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European research and innovation in aviation emissions reduction

An assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)

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Contents

Abstract

Research and innovation is highly important for the development and adoption of new aviation concepts and technologies. This report provides an analysis of research and innovation initiatives in Europe in aviation, with a focus on emissions reduction. The assessment follows a structured methodology developed by the European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS). The report addresses aviation research by thematic area and technology, highlighting recent developments and future needs. It also provides insight from the academia and the private sector by means of focused scientific literature and patent analysis.

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Executive summary

The report presents an analysis of research and innovation (R&I) in aviation in Europe, with a focus on emissions reduction. The report assesses European Union (EU) funded projects, based on the Transport Research and Innovation Monitoring and Information System (TRIMIS). It identifies seven thematic fields in emissions reduction (*aerodynamics, structures, propulsion, systems, operations, eco-design and rotorcraft*) and analyses the evolution of funding and researched technologies, while providing the market and policy contexts in Europe.

Policy context

The European Green Deal has introduced the target to achieve a 90% reduction in all transport emissions by 2050. It also highlights the need to restart the efforts to adopt a Single European Sky (SES), while reducing fossil fuel subsidies and tax exemptions in aviation. The European Green Deal targets are reinforced by the Sustainable and Smart Mobility Strategy, published by the Commission in December 2020. It sets the framework for the development of EU transport policy for the next decade.

There are two Joint Undertakings that coordinate research in aviation, Single European Sky ATM Research (SESAR) and Clean Sky. They have both been included in the Horizon Europe Research and Innovation Programme: SESAR 3 (building on the work of SESAR 2020) and Clean Aviation (following up Clean Sky 2).

Key conclusions

Quantitative and qualitative assessments of EU funded projects related to emissions reduction in aviation were carried out, followed by an analysis of technologies, publications and related patents. Key conclusions are:

— sustainable alternative fuels (SAFs) have the potential to reduce CO_2 emissions by a considerable amount, without the need of extensive or revolutionary technology improvements of aircraft. Higher market uptake depends on cost efficient solutions;

— reduction of other pollutants (such as NO_x) depends on the improvement of current engine technologies which can lead to highly efficient and clean engines;

— aerodynamic improvements can help reduce emissions, but with limited gains, due to its already near-optimal stage in aircraft in general;

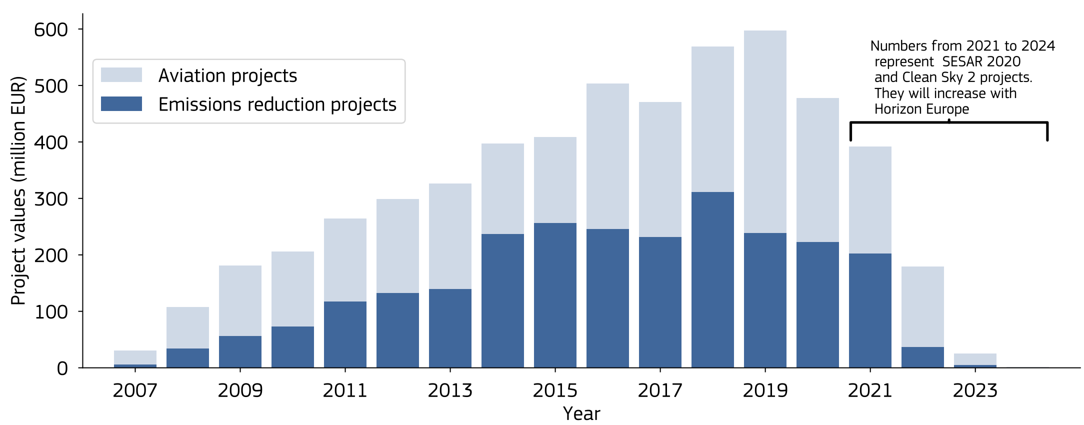
— integrating air transport with other transport modes is another means of reducing emissions;

— most technologies originating from research projects are in the *research* or *validation* phases;

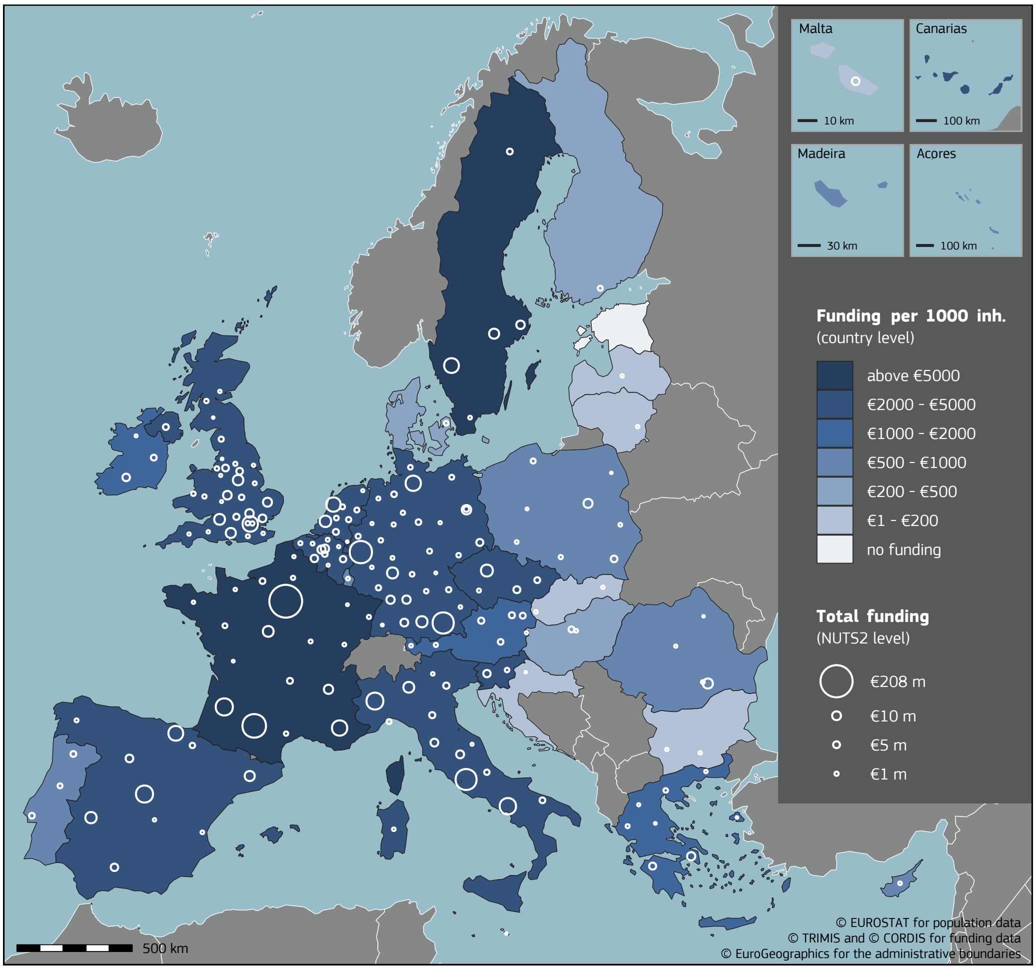
— emissions due to manufacturing and end-of-life of aircraft become more significant as use-phase emissions diminish, therefore eco-design of aircraft gains importance.

Main findings

The report presents an analysis of aviation projects from the 7th Framework Programme for Research (FP7) and Horizon 2020 Framework Programme for Research and Innovation (H2020), with a focus on projects that research emissions reduction in aviation. The figure below shows a yearly comparison of project values between all aviation projects and those that focus on emissions reduction:



And the geographical distribution of European Commission (EC) funding for FP7 and H2020 projects related to emissions reduction in aviation is shown in the figure below:



Other main findings of the report analyses include:

— there are in total 1967 projects labelled under the air transport mode in TRIMIS, with a steady increase since 1995. The majority of projects started in the FP7 and H2020 Framework Programmes (FPs) and funding peaked in 2019 with approximately 600 million EUR project values and over 500 active projects;

— emissions reduction projects were categorised under 7 sub-themes: *aerodynamics*, *structures*, *propulsion*, *systems*, *operations*, *eco-design* and *rotorcraft*. *Structures*, *propulsion* and *systems* projects have the highest number of projects and are among the highest project costs;

— Clean Sky projects are on the top of the list of projects with highest funding. French entities received the highest amount of funding, followed by German and Italian entities, with a high proportion of collaboration between the first two.

Related and future JRC work

This TRIMIS report is the last of a series of reports addressing specific transport modes. The previous reports address rail R&I, waterborne transport research with a focus on decarbonisation and research and innovation in road vehicle emissions control. This report contributes to expanding TRIMIS and Joint Research Centre (JRC) activities related to aviation.

Quick guide

Chapter 1 provides the context for the report, as well as an introduction to TRIMIS and the scope of the report. The methodological approach is defined in Chapter 2, while Chapters 3 and 4 provide state of play and policy context, respectively. Chapters 5, 6 and 7 provide the main contributions of this report: the quantitative, qualitative and technological assessment of aviation R&I. Finally, Chapter 8 concludes the report with a brief summary and recommendations.

1 Introduction

1.1 Context

Aviation is an important transport sector which contributes to the socio-economic development of the European Union (EU). According to the Aviation Strategy for Europe (European Commission, 2015), "The EU aviation sector directly employs between 1.4 million and 2 million people and overall supports between 4.8 million to 5.5 million jobs. The direct contribution of aviation to EU gross domestic product is EUR 110 billion".

However, growing emissions in aviation are of concern, despite the recent dip due to the COVID-19 pandemic. In the European Union Aviation Safety Agency (EASA) European Aviation Environmental Report (European Union Aviation Safety Agency, 2019), it is presented that even though the average fuel consumption (litres of fuel per 100 passenger kilometres) from civil aircraft has decreased since 2005, full flight nitrogen oxides (NO_x) and carbon dioxide (CO_2) have increased.

The new framework for the development of EU transport policy for the next decade is set in the 2020 Sustainable and Smart Mobility Strategy (European Commission, 2020b). It states that air transport has great decarbonisation challenges, with a lack of market ready zero-emission technologies, as well as long development and life cycles of aircraft.

In this context, technology development remains one of the main tools to reduce emissions, and in this way be able to ensure climate targets set by the European Green Deal (European Commission, 2019). In the 2020 New Industrial Strategy for Europe (European Commission, 2020a), the industry is considered to have a leading role in tackling the European Green Deal's challenges, with the need to become greener and more circular, reducing its carbon footprint.

Therefore, research and innovation (R&I) remains a key instrument to develop new technologies. For this purpose, the EU and major industrial players have established Joint Undertakings (JUs), which are public-private partnerships, with the goal of promoting the development of the sector through targeted R&I actions.

There are 2 JUs that are related to aviation - Single European Sky ATM Research (SESAR), which coordinates research related to air traffic management (ATM) and Clean Sky which carries out activities related to improving aircraft environmental performance. Currently, both JUs have been included in the Horizon Europe Research and Innovation Programme (European Commission, 2021), SESAR 3 (SESAR Joint Undertaking , 2019) and Clean Aviation (Clean Aviation, 2020), building on the work of the previous versions.

The following topics are focused in the Clean Aviation partnership:

— hybrid and full electric aircraft propulsion concepts;

— ultra-efficient aircraft architectures;

— disruptive technologies to enable hydrogen-powered aircraft.

The SESAR 3 partnership focuses on the following areas:

— automated ATM benefiting of the use of artificial intelligence (AI);

— autonomous flying and self-piloting technologies;

— cybersecurity.

Together, the newly accepted JUs propose to contribute to reducing the environmental footprint of the aviation sector and support the market deployment of innovative solutions.

1.2 Transport Research and Innovation Monitoring and Information System

The European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS)[1] was launched in September 2017 with the aim of supporting the implementation and monitoring of the Strategic Transport Research and Innovation Agenda (STRIA), analysing technology trends and R&I capacities in the European transport sector. STRIA consists of seven roadmaps that lay down the current state and envisaged progress of different thematic fields, namely:

[1] https://trimis.ec.europa.eu/

— connected and automated transport (CAT);

— transport electrification (ELT);

— vehicle design and manufacturing (VDM);

— low-emission alternative energy for transport (ALT);

— network and traffic management (NTM);

— smart mobility and services (SMO);

— transport infrastructure (INF).

TRIMIS contains an open-access, searchable database of projects and programmes projects grouped according to the seven roadmaps that have been financed by EU Research Framework Programmes, EU Member States (MSs) and other countries (Marques dos Santos et al., 2021).

1.3 Scope and Objectives

The scope of this report is to provide an analysis of R&I activities related to the reduction of pollutant emissions in the aviation sector. The focus is on recent (7th Framework Programme for Research (FP7) and Horizon 2020 Framework Programme for Research and Innovation (H2020)) EU funded projects, based on the TRIMIS assessment methodology (Tsakalidis et al., 2018). Noise emissions are not considered explicitly.

Progress in research activities is assessed by analysing different areas:

— state of play and market context;

— policy context;

— project overall funding;

— project results assessment;

— academic publications, patents and technology analysis.

Based on the analyses, the objective is to provide a view of past, ongoing and possible future research activities in the EU related to pollutant emissions reduction in aviation.

1.4 Report structure

This report is structured as follows:

— Chapter 2 presents an overview of the different methodologies carried out for the analyses, as well as the definition of subthemes;

— Chapter 3 gives a brief summary of the market context in aviation;

— Chapter 4 summarises relevant policy in Europe and the world, as well as an introduction to the research programmes;

— Chapter 5 shows a quantitative assessment of the TRIMIS database, with a focus on aviation emissions reduction;

— Chapter 6 summarises activities of some projects carried out in the context of FP7 and H2020 research programmes;

— Chapter 7 provides an analysis on patents, academic publications and researched technologies;

— Chapter 8 concludes the report, providing a summary of the results, as well as forward looking recommendations.

2 Methodological approach

The main goal of this report is to review and assess EU funded aviation R&I, with a focus on emissions reduction. TRIMIS contains a continuously updated database of EU and MS funded programmes and projects (currently around 9 000) on transport R&I. Of these, more than 1 900 projects are related to air transport. To analyse these projects, methodologies were developed to identify relevant projects related to emissions reduction in aviation and to assess technologies researched within R&I Framework Programmes (FPs), while also deciding on a specific approach for a qualitative analysis of selected projects. A description of these steps is provided in the following sections.

2.1 Identification projects related to emissions reduction in aviation

There is a large number of projects related to air transport. Therefore, a selection and identification of relevant projects was carried out. The purpose of the methodology was to:

— select projects related to emissions reduction in aviation;

— define sub-themes relevant for the topic;

— categorise each project within one main sub-theme and their relation to other sub-themes.

The first step of the methodology was to select projects that were relevant to emissions reduction in aviation. Due to the large number of aviation R&I projects in the TRIMIS database, the methodology focused on projects from the FP7 and H2020 FPs which were exclusively related to aviation (thus, no multimodal projects were considered).

Then, keywords which represented the emissions reduction topic were selected, with the purpose of identifying R&I projects which contribute to the topic. These keywords are presented in Annex 8.5. If a given project has at least one of these keywords, it is considered for the sub-themes categorisation.

