectories for civil air traffic. It will therefore reduce fuel consumption and $CO_2$/ NOx emissions while maintaining capacity of hub airports and highly frequented airspaces.





The GreAT project will be conducted in collaboration with seven European and six Chinese Partners, including air navigation service providers, aviation research institutes, universities and airspace users. Researchers will focus on optimization strategies for short-haul flights on the European side; and for long-haul flights on the Chinese side.

**PROJECT DURATION**

Start date: 01/01/2020 → End date: 30/06/2023

**COORDINATOR**

DLR

**PROJECT NUMBER**

875154

**EU FUNDING**

€2,681,532.50

**WEBSITE**

http://project-great.eu/

# SECTION 7 - AIR QUALITY AND NOISE

Aviation is one of the many sectors that impact air quality and perceived noise levels, in both the vicinity of the airport and the surrounding communities. In these areas, air quality is not only impacted by the emissions from aircraft engines, but also from other sources such as ground operations, surface access road transport and airport on-site energy generation and heating[1]. Aircraft noise, on the other hand, impacts airport-neighbouring communities especially at aircraft take-off and landing, and with increased operations.

Air pollution has been linked to significant impacts on the health of the European population, particularly in metropolitan cities and urban areas. Some of the most significant pollutants in terms of harm to human health are particulate matter, nitrogen dioxide ($NO_2$), sulphur oxides (SOx) and non-methane volatile organic compounds (NMVOCs). One of the main concerns is that some of the primary pollutants undergo chemical and physical transformations in the atmosphere that in turn produce secondary particulate matter and ground-level ozone[2]. Although focus was until recently on NOx emissions, aviation is also an important contributor of ultrafine particles[3], as highlighted in numerous studies[1,4]. It has thus been concluded that future combustor technologies should address both ambitious NOx and nvPM (non-volatile) objectives.

Long-term exposure to aircraft noise is linked to a variety of health impacts even at relatively low noise levels, including ischaemic heart disease, sleep disturbance, annoyance and cognitive impairment[5]. The World Health Organization Europe published a document in 2018 on the maximum acceptable outdoor noise levels to avoid health effects[6]. In February 2013, the ICAO's Committee on Aviation Environmental Protection (CAEP) agreed to a new global noise reduction standard, concluding that the most beneficial area of future noise reduction is technology development to reduce noise at source, where significant progress has already been made. By 2040, further improvements are expected to reduce the average noise energy per flight by 24%[1].

This section presents the main objectives, activities and results of projects focusing on air quality and noise levels. In particular, emphasis is given to the i) quantification and assessment of aircraft engine emissions; ii) understanding of the primary emissions of non-volatile particulate matter and secondary aerosol precursor gasses; iii) development of advanced noise reducing technologies and new approaches to manage and mitigate noise at airport and surroundings, including land-use planning, hence enhancing the capability of aviation systems to respond to growing traffic demands; iv) and, with the potential return of supersonic civil flight opportunities, in providing quantified evidence needed to support new regulations for low-boom aircraft operations.

[1] European Aviation Environmental Report 2016 & 2019, https://www.easa.europa.eu/eaer/.
[2] United States Environmental Protection Agency EPA, Health and Environmental Effects of PM, 2018.
[3] ACI EUROPE, 2018, Ultrafine Particles at Airports.
[4] Joint WHO/Convention Task Force on Health Aspects of Air Pollution, Health Effects of PM, 2013.
[5] ICAO, Balanced Approach to Aircraft Noise Management, 2020.
[6] World Health Organization Europe, 2018, Environmental Noise Guidelines for the European Region.

# AVIATOR

## ASSESSING AVIATION EMISSION IMPACT ON LOCAL AIR QUALITY AT AIRPORTS: TOWARDS REGULATION

The AVIATOR projects is improving description and quantification of aircraft engine emissions, through a multi-level measurement, modelling, and assessment approach. The project places specific attention on creating a more detailed understanding of the primary emissions of non-volatile particulate matter and secondary aerosol precursor gasses, as well as their impact on air quality.