Based on the list of aviation projects, 7 sub-themes were defined, to allow for the assessment of R&I focusing on specific areas of interest. Table 1 shows the sub-themes and their descriptions.

Table 1: Aviation emissions reduction R&I sub-themes

Sub-theme	Sub-theme description
Aerodynamics	Research projects that investigate technologies and improvements to the aerodynamics of aircraft, such as drag reduction, novel wing configurations and wing control surfaces
Structures	Technologies related to the structure and airframe, including lightweight materials (such as composites and alloys) and optimal structure configuration
Propulsion	Innovations that focus on the improving propulsion of the aircraft, including electric and hybrid propulsion, alternative fuels and innovative propellers
Systems	Projects that research the improvement of non-propulsive systems in aircraft including energy management, avionics, sensors and power electronics systems
Operations	Focus on optimal operational activities in aviation, such as air traffic management, flight trajectory planning and airport operations
Eco-design	Methods to reduce the environmental impact of aircraft beyond their use phase, particularly for the manufacturing and end-of-life phases, as well as life cycle assessment methodologies
Rotorcraft	Research that focuses on improving the performance and efficiency of rotorcraft

Source: TRIMIS.

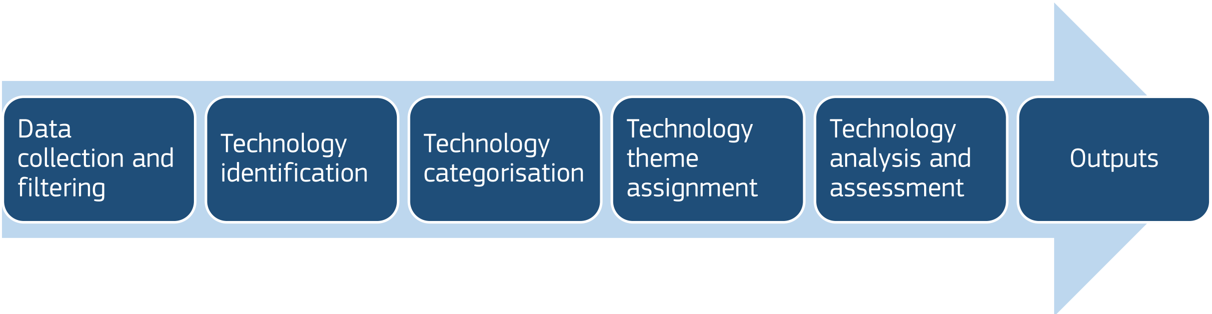
The procedure to categorise the relevant R&I projects into the sub-themes consisted of the identification of relevant keywords for each sub-theme, followed by a search into the project objectives and results. Each project is assigned a main sub-theme according to the highest amount of keywords found and secondary sub-themes are assigned if enough keywords are found related to them. The full list of projects and sub-themes is shown in Annex 8.5.

2.2 Identification and assessment of the technologies researched within R&I Framework Programmes

The TRIMIS technology analysis currently focuses on technologies researched in European FPs, specifically FP7 and H2020 projects from the TRIMIS database. Within these projects, technologies were identified within technology themes through a Grounded Theory approach (Glaser et al., 1968). An iterative approach led to the development of a consistent taxonomy for transport technologies and technology themes.

Figure 1 provides an overview of the methodology used for the technological assessment of the projects.

Figure 1: Technology assessment methodological steps



Source: (Gkoumas et al., 2020).

The methodology steps are the following:

1. first, the results of a study that identified technologies within European transport research projects (INTEND, 2017) were analysed by three researchers who have complementary experience in the field of transport innovation and who have individually assessed the technology list. Based on this review, the researchers came up with a standardised approach on what constituted a distinct technology and how to label them;

2. following this approach, all project descriptions were assessed and flagged when a technology was mentioned or hinted. This filtering exercise was required because EU funded projects also cover non-technology focused projects. Once a technology was flagged in the project description, another researcher would validate the flagging and record the technology name;

3. in a next step, the full list of technologies was evaluated, and the labelling of similar technologies was aligned. Existing taxonomies, such as those under the Cooperative Patent Classification (CPC, 2019) were used as a basis for the labels;

4. when the technology list was established, a number of overarching technology themes was defined. Themes enable a better understanding of how technologies cluster together and which fields of research receive relatively greater interest. An extensive list of themes was created and consequently reduced to the minimum number of themes under which all technologies could still be logically placed;

5. moreover, the funds associated with each technology were determined by linking them with the total project budget. If multiple technologies were researched in the project, the budget allocated to the technology of interest was determined by dividing the project budget by the number of associated technologies. The limitations of this attribution approach are acknowledged, but it is considered to be transparent and appropriate in the absence of technology-budget reports.

Finally, a set of metrics was established to assess the identified technologies. These metrics are intended to indicate the potential for the technology to be taken forward to application through the level of support for its development.

In addition, technologies in all projects have been assigned with a development phase, corresponding to the readiness of the technology at the time the project commenced. These development phases were built on a similar concept to that of the technology Readiness Level (TRL) introduced by the National Aeronautics and Space Administration (NASA) (Héder, 2017), with the number of readiness levels (or development phases) reduced from nine to four. This reflects the uncertainty in attempting to allocate TRLs within research projects, given the limited information that is usually available for the status of the technologies being researched. The four TRIMIS development phases, and their relationship to the NASA TRL scale, are shown in Table 2.

Table 2: Technology readiness levels (TRLs) and TRIMIS development phase allocation

TRL	Description	TRIMIS development phase
1	Basic principles observed	Research
2	Technology concept formulated	
3	Experimental proof of concept	Validation
4	Technology validated in lab	
5	Technology validated in relevant environment	Demonstration/prototyping/pilot production
6	Technology demonstrated in relevant environment	
7	System prototype demonstration in operational environment	
8	System complete and qualified	Implementation
9	Actual system proven in operational environment	

Source: TRIMIS; TRL scale based on (European Commission, 2014).

For the current assessment, the TRIMIS database with entries as of January 2021 has been used. The technology database includes 871 technologies, under 46 overarching technology themes, researched in 3 477 EU funded projects from FP7 and H2020.

2.3 Qualitative analysis of projects

The objective of the qualitative analysis of projects is to carry out an in-depth assessment of selected projects from different FPs, to be able achieve a better understanding of the state of the art in R&I in the EU. For this purpose, a few projects from each sub-theme have been selected for a deeper analysis, assessing their achievements and implications for future research.

Projects were selected for this analysis based on their size and budget, as well as availability of results and relevance to the sub-theme.

Box 1. Methodological approach summary

— R&I projects related to emissions reduction in aviation are selected based on keyword searches through project objectives and results

— To carry out a more detailed analysis, sub-themes were defined, also based on topics and keywords

— An assessment of technologies researched in these projects is also part of the scope of the report

3 State of play on aviation and emissions

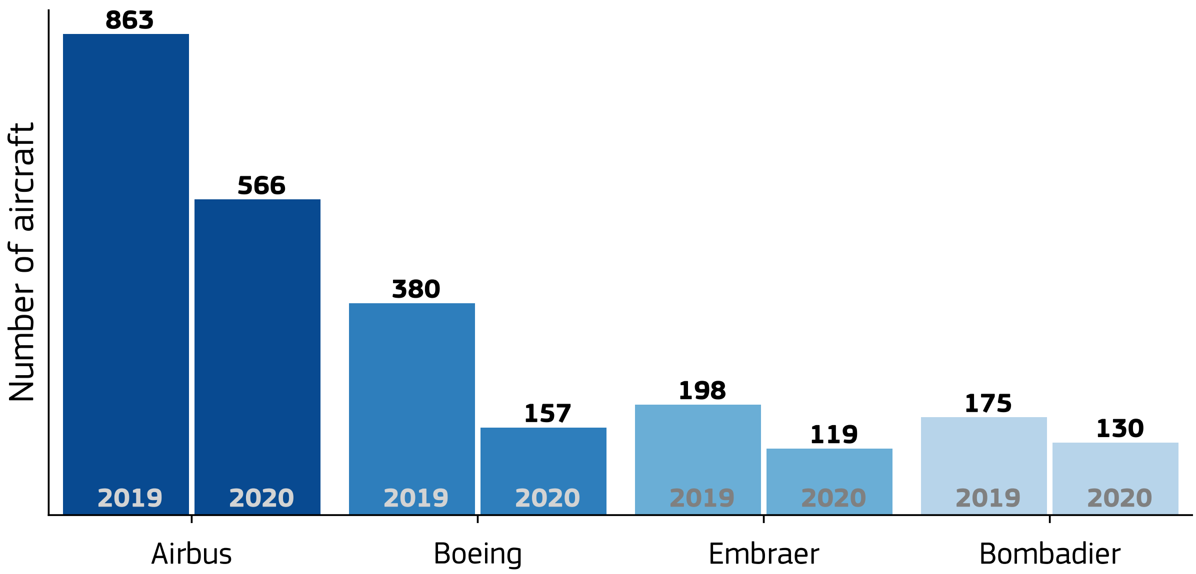
The outputs of R&I activities in the aviation field are almost universally exploited by the world's major aircraft manufacturers, who supply the fleets flown by the aircraft operators. Innovative solutions which decrease the environmental impact therefore provide an economic opportunity for manufacturers to gain a competitive advantage.

3.1 Market context

The passenger aircraft market is dominated, globally, by Airbus and Boeing, with smaller numbers of regional aircraft manufactured by Bombardier[2] and Embraer.

In 2019, Airbus delivered a total of 863 aircraft globally, with Boeing delivering 380 aircraft in the same year. The latter figure was impacted heavily by the problems that Boeing were having with the 737 Max model, which was grounded in March 2019 following two fatal accidents and Boeing were unable to deliver aircraft to their customers. The number of aircraft delivered by the two regional aircraft manufacturers (including business aircraft) is 198 for Embraer and 175 for Bombardier (see Figure 2 below). In 2020, deliveries were heavily affected by the COVID-19 pandemic, with Airbus having the highest number of aircraft delivered, Boeing being impacted considerably by the pandemic and the 737 incidents, while Bombardier had a higher number of deliveries when compared to Embraer.

Figure 2: Global aircraft deliveries for 2019 and 2020



Source: Statista "Number of jets added to the global aircraft fleet from 1999 to 2019, by manufacturer" and "Key figures of the four largest aircraft manufacturers worldwide in FY 2020".

Competition is strong between the two major manufacturers, driven by the demand of airlines for more fuel efficient aircraft with lower operating costs. Both Airbus and Boeing introduced new, more fuel-efficient versions of their respective single-aisle aircraft families (which also deliver significant reductions in emissions and noise) in recent years. Both have also introduced new products for the twin-aisle market since 2012, with the 787 series from Boeing and the A350 series from Airbus.

Airbus have also developed a re-engined version of the A330 (the A330neo), while Boeing is continuing to develop the 777X series, with entry into service expected in 2021 or 2022. This new type is expected to deliver significant fuel efficiency improvements over the 777 type that it replaces.

Based on data from Eurostat[3], the aircraft fleet registered in the 27 Member States of the EU (EU 27) in 2017 included 5 399 commercial aircraft, of which 1 079 were less than five years old. This suggests annual deliveries

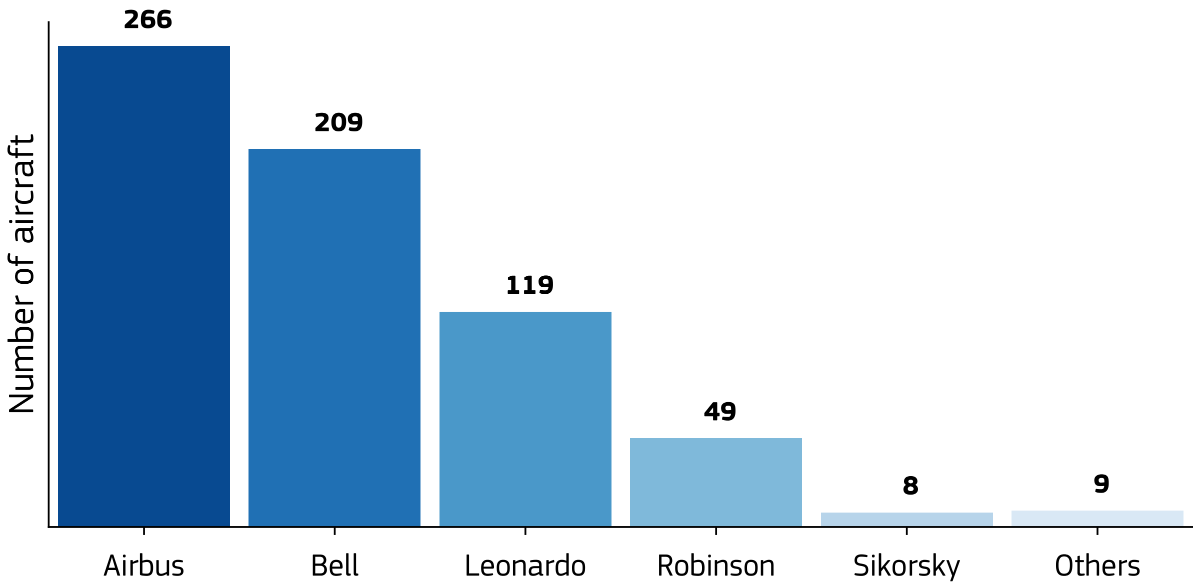
[2] Since 2017, Bombardier have sold off their interests in their turboprop aircraft (the Dash-8 Q400, sold to Longview Aviation Capital Corp.) and in their regional jet aircraft (the CSeries, sold to Airbus, who now produce it as the A220, and the CRJ models to Mitsubishi) and will concentrate on their business aviation market in the future.

[3] https://ec.europa.eu/eurostat/databrowser/view/avia_eq_arc_age/default/table?lang=en

of about 216 aircraft or about 4% of the fleet. It also corresponds to approximately 19% of the global deliveries by the four manufacturers mentioned above.

In the rotorcraft market, data compiled by Statista[4] show that the global market is largely dominated by Airbus Helicopters, Leonardo and Bell, with significantly smaller numbers produced by Robinson and Sikorsky. The numbers of helicopters delivered for the commercial market in 2019 are shown in Figure 3.

Figure 3: Global commercial helicopter deliveries for 2019



Source: Statista collation of "Global commercial helicopter deliveries in 2018 and 2019, by manufacturer".

The top three manufacturers all produce a wide range of helicopters for civil applications, covering sizes from small passenger types up to large, heavy-lift ones.

As well as improvements to their production helicopter types, manufacturers have also investigated more significant changes to rotorcraft technology, often targeting higher cruising speed, which is commonly limited due to the helicopter rotor "retreating blade" effect[5].

Airbus Helicopters developed the X3 prototype compound helicopter[6] to investigate means of overcoming this limitation. The X3 featured a helicopter rotor to provide the vertical take-off and landing capability, but it was also equipped with short 'stub-wings' to provide lift at high forward speeds and propellers to provide the required thrust. With the X3, Airbus was able to demonstrate speeds of 410 km/h, around 50% higher than a typical fast helicopter cruise speed.