To provide an enhanced understanding of non-volatile particulate matter, volatile particulate matter (down to <10 nm), and volatile PM gaseous precursors, AVIATOR will measure aircraft engine emissions: i) within a well characterized test cell at the engine exit and in the exhaust chamber (50m) and ii) on-wing at an in-service aircraft. The project will thus obtain critical insight into the scalability between the regulatory test cell and real-world environments.

AVIATOR will also develop and deploy across multiple airports, a proof-of-concept low-cost sensor network for the monitoring of ultra-fine particles, total particulate matter and gaseous species across the airport and in surrounding communities. The measurement campaigns will be complemented by high-fidelity aircraft exhaust modelling and by microphysical and chemical processes within the plume.



Photo caption: IINTA Testbed with the Optical Ring and an engine

AVIATOR will contribute to the Flightpath 2050 by providing critical insight to support goal-setting for non-volatile and volatile particulate matter, by providing airports and communities with guidance tools to measure and model aircraft emissions and by working with the health community to develop protocols and techniques for representative sampling of particulate matter emissions.

The findings of the project will support the work of European and International bodies responsible for informing policy makers, aircraft engine emission regulations (ICAO/EASA), Occupational Health and Safety (EU-OSHA), and Ambient Air Quality (EEA/WHO).

AVIATOR is a Research and Innovation Action which has embedded International Cooperation. The National Research Council Canada is a co-founder and the project and through its international Advisory Board has engaged the support of key partners from the USA and China.

### PROJECT DURATION

Start date: 01/06/2019 ⇢ End date: 31/05/2022

### COORDINATOR

INTA

### PROJECT NUMBER

814801

### EU FUNDING

€5,103,718.16

### WEBSITE

https://www.aviatorproject.eu

### VIDEO

Aviator project video

https://aviatorproject.eu/multimedia/



References under "AVIATOR" on page 64

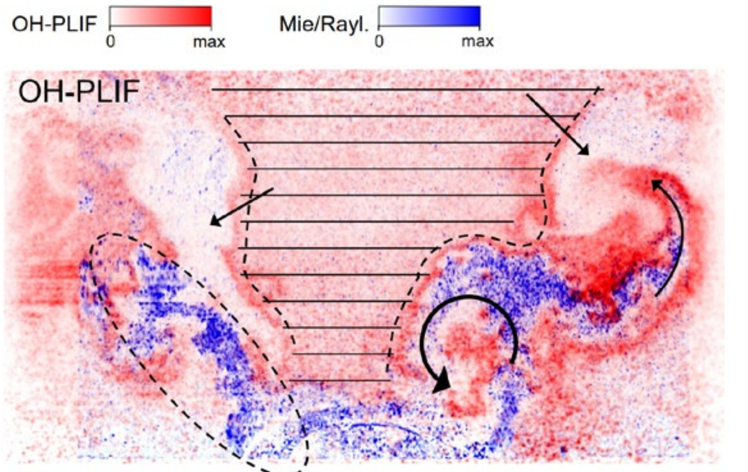


# SOPRANO

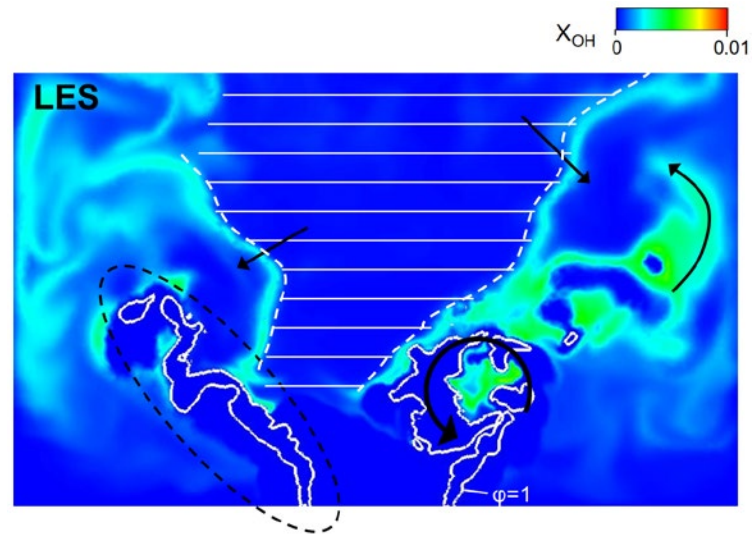
## SOOT PROCESSES AND RADIATION IN AERONAUTICAL INNOVATIVE COMBUSTORS

The SOPRANO project is reducing aircraft engine particle emissions. The consortium has enhanced the knowledge base and has achieved a qualitative shift in the experimental and numerical approaches for characterization and prediction of soot emission and its radiative effect on combustor walls at engine-relevant operating conditions.

SOPRANO achieved significant progress in the development of experimental techniques for the characterization of representative turbulent sooting flames. The consortium has also developed numerical methods for soot modelling and used their extensive database of obtained experimental data to validate these models and to enhance their predictive accuracy.






More specifically, SOPRANO has achieved major advances in soot modelling in a complex combustion environment; one can highlight the advances in the description of number density, volume fraction and size distribution of soot, which the consortium derived by combining the advantages of different statistical approaches.

The SOPRANO project contributes to the goals outlined by Flightpath 2050 by enabling aircraft engine manufacturers to reduce soot particle emissions from their engines and to optimize the combustor life span, hence allowing them to efficiently address future aero-engine certification legislation.

Photo caption: Comparison of instantaneous OH distribution from experiment (top) and LES simulation (bottom) for pressurized sooting swirl flame (DLR FIRST combustor). The left plot features OH distribution (red) and cold inflowing gases (blue), while the main features including multiple quantities are well captured by the LES calculation: inflowing gases, flame fronts (dashed), vertical structures, region of homogeneous OH distribution (central of plots).

### PROJECT DURATION

Start date: 01/09/2016 ⇢ End date: 31/08/2020

### COORDINATOR

SAFRAN

### PROJECT NUMBER

690724

### EU FUNDING

€6,829,310.00

### WEBSITE

http://www.soprano-h2020.eu/



"SOPRANO" on page 64

# ANIMA

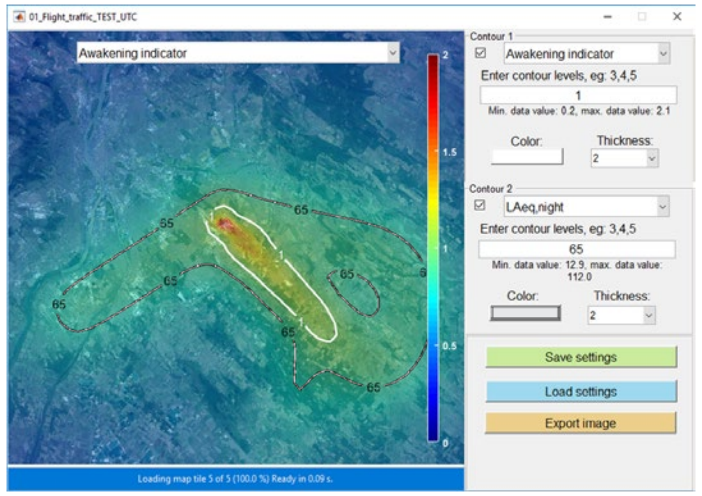
## AVIATION NOISE IMPACT MANAGEMENT THROUGH NOVEL APPROACHES

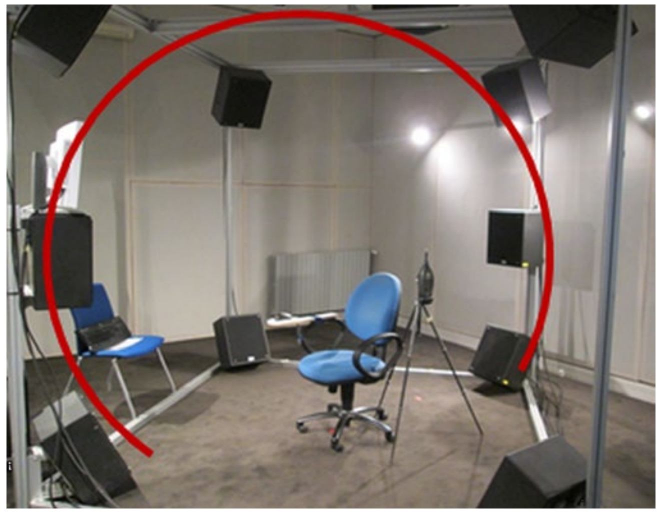
The ANIMA projectis developing new methodologies, approaches and tools to manage and mitigate the impact of aviation noise, thus enhancing the capability of aviation systems to respond to growing traffic demands. ANIMA does not intend to mitigate noise generation at the source, but rather to examine how noise impacts people on the ground.