Sikorsky Helicopters has also followed a compound helicopter approach for their development for advanced concepts, but the combined a tail-mounted propeller with counter-rotating rotors to be able to provide thrust and lift for high-speed forward flight.

Leonardo's approach to addressing a similar problem is the AW609 tilt-rotor aircraft. This has large tilting propellers at the ends of its wings, which are rotated to the vertical position to provide the lift for take-off and landing and the horizontal position to provide the thrust for high-speed horizontal flight. The lift for the horizontal flight is provided by the wings that the tilt-rotors are attached to.

Bell Helicopters has also developed tilt-rotor technology, in particular for military applications.

[4] https://www.statista.com/statistics/1176635/commercial-helicopters-delivered-globally-manufacturer/

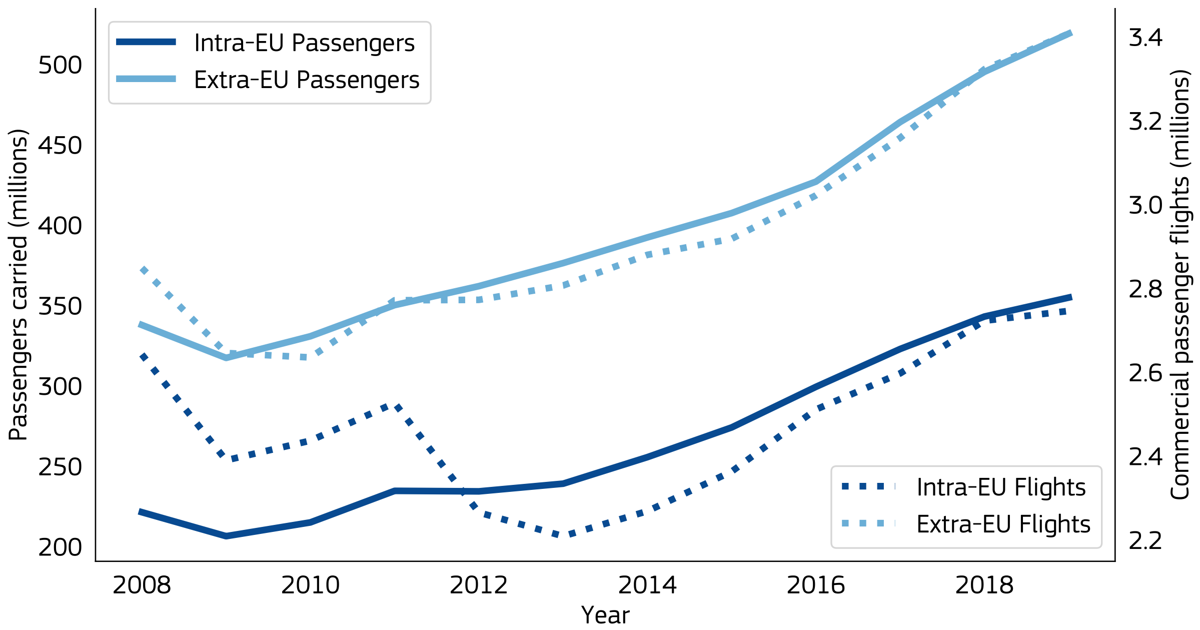
[5] At high helicopter speeds, the rotor blades that are moving towards the tail have a speed relative to the stationary air that reduces towards zero. As a result, it is not possible for the blades on that side of the helicopter to produce sufficient lift to keep the vehicle level. The forward speed of conventional helicopters is constrained by the need for the rotor to produce equal lift on the two sides of the airframe.

[6] https://www.airbus.com/newsroom/events/X3.html

3.2 Air travel

Demand for air travel continued to grow until 2019, prior to the significant impacts of the COVID-19 pandemic on global air travel. Based on data from Eurostat[7], Figure 4 shows the growth in international air travel, separately for intra-EU and extra-EU (using the EU27 Member States for all years) and for passengers carried and flights.

Figure 4: Passengers carried and flights, intra-EU 27 and extra-EU 27 since 2008



Source: Eurostat data tables, "International intra-EU air passenger transport by country and airports (avia_pai)" and "International extra-EU air passenger transport by country and airports (avia_pae)".

Between 2008 and 2019, the numbers of passengers carried increased at an average annual rate of 4.4% (for intra-EU flights) and 4.0% (for extra-EU flights). At the same time, the numbers of flights increased more slowly, at 0.35% per annum for intra-EU flights and 1.64% for extra-EU flights. The differences between the rates of growth of the numbers of passengers and numbers of flights indicates a combination of an increase in load factors and an increase in the average aircraft size.

The flights data in Figure 4 show that, in 2019, there were a total of 6.1 million international flights from EU 27 Member States. Data published by European Organisation for the Safety of Air Navigation (EUROCONTROL) in their industry monitor from December 2019[8] show that there were, on average, about 30 000 flights handled per day in the European Civil Aviation Conference (ECAC) area, corresponding to an annual total of almost 11 million flights. As well as domestic flights in the Member States (not included in Figure 4), this shows the influence of the number of flights that pass through European airspace and add to the requirements for air traffic management in the area.

3.3 Aviation emissions

The typical fuel used for aircraft engines is kerosene, with its main emissions being CO_2, NO_x, sulphur oxides (SO_x) and particulate matter (PM). Moreover, there is a large amount of water vapour, which leads to vapour trails (or contrails). Contrails are known to contribute to atmospheric warming (Bock and Burkhardt, 2019). The use of hydrogen as a fuel can worsen this type of effect. Overall, research shows that non-CO_2 impacts can contribute to about two-thirds of the net radiative forcing (Lee et al., 2021) and thus can contribute significantly to global warming.

Aviation accounts for a significant share of emissions from transport - According to the European Aviation Environmental Report 2019 (European Union Aviation Safety Agency, 2019), in 2016 the EU aviation accounted for more than 13% of greenhouse gas (GHG) emissions related to transport, and NO_x emissions accounted for 14% of transport emissions. The Statistical Pocket book 2020 – EU Transport in figures (European Commission, 2020c) shows a similar proportion of the aviation GHG emissions related to transport in 2018.

[7]https://ec.europa.eu/eurostat
[8]https://www.eurocontrol.int/sites/default/files/2019-12/eurocontrol-industry-monitor-214-upd.pdf

When analysing emissions by aircraft class, the International Council on Clean Transportation (ICCT) reported that narrowbody and widebody aircraft together made for more than 90% of global aviation CO_2 emissions in 2019 (Graver et al., 2020). Regional aircraft were responsible for almost 30% of global departures, but only 4% of total passenger kilometres and 7% of CO_2 emissions. Table 3 (adapted from (Graver et al., 2020)) shows these numbers in more detail:

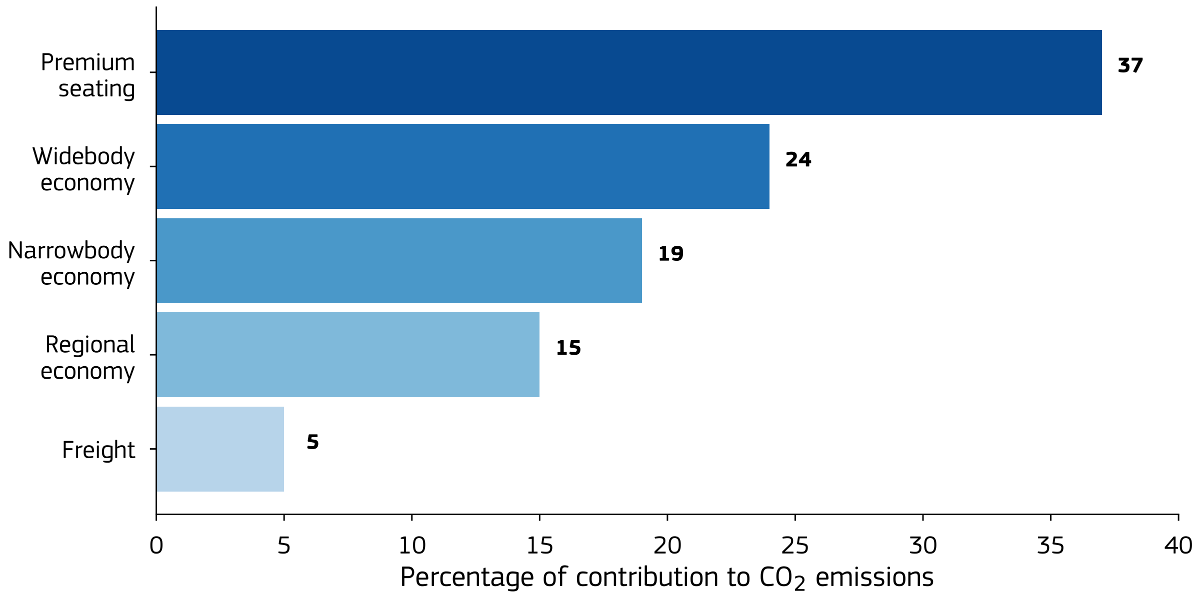
Table 3: Aircraft departures, passenger kilometres and CO_2 emissions by aircraft classes for 2019

	Departures		Passenger kilometre		CO_2	
Aircraft class	Million	% of total	Billion	% of total	Million tonnes	% of total
Regional	11.2	29	345	4	56	7
Narrowbody	24.4	63	4 588	53	393	51
Widebody	3.21	8	3 777	43	336	42
Total	**38.8**	**100**	**8 710**	**100**	**785**	**100**

Source: (Graver et al., 2020).

Additionally, in the same report, average emissions from passengers in different seating classes for 2019 were estimated and are shown in Figure 5. The conclusions were that premium seating classes were responsible for almost 20% of CO_2 emissions and were larger than the emissions related to cargo transport.

Figure 5: Percentage of CO_2 emissions by aircraft seating class and freight for 2019



Source: (Graver et al., 2020).

With respect to average fuel consumption, even though it has been decreasing since 2005, aviation emissions have been on the rise (due to the increase of number of flights) and are forecast to increase in 2040 (in the likely event that travel demand increases after the COVID-19 pandemic). Table 4 (adapted from (European Union Aviation Safety Agency, 2019)) presents fuel consumption and emissions indicators for key years and a forecast (based on the IMPACT model [9]) for 2040 based on existing technology and improved technology.

[9]https://www.eurocontrol.int/model/advanced-emission-model

Table 4: Aviation emissions indicators for key years and forecast for 2040

Indicator	2005	2014	2017	2040 (same technology)	2040 (advanced technology)
Average fuel consumption (litres per 100 passenger kilometres)	4.4	3.7 (-17%)	3.4 (-24%)	3.0 (-33%)	2.6 (-41%)
CO_2 (million tonnes)	141	148 (+5%)	163 (+16%)	224 (+59%)	198 (+40%)
NO_x (thousand tonnes)	669	749 (+12%)	839 (+25%)	1358 (+103%)	972 (+45%)

Numbers in brackets show the percentage of change since 2005. *Source:* (European Union Aviation Safety Agency, 2019) based on the EUROCONTROL IMPACT model.

Box 2. State of play summary

— The civil aircraft market has four major players, two of which are regional aircraft manufacturers

— The main rotorcraft manufacturers are 5, and they produce a wide range of sizes and types of helicopters

— The number of passengers and flights, both intra-EU and extra-EU are in constant increase since 2013. There has been a sharp decrease in air traffic due to the COVID-19 pandemic, but travel demand will likely pick up.

— Emissions have been on the rise since 2015, and are likely to continue increasing after the end of the COVID-19 pandemic, thus forecast to be higher by 2040

4 Policy context

4.1 European transport policy related to aviation

At a global level, the regulation of international aviation is the responsibility of the International Civil Aviation Organization (ICAO) . As well as safety aspects, the ICAO also define the certification requirements for aircraft and engines related to environmental impacts, covering noise, CO_2 and pollutant emissions. In Europe, these regulations are then implemented by the EASA[10].

The management of European airspace is now coordinated by the EUROCONTROL[11], with the aim of making European aviation safer, more efficient, more cost-effective and minimising its environmental impact. The scope of EUROCONTROL is wider than just the 27 EU Member States; in total there are 41 member states of the organisation. Key in the work of EUROCONTROL is the delivery of the vision of a Single European Sky (SES); to support this, it manages the SESAR programme.

The publication of the European Green Deal in 2019 introduced some updated policies relating to aviation, with a target to achieve a 90% reduction in transport emissions by 2050, with all modes (including aviation) needing to contribute to the reduction. It identified a need for the price of transport to reflect its impact on the environment and proposed a review of the tax exemption for aviation fuel and a reduction in the free allocation of allowances to airlines under the EU emissions trading system (ETS). The European Green Deal also noted the need to restart work on the SES to deliver on the potential emissions savings.

In 2017, the Advisory Council for Aviation Research and Innovation in Europe (ACARE) published an update to its strategic research and innovation agenda from 2011[12]. This update identified five key challenges for aviation:

— meeting societal and market needs;

— maintaining and extending industrial leadership;

— protecting the environment and the energy supply;

— ensuring safety and security;

— prioritising research, testing capability and education.

It then proposed action areas to meet these challenges. Subsequently, the European Commission has published a draft Strategic Research and Innovation Agenda (SRIA), including a proposal for the creation of a European partnership for clean aviation[13]. This notes the objective of climate neutrality set by the European Green Deal, set against an expectation that global aviation demand was expected to grow by a factor of four between 2020 and 2050.

It should be noted that the SRIA was written prior to the demand for aviation being severely impacted by the COVID-19 pandemic (as also are many other sectors of the economy). Nonetheless, it is likely that demand for travel will recover (if not to the levels previously forecast) giving significant growth to 2050.

The SRIA identifies that a key focus is the need to achieve net-zero emissions from aviation. To achieve their goals, the development of new aircraft giving significant gains in performance and efficiency will be required, with this development needing to be significantly faster than the traditional development cycle. Therefore, it will require:

— exceptional research and technology effort;

— development and deployment of sustainable alternative fuels;

— optimised green air operations and networks;

— global aviation regulatory framework.

Consequently the SRIA proposes the creation of a European partnership for clean aviation to deliver against these requirements. Given the scale of the task (to achieve net-zero emissions from European aviation) and the limited resources, the SRIA proposes a focus on the demonstration of two disruptive applications of technology:

[10] https://www.easa.europa.eu/
[11] https://www.eurocontrol.int
[12] https://www.acare4europe.org/sria
[13] https://www.clean-aviation.eu/files/Clean_Aviation_SRIA_R1_for_public__consultation.pdf

— ultra-efficient short/medium range aircraft;

— hybrid electric regional and short-range aircraft.

The selection of these two applications is based on an expectation that it will be possible to introduce step-change technology, with significant impacts, in these classes more rapidly than in longer-range aircraft.

In addition to the demonstration of these two applications, the SRIA also proposes a research focus on technologies to enable the adoption of liquid hydrogen as a non-drop-in zero-carbon fuel, with potential application to long-range aircraft.