The ANIMA project has assessed how noise regulations are implemented by airports and how latest scientific findings are taken into account. It has refined the very concept of annoyance and its relation to non-acoustical factors and has also provided tools to assess annoyance due to air traffic. ANIMA will channel these outcomes into a best practice portal and will provide authorities and airports with a versatile noise management toolset to forecast the impact of air traffic on noise and on the annoyance of neighbouring communities. This will allow communities to implement tailored measures.

The achievements of ANIMA contribute to the ICAO's objectives for community engagement for aviation environmental management. These efforts complement the traditional balanced approach of ICAO which is based on reduction of noise at the source (technology standards), land-use planning and management, noise abatement operational procedures, and operating restrictions.

ANIMA is contributing to the Flightpath 2050 goal of reducing the perceived noise emission of aircraft. The approach of engaging communities to seek consensus on issues such as land-use planning or traffic trade-offs is a prerequisite for reaching this ambitious objective on perceived noise. ANIMA has thus been communicating towards noise-impacted communities and has organized several conferences and workshop with local communities and stakeholders.



ALL IMAGES © ANIMA

Left: Example of awakening indicators maps that are going to be computed by the noise management toolset.
Right: A noise simulator for experiencing, comparing and assessing aircraft noise.

### PROJECT DURATION

**Start date: 01/10/2017** ⇢ **End date: 30/09/2021**

### COORDINATOR

ONERA

### PROJECT NUMBER

769627

### EU FUNDING

€7,482,118.50

### WEBSITE

www.anima-project.eu

### VIDEO

Aviator project video
https://aviatorproject.eu/multimedia/



References under "ANIMA" on page 64



# ARTEM

## AIRCRAFT NOISE REDUCTION TECHNOLOGIES AND RELATED ENVIRONMENTAL IMPACT

The ARTEM project is developing efficient solutions for noise reduction technologies, focusing on novel liner concepts, noise shielding, dissipative surfaces and metamaterials.

ARTEM investigates the interaction of all relevant components of future aircraft configurations (such as semi-buried engines and blended-wing-body) that are expected to enter into the market between 2035 and 2050. The project applies analytical tools, low- and high-fidelity numerical simulations and dedicated experiments to obtain noise predictions relevant to future aircraft. It also develops low-noise design solutions, improved tools and optimization strategies. The project will bring "Generation 3" noise reduction technologies to a TRL of 3 to 4.

The project has developed novel passive and active liner concepts. It has performed extensive experimental studies on jet noise shielding effects, landing gear noise generation and 3D trailing edge surface treatments for noise reduction. The consortium will use the obtained experimental data to validate the developed models and numerical methods. ARTEM has also successfully performed high-fidelity numerical studies of existing benchmark configurations in order to validate the different numerical tools and tool chains to be used for its noise reduction studies.

The ARTEM project contributes to the Flightpath 2050 goals by contributing to developing more silent aircraft. Moreover, through technology development, ARTEM is paving the way for maintaining and increasing mobility in Europe while providing relief to communities around airports.