Finally, even though the main focus of this report is to assess technological aspects of R&I in aviation, it is important to highlight other non-technological aspects which can also contribute to reduction in emissions. The European Green Deal refers to carbon pricing strategies as a means to reduce emissions, also linked to public transport usage and multimodality.

Some market based measures include the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and the EU ETS, which can compensate for or reduce aviation emissions. However, carbon offsetting alone is not enough to achieve the European Green Deal objectives (Eurocontrol, 2020), and technological improvements are necessary to keep up with emission reduction targets. Moreover, multimodality can help reduce emissions for short-haul flights, while longer flight emissions should be reduced by other means.

4.2 European research programmes on aviation

Since 2008, the main focus of European research on aviation technology (excluding ATM-related research) has been the Clean Sky (under FP7) and Clean Sky 2 (under H2020) programmes, while the focus of ATM-related research has been the SESAR programme. There are also other collaborative research projects from FP7 and H2020 which are not related to the JUs, such as the grants of the European Research Council (ERC) to support frontier research and Marie Skłodowska-Curie actions (MSCA).

The Clean Sky programme (2008-2014) comprised seven project areas, including six integrated technology demonstrators (ITDs) and a technology evaluator. The Clean Sky 2 programme (2008 to present) consists of nine project areas, including three innovative aircraft demonstrator platforms (IADPs), three ITDs, two transverse activities and a technology evaluator. The project areas under Clean Sky were:

— Green Regional Aircraft (GRA): Development and demonstration of technologies to reduce noise and emissions from regional transport aircraft; Flight test demonstration of turboprop aircraft fitted with light weight panel with acoustic dampening and a flight test of a new electrical power management system as a step towards an all electric aircraft.

— Eco-Design (ECO): Focused on the minimisation of the use of energy resources in the production of aircraft and on reductions in their energy use in service;

— Sustainable and Green Engines (SAGE): Development and demonstration of engine technologies for increased efficiency and reduced emissions for all aircraft types, including novel engine architectures such as open rotors and geared turbofans;

— Smart Fixed-Wing Aircraft (SFWA): Development of smart wing concept, integrating passive and active laminar flow control and load control technologies, also innovative powerplant, empennage and rear fuselage concepts;

— Systems for Green Operations (SGO): Development of advanced on-board systems for energy management and for efficient and environmentally friendly flight trajectories;

— Green Rotorcraft (GRC): Development of technologies for increased efficiency and reduced noise and emissions from helicopters and tilt-rotor aircraft;

— Technology Evaluator (TE): Analyses of global benefits (fuel consumption, noise and emissions) of combinations of the individual technologies developed in the other project areas.

The project areas under Clean Sky 2 are:

— Large Passenger Aircraft: This IADP is focusing on maturing technologies for large, mainly long-range, aircraft that were developed under Clean Sky, including the integration of new propulsion systems (such as open-rotor) on the aircraft, new cabin architectures and the cockpit of the future;

— Regional Aircraft: This IADP is examining the application of new technologies in the design of a future regional aircraft, including low weight, advanced aerodynamics and low noise;

— Fast Rotorcraft: This IADP is investigating the potential for future high-speed rotorcraft based on tilt-rotor and compound helicopter concepts, with a particular emphasis on noise and emissions;

— Airframe: This ITD is advancing technologies in airframe design for reduced weight and increased efficiency, including an extended use of composite materials;

— Engines: The Engines ITD is building on the work of the Clean Sky SAGE ITD, with the aim of developing and testing a range of novel engine architectures, including jet, turboprop and piston engines;

— Systems: The Systems ITD is developing a range of on-board technologies to improve the operation of the aircraft (cockpit systems, cabin and cargo systems, landing gear, etc.);

— Small Air Transport: This transverse activity is focused on the development and demonstration of technology applicable to small aircraft with less than 19 seats;

— Eco-Design: The Eco-Design transverse activity builds on the work done on eco-design in Clean Sky, develops it further and extends the applicability to the full cradle to grave concept;

— Technology Evaluator: As in Clean Sky, the technology evaluator analyses the global benefits (fuel consumption, noise and emissions) of combinations of the individual technologies developed in the other project areas.

The SESAR[14] programme was launched in 2004 to support the development and rollout of the SES. SESAR itself is managed by the SESAR Joint Undertaking (SESAR JU), which has been established as a public-private partnership. The SESAR JU has the responsibility of coordinating all ATM-relevant research in the EU to support the modernisation of the European ATM systems. The SESAR JU is funded through three channels:

— the EU;

— EUROCONTROL;

— industry partners.

Each of them contributes approximately one third of the total funding. For the period 2016 to 2024, the total funding for SESAR is EUR 1.6 billion.

The main aims of SESAR are to develop a modular, automated and interoperable European ATM system that is focused on improvements to flights and to air traffic flow. Its objectives are aligned with reduced environmental impacts of European air transport, increased capacity of the air traffic system, increased safety, increased cost effectiveness and improved predictability.

The SESAR programme supports exploratory research, targeting new concepts and emerging technologies, industrial research, validating technologies and concepts in simulated and actual operational environments, and very large-scale demonstrations, with the aim of proving the applicability of the technologies and accelerating their wide-scale implementation.

TRIMIS includes details of projects under Clean Sky and Clean Sky 2 that are available in Community Research and Development Information Service (CORDIS), while the JU provides more data and information on their different projects. Due to the structure of SESAR, a significant part of their research is performed through direct contracts, while this report uses only data from projects disseminated through CORDIS (and therefore TRIMIS). The numbers and values of aviation-relevant projects included in TRIMIS are presented in Table 5.

[14] https://www.sesarju.eu/

Table 5: Numbers and values of aviation research projects funded under FP7 and H2020 programmes

Funding action	Number of projects	Total funding (million EUR)
FP7		
FP7-TRANSPORT - Transport (Including Aeronautics) - Horizontal activities for implementation of the transport programme (TPT)	236	962.11
FP7-AAT - Aeronautics and air transport	9	45.45
FP7-ENERGY - Specific Programme "Cooperation": Energy	1	9.38
FP7-JTI - Specific Programme "Cooperation": Joint Technology Initiatives	484	207.48
FP7-SPACE - Specific Programme "Cooperation": Space	1	2.00
FP7-SECURITY - Security	9	59.19
FP7-SME - FP7-SME - Specific Programme "Capacities": Research for the benefit of SMEs	1	1.00
FP7-PEOPLE - FP7-PEOPLE - Specific programme "People" implementing the Seventh Framework Programme of the European Community for research, technological development and demonstration activities	1	1.88
Horizon 2020		
H2020-EU.3.4. - Horizon 2020: Smart, Green and Integrated Transport	735	2 132.03
H2020-EU.3.4. - Horizon 2020: Smart, Green and Integrated Transport, H2020-EU.2.3. - Horizon 2020: INDUSTRIAL LEADERSHIP - Innovation In SMEs	1	0.05
H2020-EU.3.7. - Horizon 2020: Secure societies - protecting freedom and security of Europe and its citizens	6	15.67
H2020-EU.2.1. - Horizon 2020: INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies	4	12.96
H2020-EU.3.3. - Horizon 2020: SOCIETAL CHALLENGES - Secure, clean and efficient energy	3	24.95
H2020-EU.2.1. - Horizon 2020: INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies, H2020-EU.2.3. - Horizon 2020: INDUSTRIAL LEADERSHIP - Innovation In SMEs	2	2.28
H2020-EU.2.1. - Horizon 2020: INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies, H2020-EU.3.4. - Horizon 2020: Smart, Green and Integrated Transport	1	2.97
H2020-EU.1.3. - EXCELLENT SCIENCE - Marie Skłodowska-Curie Actions	2	3.29
H2020-EU.2.3. - Horizon 2020: INDUSTRIAL LEADERSHIP - Innovation In SMEs, H2020-EU.2.1. - Horizon 2020: INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies	1	0.05
H2020-EU.3.7. - Horizon 2020: Secure societies - protecting freedom and security of Europe and its citizens, H2020-EU.2.3. - Horizon 2020: INDUSTRIAL LEADERSHIP - Innovation In SMEs	1	0.05
Total	**1498**	**3 482.79**

Source: TRIMIS.

4.3 Aviation in non-European countries' policies

As noted previously, regulations concerning the environmental impacts and safety of international aviation are developed and adopted by ICAO. These regulations have been implemented almost universally in national regulations in all countries that build and operate aircraft. Although the jurisdiction of ICAO covers only international aviation, aircraft used on domestic flights are generally of the same types as those used on international flights and, hence, are designed, manufactured and operated to the same standards.

In their Environmental Report 2016 (International Civil Aviation Organization, 2016), ICAO defines their four pillars to achieve sustainable aviation: market-based measures, disruptive technology, improved infrastructure and operations, and the uptake of sustainable alternative fuels (SAFs). Moreover, in their subsequent report, Environmental Report 2019 (International Civil Aviation Organization, 2019), they state that emissions from international aviation are expected to increase by 2050, by a factor ranging from 2 to 4 times the 2015 levels (depending on the type of emissions - CO_2, NO_x or PM), showing the need for technological advancement to reduce emissions.

In the United States, the Federal Aviation Administration (FAA) has published the Destination 2025 report[15], which outlines the vision for the future of aviation in the country. It targets the provision of the safest and most efficient aviation system in the world. Much of this will be achieved through the implementation of the NextGen project, which is aimed at advancing the performance of the United States of America (US) ATM system, in much the same way as SESAR in Europe.

In 2019, the FAA published their Strategic Plan[16], which covers the period through to 2022. Particular trends noted in the plan included:

— continued growth in commercial aviation demand;

— growth in unmanned aircraft systems and commercial space operations;

— increased use of large data and automation;

— increased competition from international contenders.

The FAA is also responsible for preparing the National Aviation Research Plan (NARP). In June 2019, it published the 2017/2018 NARP[17]. This focuses on three Department of Transport strategic goals:

— safety: Reduce transport-related fatalities and serious injuries;

— infrastructure: Invest in infrastructure to ensure safety, mobility and accessibility and stimulate economic growth;

— innovation: Lead in the development and deployment of innovative practices and technologies.

To address these trends, the FAA plan includes a wide range of strategies, including improving the collection of data on fatalities, identifying the risk factors related to accidents, streamlining the environmental review process for infrastructure projects, restoring infrastructure and integrating advanced technologies for NextGen implementation, improving system reliability, increasing international market access by eliminating trade barriers and focusing on research and development to improve aviation safety. For 2019, the total research and development budget requested was USD 346 million, with an expectation that this would rise slowly over subsequent years, reaching USD 387 million by 2023.

Moreover, there has been international collaboration between the EU and the US within and outside of the framework of EU R&I. There have been efforts by the Deutsche Zentrum für Luft- und Raumfahrt (DLR), Office National d'Etudes et de Recherches Aérospatiales (ONERA) and NASA on different fields such as biofuels (Moore et al., 2017), contrails (Anderson et al., 2018, Bräuer et al., 2021) and environmental friendly rotorcraft (Russell and Basset, 2015).

In China, the Civil Aviation Administration of China (CAAC) has responsibility for regulating civil aviation in the country, including the development of industrial strategy and a mid- and long-term plan for civil aviation. The

[15] https://www.faa.gov/about/plans_reports/media/destination2025.pdf

[16] https://www.faa.gov/about/plans_reports/media/FAA_Strategic_Plan_Final_FY2019-2022.pdf

[17] https://www.faa.gov/about/office_org/headquarters_offices/ang/offices/tc/about/campus/faa_host/rdm/media/pdf/2017_2018NARP.pdf

CAAC appears not to have published an overall aviation policy, however the country has achieved strong growth in aviation demand over the past five years. In October 2020, the CAAC announced[18] that in the 13th five year plan, the country had achieved growth in flight hours and flight movements of 56% and 43% relative to the same period in the preceding 12th five year plan, corresponding to average annual growth rates of 9.3% and 7.4% respectively.

In 2016, India published its National Civil Aviation Policy[19]. This noted that the country had the potential to be in the top three nations worldwide in terms of domestic and international air transport, but (at that time) it was ranked only 10th. Therefore, the Government planned to reduce the costs of air travel in order to allow more citizens to fly and hence increase overall demand.

The aim was to achieve 300 million (30 crore) domestic passengers by 2022 and 500 million by 2027, with international demand increasing to 200 million by the same point. This would be achieved by the establishment of an integrated eco-system to enable the growth, ensuring the safety, security and sustainability of the aviation sector, enhancing regional connectivity and easing doing business by deregulation and simplified procedures. The achievement of this growth was to be supported by changes in aviation taxes and by the Government making land available for airport construction free of charge.

Box 3. Policy context summary

— EASA regulates environmental impacts covering noise, CO_2 and pollutant emissions in the EU

— EUROCONTROL is in charge of European air traffic, to ensure more efficiency and minimising environmental impact

— The European Green Deal aims at a very significant reduction of aviation emissions reduction by 2050

— Relevant research programmes in the EU include FP7, H2020 and also two JUs, Clean Sky and SESAR

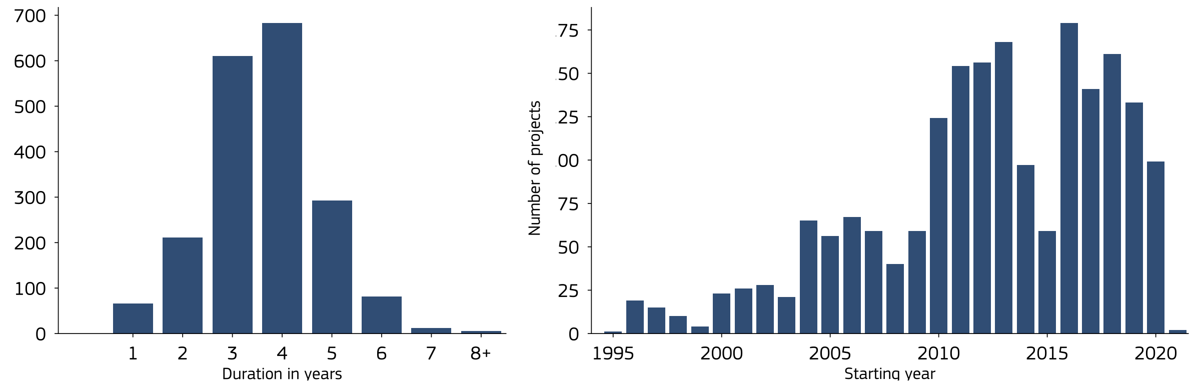
[18] http://www.caac.gov.cn/en/XWZX/202010/t20201023_204920.html
[19] https://www.civilaviation.gov.in/sites/default/files/Final_NCAP_2016_15-06-2016-2_1.pdf

5 Database quantitative assessment

5.1 Aviation projects

There are in total 1967 projects labeled under the air transport mode in TRIMIS. Most of these projects have a duration of 3 or 4 years, with a steady increase in the number of projects since 1995, while the majority of projects started in the periods corresponding to the latest two European FPs, FP7 and H2020, as seen in Figure 6.