© ARTEM

### PROJECT DURATION

**Start date: 01/12/2017** ⇢ **End date: 30/11/2021**

### COORDINATOR

DLR

### PROJECT NUMBER

769350

### EU FUNDING

€7,498,742.50

### WEBSITE

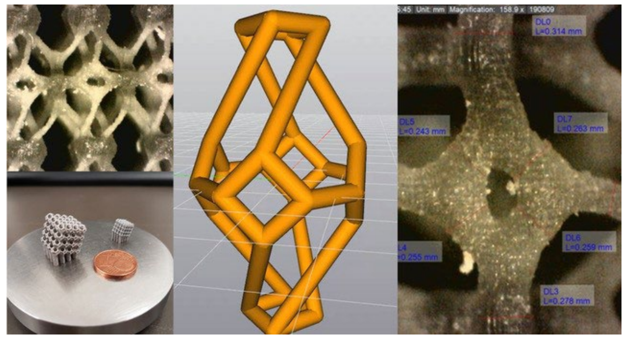
www.dlr.de/ARTEM

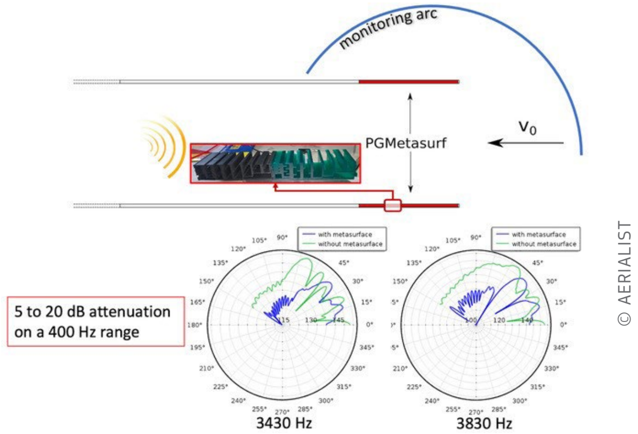


References under "ARTEM" on page 64

# AERIALIST

## ADVANCED AIRCRAFT-NOISE-ALLEVIATION DEVICES USING METAMATERIALS






The AERIALIST project disclosed the potential of metamaterials in aeronautics through four pillar actions: i) consolidated the aeroacoustic theory of metamaterials; ii) developed and assessed methods for efficient additive manufacturing of metamaterials; iii) validated models and design through wind-tunnel experiments; iv) assessed the entire toolchain loop modelling-manufacturing-experiments and provided a development roadmap towards TRL of industrial relevance.

The activity of AERIALIST can be summarized in the following points: extension of a generalized metacontinuum model to aeroacoustics; development of an inverse method for acoustic material design tailored to a target response and the identification of the continuum equivalent to a micro-periodic structure; reduced-order modelling of visco-thermal losses for macro-scale calculations; enhanced boundary-field element methods and finite-element methods; development of reliable additive manufacturing strategies; design and manufacturing of an experimental rig tailored to metamaterial measurements.

The AERIALIST project performed research on modelling, design, manufacturing and experiments. It produced remarkable results in the optimization of reflection-steering metasurfaces by improving their effective range up to 600 Hz. The project also achieved efficient lining of ducts with metasurfaces, resulting in 5 to 20 dB reduction of downward propagating noise. Moreover, the AERIALIST consortium corrected statically designed metamaterials to operate in moderate Mach number (Ma) flows, resulting in almost perfect scattering cancellation for Ma ≤ 0.3, and identified the tailored equivalent continuum from anisotropic periodic structures (extensive control of stiffness, shear modulus and Poisson's ratio). AERIALIST achieved TRL 3, as was foreseen at the beginning of the project.

Left: From design to additive manufacturing of micro structures with a specific target response.
Right: Experimental and numerical validation of a metasurface-lined duct.

AERIALIST also delivered a development roadmap towards higher TRL, in order to effectively contribute to the goals set by Flightpath 2050. AERIALIST has paid specific attention to the future integration of the metamaterial design toolchain into an industrial development process, through a comprehensive and holistic approach.