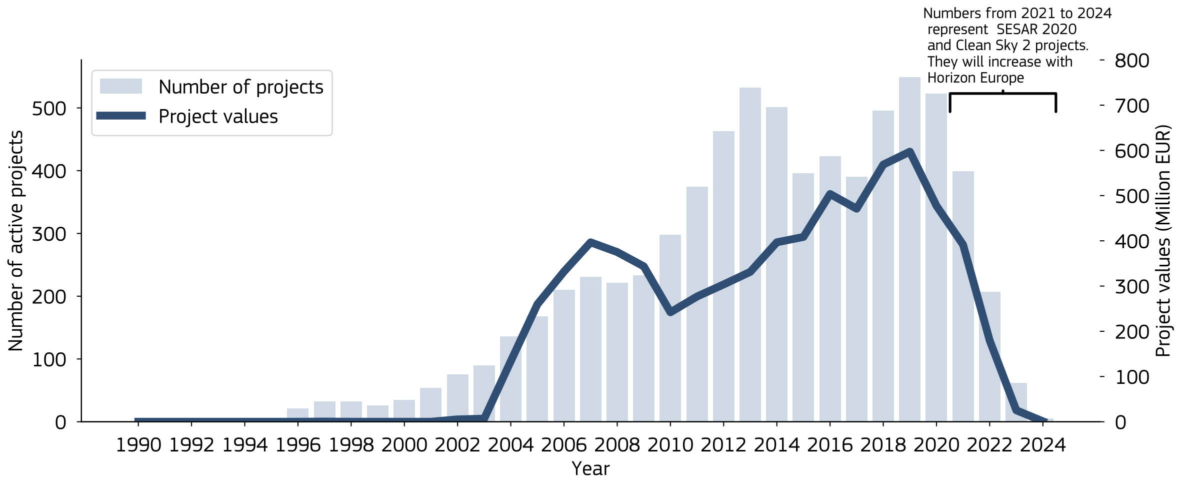
Figure 6: Project count by duration and starting year



Source: TRIMIS.

The number of active aviation projects per year since 1990 is shown in Figure 7, as well as the total project values for each year (with values from 2021 and later years being an estimate based on the available project end dates). There is a constant increase of both project values and number of active projects, representing growing EU investment in research projects. Funding peaked in 2019 (with around 600 million EUR project values and over 500 active projects) with some decrease in 2020. It should be noted that values from 2021 and onwards are expected to change with Horizon Europe research and innovation framework programme (HE), which will be active from 2021 onwards, and thus the complete picture for 2021 is not shown in the figure. Nonetheless, since both Clean Sky 2 and SESAR H2020 continue until 2024, these years have been included in this and the subsequent analyses.

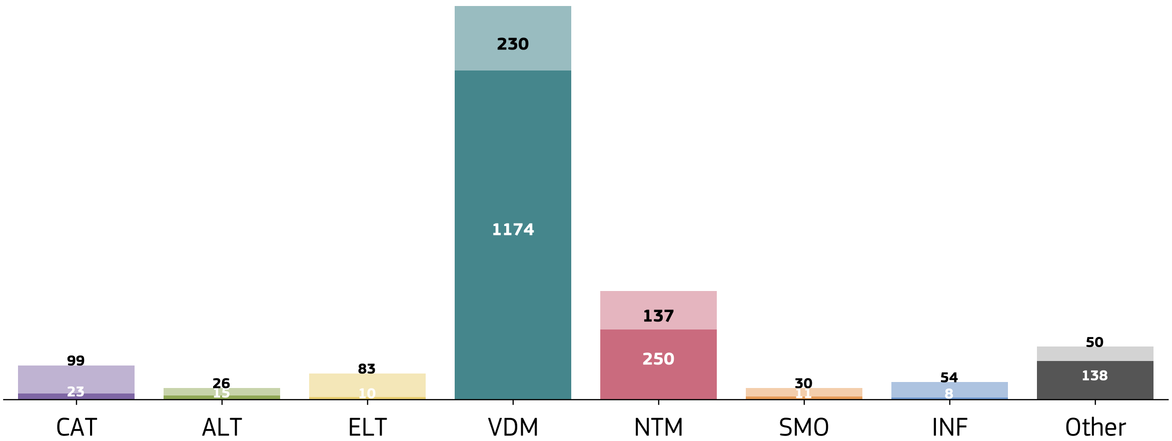
Figure 7: Number of active aviation projects per year and the respective project values



Source: TRIMIS.

A breakdown of STRIA roadmap categories for aviation projects was also carried out and is shown in Figure 8, where the number of projects exclusively belonging to a single roadmap are represented with darker colors, while lighter colors depict projects which are linked to more than one roadmap. The great majority of aviation research projects belongs to the VDM roadmap, followed by NTM. The other roadmaps make for a low proportion of projects, most of which are shared with other roadmaps. The *Other* category comprises the third highest number of projects. These are projects that are present across all STRIA roadmaps.

Figure 8: Aviation project count per roadmap: darker colors represent projects uniquely in the roadmap and lighter colors represent projects that are categorised in more than one roadmap



Abbreviations: connected and automated transport (CAT); low-emission alternative energy for transport (ALT); transport electrification (ELT); vehicle design and manufacturing (VDM); network and traffic management (NTM); smart mobility and services (SMO); transport infrastructure (INF)

Source: TRIMIS.

5.2 Emission reduction aviation projects

This section analyses research and innovation projects in aviation which are related to emissions reduction, which were categorised under 7 sub-themes, covering the key areas of research being undertaken under in the topic. The methodology for identifying emissions reduction projects and dividing them in sub-themes is explained in Chapter2. The 7 sub-themes are:

1. **Aerodynamics**: focus on improving the aerodynamics of aircraft, primarily with a view to reduce drag and improve efficiency;
2. **Structures**: improving the structures of aircraft and their production methods;
3. **Propulsion**: more efficient and environmental properties of propulsion systems in aircraft;
4. **Systems**: improvement of systems in aircraft including electrical, fuel and construction systems;
5. **Operations**: optimising operational activities in aviation, including ATM and flight trajectory planning;
6. **Eco-design**: methods technologies to reduce the environmental impact of aircraft, particularly the construction and disposal phases;
7. **Rotorcraft**: focuses on improving the performance and efficiency of rotorcraft.

For the sub-theme assignment, solely recent projects were selected, from FP7 and H2020 calls (including Clean Sky and SESAR). There were in total 518 projects selected for the exercise, with the full list (and sub-theme assignment) shown in Annex 8.5. Each project was assigned to one main sub-theme (which is used for the assessment of number of projects and values) and up to 3 other additional sub-themes (which are used to assess the relation and links between sub-themes).

Table 6 provides a summary of the number of projects identified under each of these sub-themes, together with the associated total project value and the EU funding contribution while Figure 9 shows a yearly comparison between the number of active aviation projects and projects dealing with emissions reduction. When comparing FP7 and H2020 projects, there has been a decrease of the share of the number projects that research emissions reduction in H2020. However, when analysing project values, in Figure 10, it is clear that the amount of investment in emissions reduction research projects has had a slight increase in H2020 when compared to FP7. Values from 2021 and onwards are estimates based on project end dates and do not take into account upcoming projects from HE.

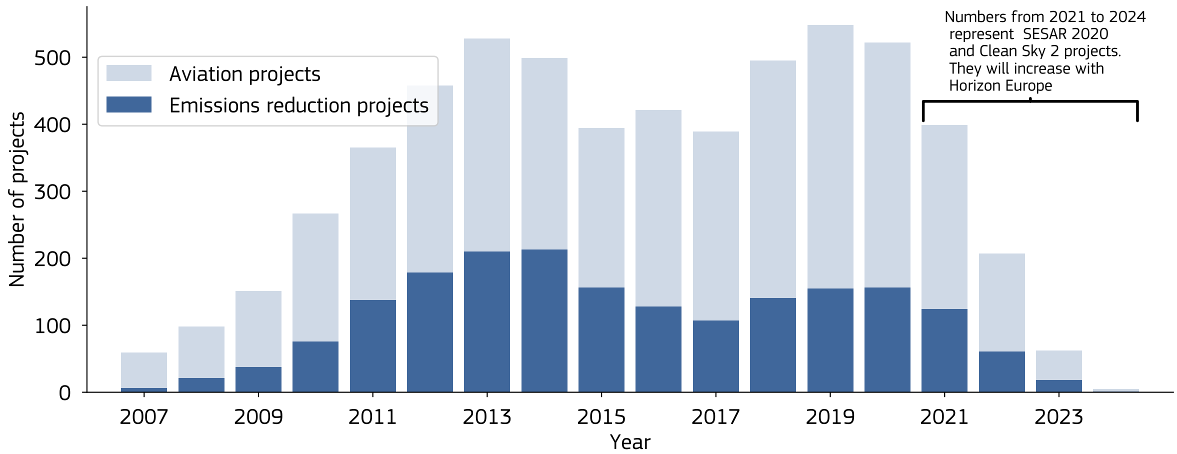
Moreover, Figure 11 shows the number of projects belonging to each sub-theme. The top 4 sub-themes with the highest number of projects are *structures*, *propulsion*, *systems* and *aerodynamics*, with the first 3 having a very similar number of projects. *Eco-design* is the sub-theme with the lowest number of projects.

Table 6: Aviation research project summary table

Aviation research sub-theme	Number of projects	Total project value (Million EUR)	Total EU contribution (Million EUR)
Propulsion	94	765.20	535.87
Systems	86	584.99	427.67
Operations	58	147.10	92.89
Eco-design	35	50.36	40.46
Aerodynamics	77	149.66	101.86
Structures	96	374.91	281.30
Rotorcraft	52	401.03	213.69

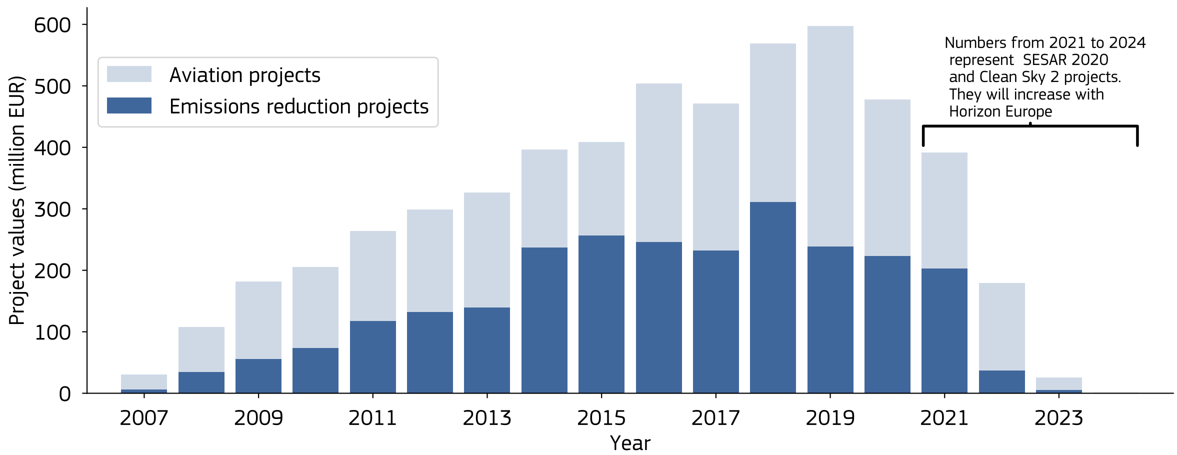
Source: TRIMIS.

Figure 9: FP7 and H2020 Aviation projects and emissions reduction projects



Source: TRIMIS.

Figure 10: FP7 and H2020 Aviation and emissions reduction reduction project values (in million EUR)

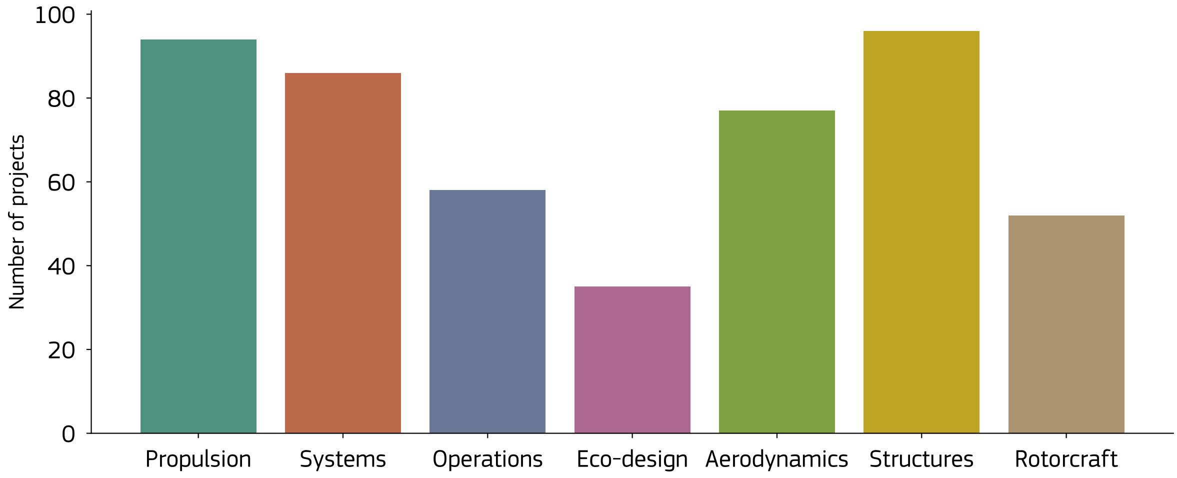


Source: TRIMIS.

When analysing the project values in Figure 12, there is some difference in the top sub-themes. While *structures* and *systems* are also the highest in terms of funding, the *structures* projects values are significantly lower, meaning that the projects within the sub-theme are mostly of smaller project values. A similar conclusion can be drawn with respect to the *aerodynamics* projects. Moreover, the projects from the *rotorcraft* sub-theme show higher project values than the average. However, it is one of the sub-themes with the lowest EU contribution, meaning that a higher share of investment comes from the project partners, when compared to the other sub-themes.

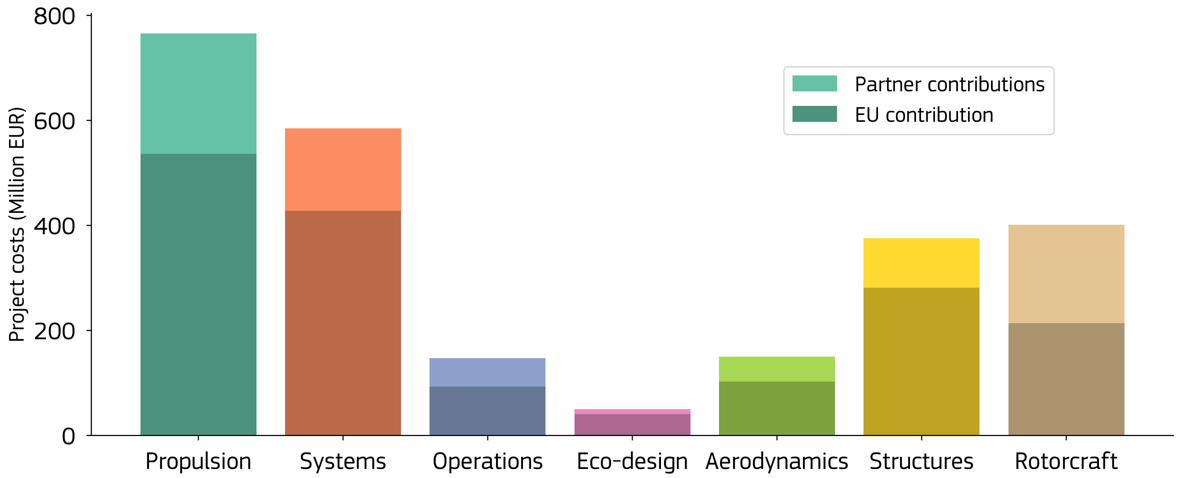
Moreover, Figure 13 shows the project values by sub-theme and per year from 2007 until 2023 (with values

Figure 11: Aviation emissions reduction number projects per sub-theme



Source: TRIMIS.

Figure 12: Project values (in million EUR) by sub-theme: EU and partner contributions



Source: TRIMIS.

from 2021 and after being estimates). It can be seen that the *systems* sub-theme is more present from 2014 onwards, which relates to H2020 funded projects. Additionally, *rotorcraft* project values are much higher after 2018, showing a higher uptake of this sub-theme by the second half of the FP. Finally, the *propulsion* and *structures* sub-themes are the ones which have relatively constant shares through the whole analysed period.

An exercise has been carried out to understand the relations between each sub-theme. Figure 14 shows a chord diagram representing the relation between sub-theme categorisations. Connections between two sub-themes represent projects that research topics belonging to both sub-themes, with the thickness being related to the number of projects.

From the diagram, some interactions can be inferred:

— the *aerodynamics*, *propulsion*, *systems* and *structures* sub-themes have a high degree of interaction, showing that usually topics in these sub-themes require solutions beyond one sub-theme;

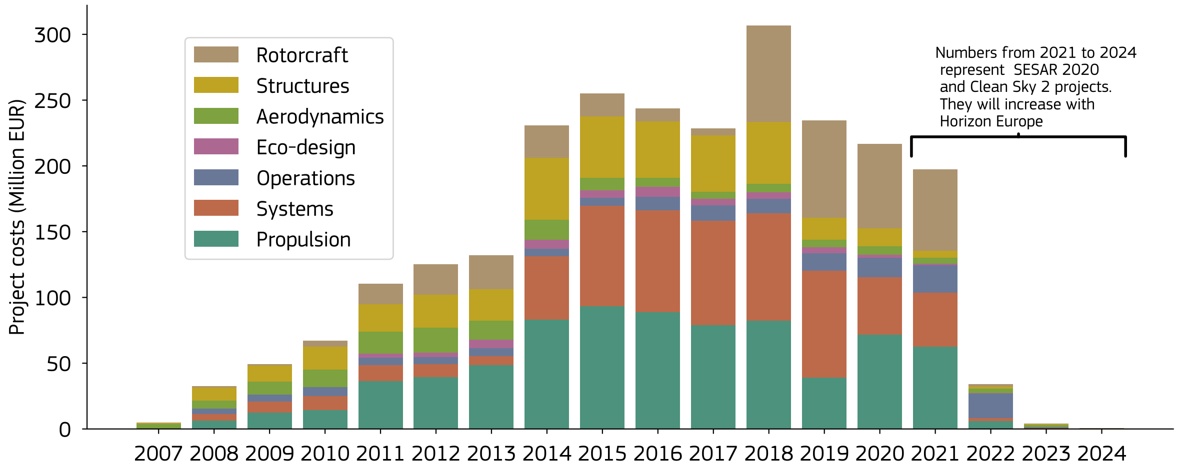
— *eco-design* has a high degree of interaction with *structures*. This can be explained as the manufacturing of structures is essential to proper eco-design methodologies;

— the *operations* sub-theme has the highest share of projects which belong exclusively to only one sub-theme. Such a result is understandable, as it is a sub-theme that does not directly deal with aircraft design, which is covered by the other sub-themes;

— *rotorcraft* projects have a very low number of projects belonging exclusively to this sub-theme, which can be explained by the multidisciplinarity of this sub-theme, as it should broadly cover all other sub-themes while researching rotorcraft.

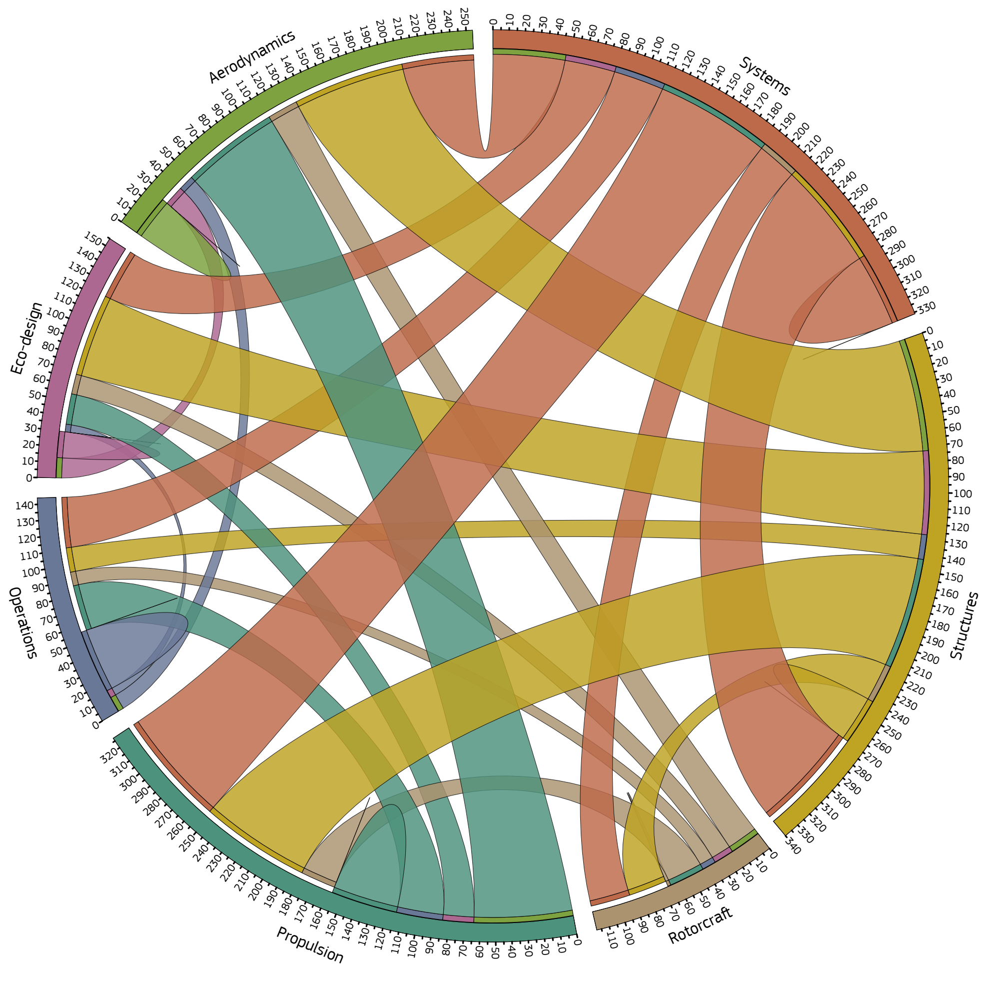
Finally, Figure 15 shows the top 15 emissions reduction projects in aviation, according to total project costs.

Figure 13: Project values (in million EUR) by sub-theme: yearly breakdown



Source: TRIMIS.

Figure 14: Chord diagram representing interactions between sub-themes[20]

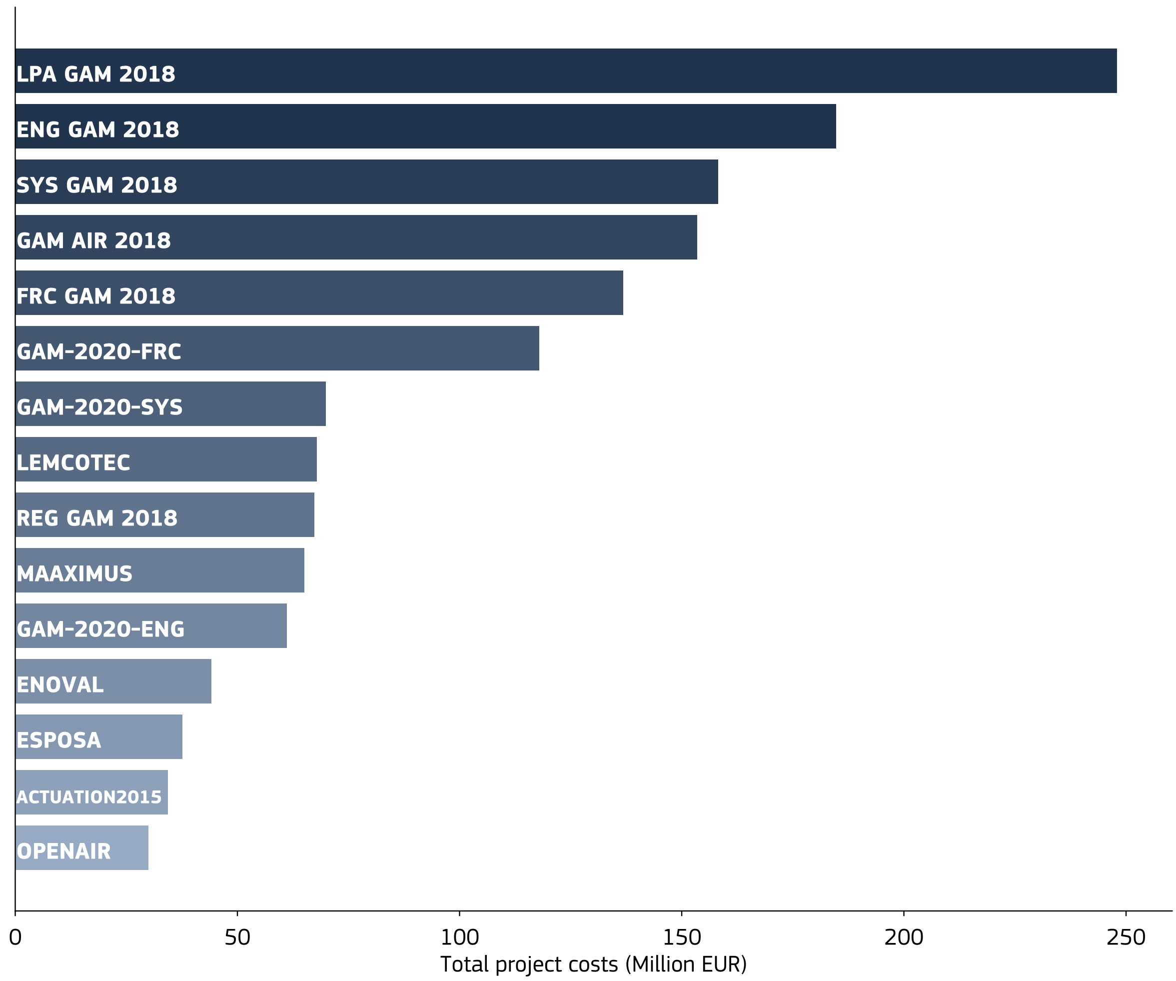


Source: TRIMIS.

[20]This diagram was created using the Circos online tool http://mkweb.bcgsc.ca/tableviewer/docs/

Most of the projects are Clean Sky IADPs, which highlights the magnitude of these projects. It is important to note that some of these projects have more than one entry in CORDIS, related to their execution periods (until December 2019 and from 2020 onwards). These projects were considered as separate projects for this analysis.

Figure 15: Top 15 aviation emissions reduction projects by total project cost



Source: TRIMIS.

5.3 European countries involvement

This section presents information regarding involvement of organisations from the EU 27 and the United Kingdom (UK) in projects co-financed from EU funds through FP7 and H2020 funding schemes. In total, data from 514 projects is included in the presented analysis. The analysis includes the UK as it continues to participate in programmes funded under the current 2014-2020 Multiannual Financial Framework until their closure[21].

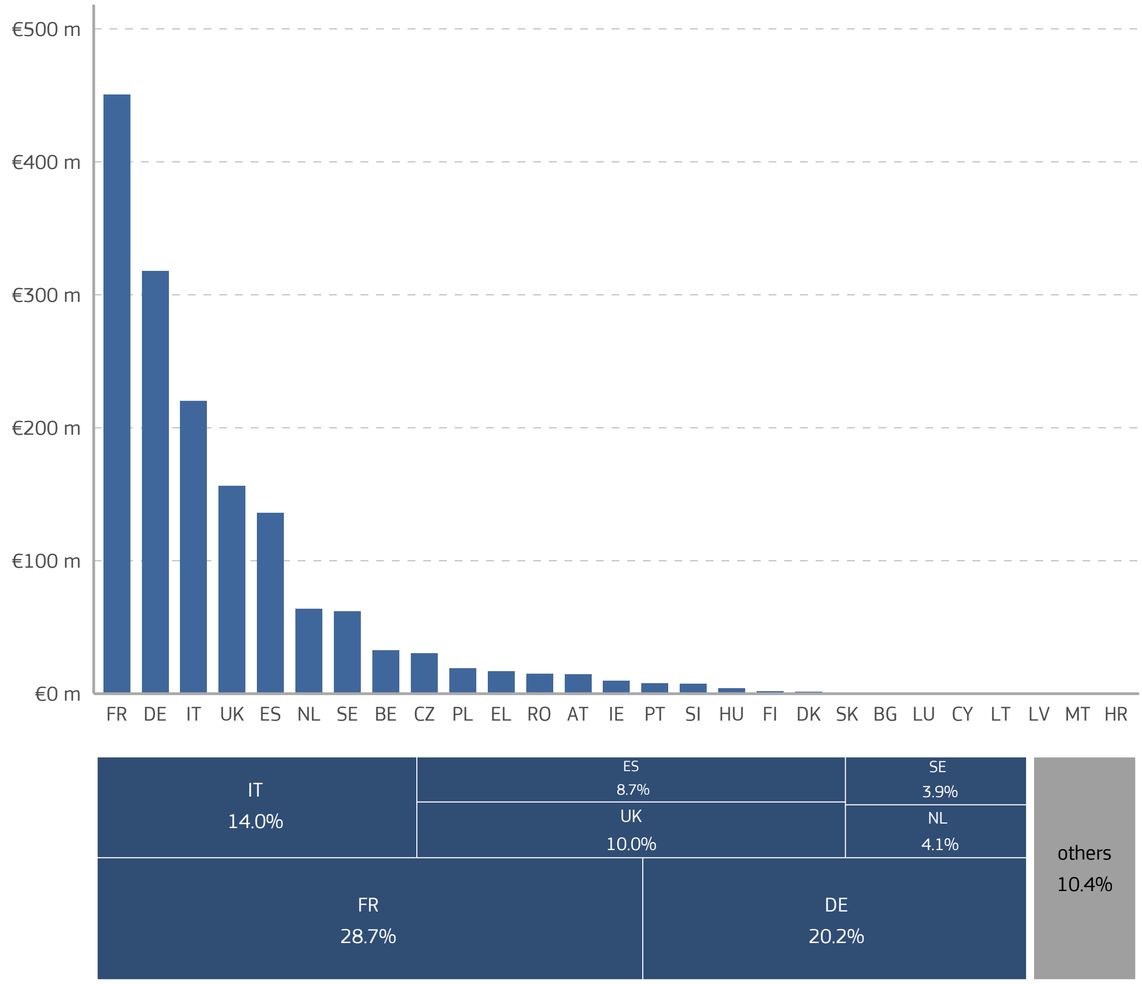
The CORDIS database on organisations is used to identify the amount of EU contribution directed to particular organisation and country. Moreover, all the data on organisations involved in the aviation projects is geocoded and then aggregated at the regional nomenclature des unités territoriales statistiques (NUTS) 2 level. The Batch Geocoding Interface, European Commission (EC) place localiser[22], enables to geocode 99.8% of all project partners. The remaining ones (22 project partners – 7 unique organisations) are geocoded using European Statistical Office (Eurostat) correspondence tables , which contain links between postcodes and NUTS level 3 codes. All the results of geocoding procedure are then aggregated to NUTS 2 and country level.