### PROJECT DURATION

Start date: 01/06/2017 ⇢ End date: 31/05/2020

### COORDINATOR

UNIVERSITA DEGLI STUDI ROMA

### PROJECT NUMBER

723367

### EU FUNDING

€2,434,330.00

### WEBSITE

https://www.aerialist-project.eu/

### VIDEOS

Experimental validation of reflection-steering metasurface
https://youtu.be/lAs2RoRjfLU

Slide show of the ISMA2018 paper "A combined design-manufacturing-testing investigation of tailoring of open poroelastic materials"
https://youtu.be/dNIgrM4afjM

AERIALIST Project @ AERODAYS 2019
https://youtu.be/lMqfTHGFW4c



References under 'AERIALIST' on page 64



# RUMBLE

## REGULATION AND NORM FOR LOW SONIC BOOM LEVELS

The RUMBLE project is producing the scientific evidence requested by national, European and international regulation authorities to determine the acceptable levels of overland sonic booms and the appropriate ways to comply with it. RUMBLE intends to provide the quantified evidence needed to support new regulations for low-boom aircraft operations.

The RUMBLE project develops sonic boom prediction tools and studies the human response to sonic boom by developing state of the art indoor and outdoor simulators. RUMBLE will validate its findings using wind-tunnel experiments and flight tests. It will also pave the way for a future low-boom flying demonstrator.

RUMBLE has successfully performed two flight test campaigns in Russia, in order to gather experimental data on sonic boom propagation on the ground and in buildings. It has also achieved the design and setup of sonic boom simulators which will be used to assess the public acceptability of reduced sonic boom. The consortium has also performed extensive numerical studies of sonic boom propagation in various types of atmosphere and buildings and has submitted ICAO working papers in support of the European position regarding supersonic flights over land. The RUMBLE project has engaged in extensive dissemination and regulatory activities, in order to ensure that the European considerations are taken into account in the evolution of international regulations affecting civilian supersonic aviation.

RUMBLE contributes to the Flightpath 2050 goals by providing the necessary data and procedures for a future, internationally agreed standard on low sonic boom flights over land. This standard will protect the European citizens' quality of life by guaranteeing, in agreement with ICAO general resolution 33-7, that no unacceptable situation is created by supersonic commercial flights.

Through the international collaboration between European and Russian partners, RUMBLE combines scientific excellence, world-class research infrastructures and industrial leadership bearing the heritage from Concorde and Tu-144, with strong involvement within the regulatory bodies.

### PROJECT DURATION

Start date: 01/11/2017 ⇢ End date: 31/10/2020

### COORDINATOR

AIRBUS

### PROJECT NUMBER

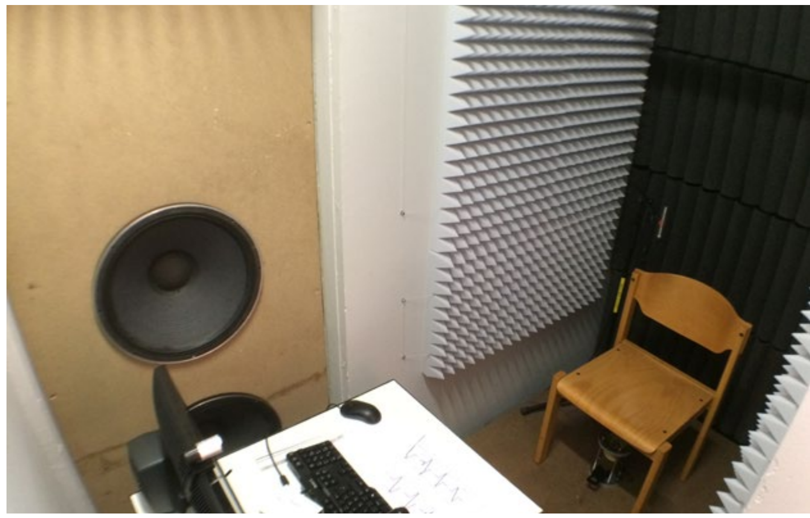
769896

### EU FUNDING

€5,042,973.75

### WEBSITE

https://rumble-project.eu/



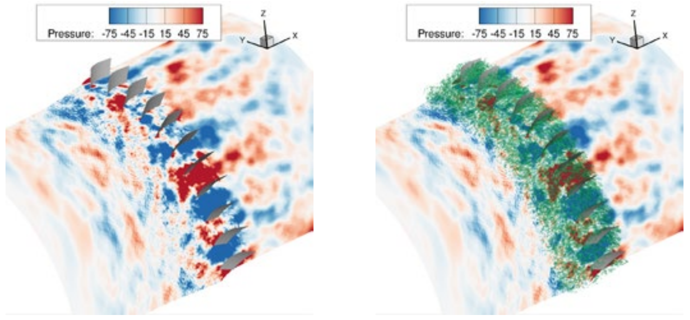
# TURBONOISEBB

## VALIDATION OF IMPROVED TURBOMACHINERY NOISE PREDICTION MODELS AND DEVELOPMENT OF NOVEL DESIGN METHODS FOR FAN STAGES WITH REDUCED BROADBAND NOISE