Figure 16 presents the total EU contribution in aviation projects received by all organisations affiliated in a given country. French entities received the highest amount of funding – roughly EUR 450 million. They are followed by German (EUR 317 million) and Italian (EUR 220 million) organisations.

[21] https://www.gov.uk/government/publications/continued-uk-participation-in-eu-programmes/eu-funded-programmes-under-the-withdrawal-agreement

[22] https://gisco-services.ec.europa.eu/batchgeocoding/

Figure 16: Total EU contribution per country



Abbreviations: France (FR); Germany (DE); Italy (IT); United Kingdom (UK); Spain (ES); Netherlands (NL); Sweden (SE); Belgium (BE); Czechia (CZ); Poland (PL); Greece (EL); Romania (RO); Austria (AT); Ireland (IE); Portugal (PT); Slovenia (SI); Hungary (HU); Finland (FI); Denmark (DK); Slovakia (SK); Bulgaria (BG); Luxembourg (LU); Cyprus (CY); Lithuania (LT); Latvia (LV); Malta (MT); Croatia (HR);
Source: TRIMIS.

Among organisations from other countries, only British and Spanish ones received more than EUR 100 million in total each. Organisations from these five countries received nearly 82% of total funding directed to aviation projects. The remaining funding, EUR 290 million, is distributed among remaining 22 countries (no Estonian organisations received funding through aviation projects).

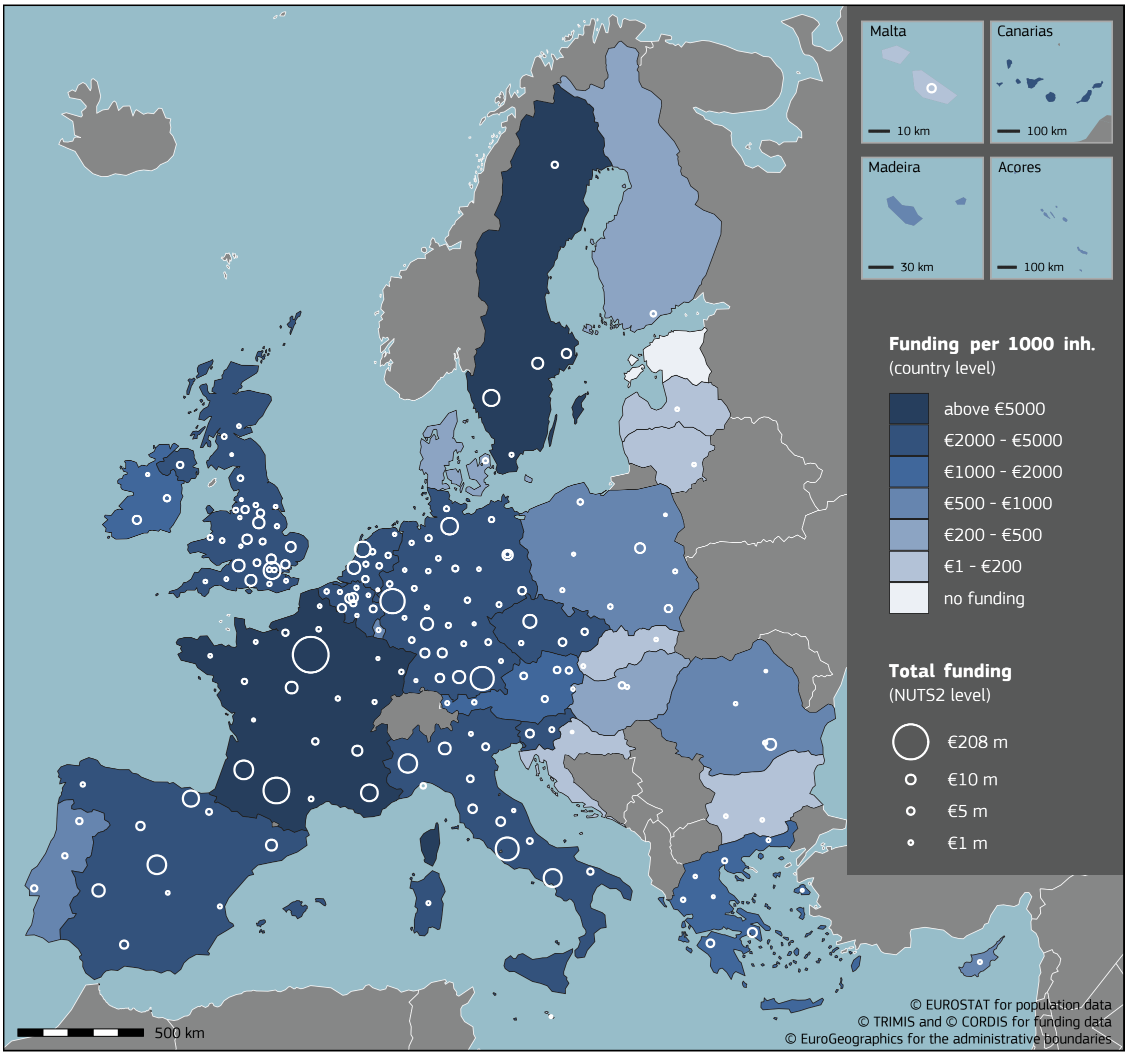
Figure 17 shows spatial distribution of funding directed to European organisations through aviation projects. In relative terms (funding per 1000 inhabitants, choropleth layer), the highest funding was directed to Swedish and French entities (above EUR 5 000 per 1000 inhabitants), while the lowest relative funding received entities from Eastern Europe (Baltic States, Slovakia, Slovenia, Bulgaria).

In most of the countries, funding of aviation projects is unevenly distributed and directed only to limited number of regions. At the regional level (NUTS 2 units), the highest funding received organisations from the metropolitan areas of capital cities (Paris, Rome, Madrid or London), and other, regions and metropolitan areas of Europe (e.g. Ruhr region and Munich in Germany, Turin and Naples in Italy, Toulouse and Bordeaux in France).

There were 1136 organisations involved in 514 aviation projects realised within FP7 and H2020 funding schemes. 1024 of them are located within EU 27 and UK. The average aviation project is realised by a consortium which consist of 6 organisations, however the largest ones grouped up to 60 different participants.

Figure 18, on the left-hand side shows the number of projects in which organisations from particular countries

Figure 17: Distribution of EC contribution to aviation emissions reduction R&I projects in EU MSs and UK and their regions



Source: TRIMIS.

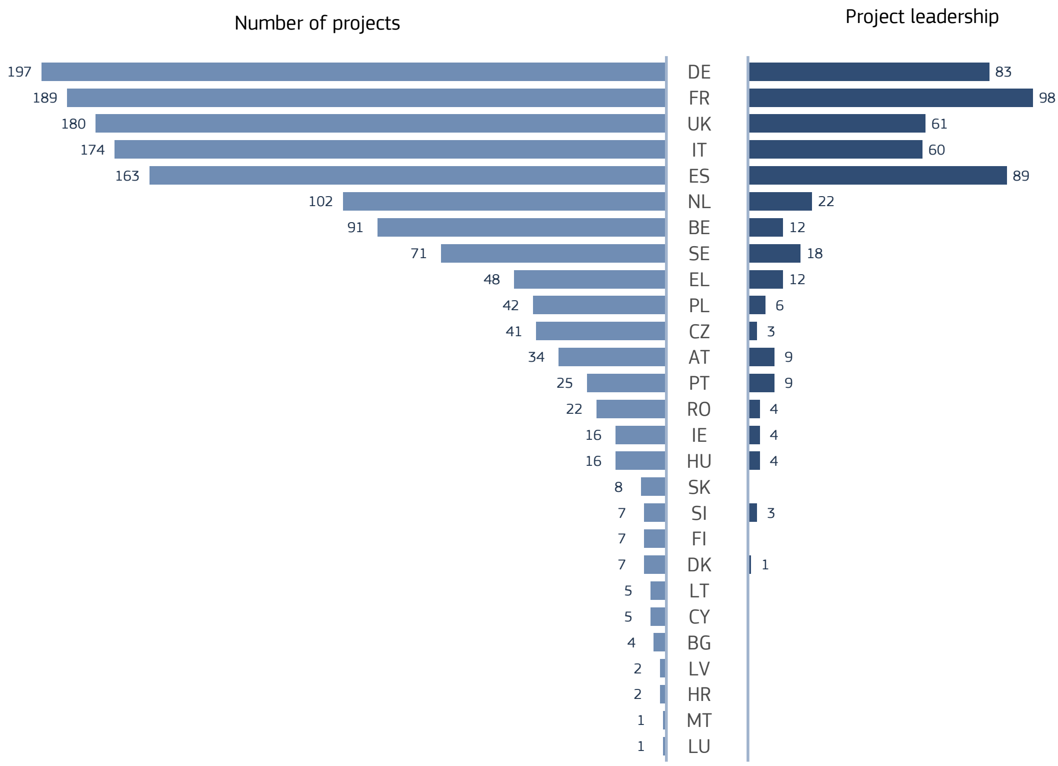
were involved. The right-hand side presents a total number of projects led by organisations from a given country. Nearly 200 projects were realised with participation of at least one German organisation. French, British, Italian and Spanish organisations were involved in roughly third part of all aviation projects (31-36%).

This distribution corresponds to a high share of total funding received by organisations from these five countries (cf. Figure 16). organisations from these five countries most often took responsibility of leading a consortium and together they lead more than three out of four aviation projects. French entities acted the most actively in terms of leading a consortium (nearly 20% of all projects), followed by Spanish and German organisations. Among all other countries, only organisations from the Netherlands, Sweden, Belgium and Greece led more than ten projects each.

Figure 19 provides an input on cooperation between leaders of consortium and project partners located in different countries. For the sake of clarity, it is limited to links between seven of the most active countries. The presented chord diagram is a directional one (i.e., not a symmetric), which means that the width of the arc at ends indicates number of partners in projects coordinated by an organisation from a given country. It shows that the two most active countries, i.e. France and Germany, are also the two with the highest mutual collaboration rate: 125 project partners from Germany were involved in 98 projects led by French entities and 115 French partners in German-led projects.

Other important links include cooperation between French leaders and partners located in the UK (100) and Italy

Figure 18: Number of projects with a partner from a given country (left) and projects led (right)



Source: TRIMIS.

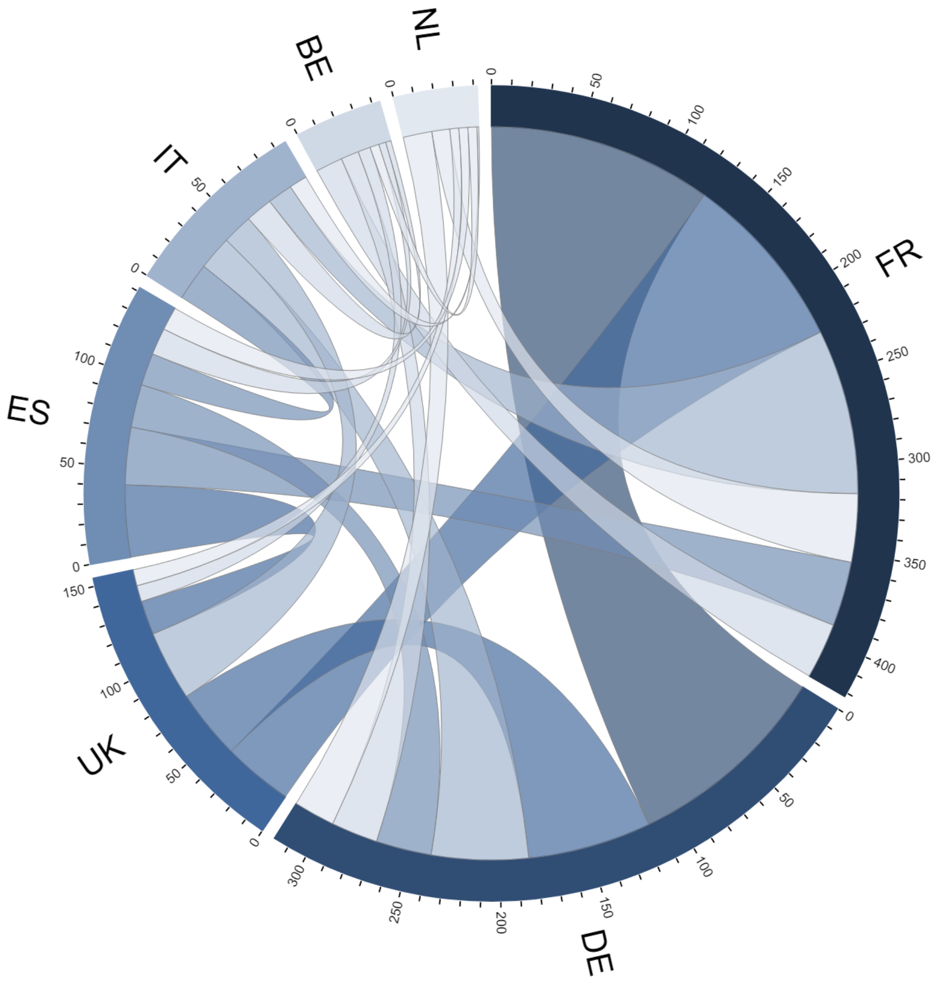
(92) but in this case the reverse links (i.e. French partners involved in UK- and Italy-led projects) were much weaker (39 and 14, respectively). Besides, German-led projects involved 69 project partners from the UK. Any other connections were weaker and did not exceed 50 project partners involved.

The analysis of the most active organisations also provides more insights on the dominance of French and German organisations. Among the ten most active ones, there are three each from these two countries.