The TurboNoiseBB project is enhancing the understanding of broadband noise generation by realistic ultra-high bypass ratio (UHBR) fans and is developing state-of-the-art prediction tools for efficient design of low broadband noise fan systems.

The project has acquired a world-unique database of noise and flow data, obtained from experiments and high-fidelity computations. The obtained database will provide the aerodynamic and aeroacoustic input to validate cutting-edge prediction methods for realistic flow conditions of an UHBR fan. The high-fidelity hybrid computational aeroacoustics methods for fan broadband noise sources will be integrated into existing system capabilities for multi-disciplinary optimization. The TurboNoiseBB project will additionally develop low broadband noise fan concepts by novel outlet guide vane design.

The ambitious goals of the Flightpath 2050 vision for aircraft noise reduction can be achieved by substantial reductions in fan noise, the contribution of which can be roughly split into 50% tonal noise and 50% broadband noise. TurboNoiseBB concentrates on the latter, expecting to achieve fan noise reduction of 3 dB by means of optimized design.






Top: Snapshots of high-fidelity scale resolving flow simulations for rotor stator stages from DLR.
Middle: Experimental test setup at ANECOM Aero Test in Wilday (left), test fan (right).

### PROJECT DURATION

Start date: 01/09/2016 ⇢ End date: 31/08/2020

### COORDINATOR

DLR

### PROJECT NUMBER

690714

### EU FUNDING

€6,702,851.25

### WEBSITE

https://www.dlr.de/turbonoisebb

References under "TurboNoiseBB" on page 64

# INEA IN BRIEF

INEA is an Executive Agency established by the European Commission to implement parts of EU funding programmes for transport, energy, telecommunications and climate action. The Agency's mission is to provide its stakeholders with expertise and high-level programme management, whilst promoting synergies among programmes, in order to benefit economic growth and EU citizens. INEA supports EU aviation activities together with the European Commission's Directorates-General for Mobility & Transport (DG MOVE) and Research & Innovation (DG RTD), as well as with the Clean Sky Joint Undertaking (JU) and the SESAR JU.

The Agency's key role is to turn aviation policy set by the European Commission into R&I and infrastructure projects.

## HORIZON 2020

Since January 2014, INEA is the gateway to funding under the Horizon 2020 Societal Challenges 'Smart, green and integrated transport' and 'Secure, Clean and Efficient Energy' with a total budget of €5.3 billion (€2.3 billion for transport and €3 billion for energy) to be granted by end 2020. With an expected budget of over €50 million in 2020, INEA's total contribution to the EU's aviation research projects will be more than €400 million by the end of 2020.

## CONNECTING EUROPE FACILITY (CEF)

INEA implements most of the CEF budget, in total €28.3 billion (€23.2 billion for transport, €4.6 billion for energy, and €0.5 billion for telecommunications). Under the CEF Transport programme, INEA's increasing aviation portfolio focuses on improving Air Traffic Management (ATM), as well as developing seamless and safe air mobility across Europe. Actions related to ATM and Single European Sky ATM Research (SESAR), are implemented by a wide range of aviation stakeholders. So far 68 Actions linked to ATM have been funded under the CEF Programme for a total amount of €1.6 billion.

## BECOME AN EXPERT EVALUATOR

*The European Commission is regularly looking for external evaluators of project proposals.*

*If you fit the expert profile rather than that of an applicant, and would like to be considered as a proposal evaluator, sign up in the Funding & tender opportunities portal:*

https://ec.europa.eu/info/funding-tenders/opportunities/portal/

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