The top-10 list contains also 2 Dutch organisations (including one university: Technische Universiteit Delft (TU Delft)), and one organisation each from Italy and the UK. The DLR took part in 83 projects, leading 18 of them (also the first position in this ranking) and received nearly EUR 84 million for the implementation of aviation related projects.

In proportions, the DLR took part in more than 42% of projects which involved at least one German entity (and more than 16% of all aviation projects), led nearly 22% of all German-led consortia and received more than a fourth of all funds directed to the German organisations.

Figure 19: Main collaboration links between project leader and project partners located in different countries



Source: TRIMIS.

Table 7: Top 10 organisations by number of projects

Short name	Country	Number of projects	Number of projects led. Rank in brackets	Total EU contribution (million EUR). . Rank in brackets
DLR	DE	83	18 (1)	83.8 (1)
ONERA	FR	55	8 (3)	36.9 (7)
NLR	NL	53	13 (2)	28.6 (12)
TU Delft	NL	38	5 (6)	12.6 (25)
CIRA	IT	33	0 (10)	16.9 (17)
Rolls-Royce	UK	27	5 (6)	30.3 (10)
Safran Aircraft Engines	FR	26	4 (7)	46.4 (3)
Airbus Operations	FR	25	2 (9)	46.1 (4)
MTU Aero Engines	DE	25	2 (9)	24 (13)
Astrium	DE	23	4 (7)	13.3 (23)

Abbreviations: Deutsche Zentrum für Luft- und Raumfahrt (DLR); Office National d'Etudes et de Recherches Aérospatiales (ONERA); Nederlands Lucht- en Ruimtevaartcentrum (NLR); Technische Universiteit Delft (TU Delft); Centro Italiano Ricerche Aerospaziali (CIRA)
Source: TRIMIS.

Box 4. Projects quantitative assessment summary

— Aviation R&I projects have been on the rise especially since FP7, with the most important STRIA roadmaps being vehicle design and manufacturing (VDM) and network and traffic management (NTM)

— The most present researched sub-themes in budget and number are *propulsion* and *systems*, with the lowest numbers belonging to *eco-design*

— Clean Sky projects are on the top of the list of projects with highest funding

— France, Germany and Italy are the countries that receive the most EU funding for emissions reduction aviation projects

— The 5 most present organisations are: Deutsche Zentrum für Luft- und Raumfahrt (DLR), Office National d'Etudes et de Recherches Aérospatiales (ONERA), Nederlands Lucht- en Ruimtevaartcentrum (NLR), Technische Universiteit Delft (TU Delft) and Centro Italiano Ricerche Aerospaziali (CIRA)

6 Projects qualitative analysis

This chapter takes an in-depth look into selected R&I projects under the seven sub-themes, which cover the key areas of research being undertaken in emissions reduction in aviation. The analysis provides an overview of the research being performed, the key results and the subsequent implications for future research and policy development. FP7 and H2020 aviation projects have also be analysed in the reports from Directorate-General for Research and Innovation (DG RTD) (European Commission, 2010, European Commission, 2012, European Commission, 2013) and European Climate, Infrastructure and Environment Executive Agency (CINEA) (European Commission, 2020d) are more suitable.

The sub-theme analysis focuses on projects funded by the FP7 and H2020 programmes. For each sub-theme, six projects were assessed in more details, and their results are reported in the following sections.

The criteria used to select projects for the analysis were: size and budget of the project, availability of results and relevance to the sub-theme. Moreover, the large Clean Sky ITDs and IADPs were not included in this analysis. Due to their size and complexity, as well as the extensive availability of data and reports from the JU[23] which display their project results, they are excluded from the in-depth analysis presented in this chapter.

For each sub-theme, the overall direction of R&I is presented, as well as the R&I activities, achievements and implications for future research and policy.

6.1 Sub-theme 1 - Aerodynamics

This sub-theme focuses on improving the aerodynamics of aircraft.

6.1.1 Overall direction of R&I

Several areas of research have investigated the development of technology related to aircraft aerodynamics. These include technologies that: improve the safety of aircraft with respect to aerodynamics; improve the aerodynamic efficiency and therefore reduce fuel usage; investigate the effects of airflow and can be used in future studies to quickly and efficiently produce results and advance technology. The projects identified that are investigating aerodynamics are funded by H2020, FP7 and Clean Sky.

Research topics within the sub-theme include the research of new wing technologies to decrease drag (using e.g. innovative control surfaces, flow control methods, high-lift devices, morphing wings), making use of computational fluid dynamics (CFD) simulation tools, as well as scaled and large scale wind tunnel testing demonstrators.

One of the key research areas has been into morphing technologies that allow aircraft structures to reshape in-flight to achieve the maximum aerodynamic benefit. These have mostly focused on morphing the leading and trailing edge of wings to optimise laminar flow over the wing surface.

Another area of research is into high-speed aircraft, those travelling above the speed of sound (Mach 1). This research has covered technologies such as waverider aircraft that use shock waves to generate lift and accompanying simulations to test the stability of aircraft at high speeds.

[23] https://www.cleansky.eu/key-documents

Laminar flow has been a core focus of many projects, investigating technologies that can alter the flow of air around an aircraft to reduce fuel usage and improve stability. These have involved inducing shock wave transitions at locations optimal for aerodynamics and using actuators to manage active flow control systems.

6.1.2 R&I activities

A total of 76 projects were assigned to this sub-theme, with a large majority of funds by FP7, as shown in Table 8.

Table 8: Sub-theme 1 research by parent programme summary

Parent programme	Number of projects	Total project value (million EUR)	Total EU contribution (million EUR)
FP7	20	85.24	54.53
H2020	6	12.21	11.88
Clean Sky	50	45.47	31.55

Source: TRIMIS.

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the aerodynamics field. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

The **HEXAFLY-INT** (High-Speed Experimental Fly Vehicles - International, 2014-2019) project partners aimed to flight test an aircraft above Mach 7 to test the aerodynamic efficiency during flight with an aircraft design that included a large internal volume. HEXAFLY-INT built upon the 3m aircraft demonstrated for the precursor HEXAFLY project.

The aircraft was classified as a waverider, an aircraft that utilises compression lift produced from its own shock waves. Research carried out in this project was believed to increase the TRL of high-speed projects such as ATLLAS I & II and LAPCAT I & II. There were six major technologies to be developed:

— High-Speed Vehicle Concepts;

— High-Speed Aerodynamics;

— High-Speed Propulsion;

— High-Temperature Materials and Structures;

— High-Speed Flight Control;

— High-Speed Environmental Impact.

The project partners aimed to carry out two different phases for the flight test, one at high speed to check the cruise capability and another at low speed to examine the handling during take-off and landing.

The **TFAST** (Transition Location Effect on Shock Wave Boundary Layer Interaction, 2012-2016) project partners aimed to study the effect of the location of the transition between laminar and turbulent flow (within the boundary layer next to the aircraft surface) on the structure of the interaction. The team tried to determine how close the induced transition could be to the shock wave whilst maintaining the typical turbulence necessary for aircraft performance and safety. The project partners wanted to develop experimental and numerical expertise in basic laminar/transitional interactions, giving industrial partners and researchers access to accurate procedures for predicting such flows.

The **SMS** (Smart Morphing and Sensing, 2017-2020) project partners' main objective was to study the effect of aerostructural morphing on the aerodynamic efficiency in take-off, cruise and landing flight regimes. The project partners aimed to increase the aerodynamic efficiency by controlling the structure of the turbulent airflow responsible for noise and vibration. Electro-active actuators allow the aircraft to modify its shape and improve its aerodynamic performance, using fibre optic pressure sensors to measure real-time aerodynamic characteristics. The project partners also aimed to design in-flight controls to utilise the technology in real-time.

The **GRETEL** (Green Turboprop Experimental Laminar Flow Wind Tunnel Testing, 2017-2022) project is building on the SMS project and is developing a 1:3 scale natural laminar flow (NLF) flexible wing capable of morphing into more aerodynamic positions. The partners will then perform wind tunnel and ground vibration tests to assess the wing's effectiveness and safety, maturing the TRL up to 6.

The **ELWIPS** (Electro-thermal Laminar Wing Ice Protection System Demonstrator, 2012 - 2016) project partners aimed to design, build and test a prototype wing for a business jet fitted with electro-thermal ice protection (ETIPS). This technology could improve aircraft safety by reducing negative effects of ice contamination which include: distorting the airflow over the wing, reducing maximum lift, significantly increasing drag and adversely affecting aeroplane handling.

The **INAFLOWT** (Innovative Actuation Concepts for Engine/Pylon/Wing Separation Flow Control (Design, Build and Wind Tunnel Test), 2017-2020) project partners aimed to develop innovative active flow control (AFC) technology to overcome local flow separation, particularly due to the close coupling of the engine nacelle to the wing. They aimed to do this at low energetic cost and low mass flow.

6.1.3 Achievements

The HEXAFLY-INT project partners produced a full-scale experimental model, testing it in the high enthalpy shock tunnel Göttingen (HEG) of the DLR. They were able to verify stable control at take-off and landing speeds with and without a propulsive jet. The project partners ran simulations to analyse the aerodynamic behaviour of the aircraft and set up an aerodynamic model with related uncertainties. They kept the panels of the fuselage below 700°C using high emissivity paint.

The pressure sensitive paint (PSP) and temperature sensitive paint (TSP) were successfully used in the TFAST project to give insights into airflows next to surfaces. The project partners studied low Reynolds number flows with efficient simulations that include wall perturbations; the costs are still prohibitively expensive for commercial use, but their potential is real. From these tests the team concluded that transitional flows are very sensitive to the level of external background fluctuations. The project partners successfully created a database for transitional shockwave boundary layer interactions under the influence of transition trips and flow control. They determined that it was not detrimental to use the shockwaves to do the work and promote transitions. The project partners concluded that the laminar flow benefit (enhanced lift and lower friction drag from the shock being pushed backwards) could be reduced when wave drag becomes comparatively significant. This shows that wave drag can be increased through laminar or transitional shock wave boundary layer interactions.

The SMS project partners successfully created two actuation systems, one operating at high deformation/low frequency and the other at low deformation/high frequency. The partners tested these on a full-scale model Airbus A320 type wing and were able to verify an increased lift of 3%, reduced drag of 4-5% and reduced noise of 8%.

The GRETEL project partners have completed the first iteration of a manufacturing-assembly-integration plan, having designed a structural carbon fibre reinforced plastic (CFRP) wing box, the lower wing structure, the ribs inside the wing box and the interface for morphing the winglet.

The ELWIPS project partners developed anti-ice and de-icing solutions for use on a high-speed business jet, with the heater technology reaching TRL 6 and the icing solution TRL 5. The partners' solutions only use power when and where it is needed, substantially reducing the power requirements compared to conventional heating methods.

The INFAFLOWT project partners designed an innovative AFC concept to overcome local flow separation, providing a near full-scale prototype and reaching a TRL 3. The partners used wind tunnel testing to validate CFD simulations and improve understanding of flow physics. They used steady suction, in addition to the already used pulsed blowing, to achieve these results. This significantly reduces the mass flow requirements for pulsed blowing.

6.1.4 Implications for future research

The HEXAFLY-INT project partners did not successfully launch the test vehicle, so in-flight research of the aircraft remains to be carried out. Test flights of similar concepts at lower speeds have already proven successful, such as Boeing's X-51 waverider, which completed a successful test flight in 2013 reaching speeds over Mach 5 for 210 seconds.

Transitional interactions proved to be an efficient way to shift transitions from the interactions to turbulence downstream. However, low and high frequency unsteadiness developed in separated interactions which has been shown to have a significant influence on the mean field of the interaction. Methods to analyse these interactions are now available, so future research should focus on analysing the turbulent field formed downstream.

The simulation methods used by the project partners are expensive so research into other simulation methods to calibrate simpler and cheaper models will help to negate this issue.

With successful application of morphing technology applied to aircraft wings in the SMS project there is now scope to apply this same technology to other surfaces of aircraft and further improve aerodynamics. This technology can then be implemented in test flights before reaching commercial viability.

The TRL achievements of the ELWIPS project support further research and development into electro-chemical ice protection, as it has shown to be a lightweight and energy efficient solution to icing problems. The technology can also be applied to other fixed-wing aircraft and fixed surfaces of rotary wing aircraft.

6.1.5 Implications for future policy development

Supersonic flights above land are banned across Europe and the US so flights at these speeds will need to use overwater routes to avoid breaking the regulations. If future policy changed to allow supersonic flights above land, there could be more drive to create these aircraft. International routes avoiding these restrictions have been mapped so policy changes are not a necessity for the continued research programme.

Water vapour produced at the high altitudes these aircraft occupy has also been raised as a concern and may affect their green credentials (even when using zero-carbon fuels). If high-altitude supersonic or hypersonic flight is to become a reality, policy will need to consider the potential adverse impacts of this water vapour emissions and consider the costs and benefits of using hypersonic aircraft, so that there would be a positive effect from their introduction.

Application of the research into this field has the potential to reduce fuel consumption of aircraft by 10%. This would significantly help the aviation industry meet its 2050 target to reduce net CO_2 emissions by 50%. It also aligns with the STRIA targets of a reduction of aircraft fuel burn of 50% by 2050. This research can also be applied to reduce heat flux to turbine blades, improving their durability and safety. This can help the aviation industry meet the safety requirements laid out in FlightPath 2050, including reducing the number of accidents by 80% compared to rates in 2000.

6.1.6 Table of reviewed projects

Table 9 provides an overview of the projects undertaken in the aerodynamics field.

Table 9: Projects included in the review of sub-theme 1

Project acronym	Project name	Project duration	Source of funding
HEXAFLY-INT	High-Speed Experimental Fly Vehicles - International	2014-2019	FP7-Transport
TFAST	Transition Location Effect on Shock Wave Boundary Layer Interaction	2012-2016	FP7-Transport
SMS	Smart Morphing and Sensing	2017-2020	H2020-3.4
GRETEL	Green Turboprop Experimental Laminar Flow Wind Tunnel Testing	2017-2020	H2020-3.4.5.2
ELWIPS	Electro-thermal Laminar Wing Ice Protection System Demonstrator	2012-2016	Clean Sky
INAFLOWT	Innovative Actuation Concepts for Engine/Pylon/Wing Separation Flow Control (Design, Build and Wind Tunnel Test)	2017-2020	H2020-3.4.5.1

Source: TRIMIS.

Box 5. Aerodynamics projects assessment summary

— Aerodynamics technologies include: improved flow for efficient fuel usage, morphed structures for optimal aerodynamic benefits

— Tools for research include CFD models and small and large scale prototypes used in wind tunnels

— Some technologies have the potential to decrease aircraft fuel consumption by 10%

6.2 Sub-theme 2 - Structures

This sub-theme focuses on improving the structures of aircraft and their production methods.

6.2.1 Overall direction of R&I

Several areas of research have emerged from the development of technology into structures. These include creating lightweight structures to reduce fuel burn, making structures from materials with a lower environmental footprint and developing non-destructive testing (NDT) methods to assess the integrity of structures. The projects identified that are investigating structures are funded by H2020, FP7 and Clean Sky.

Research topics within the sub-theme include research into lightweight composite materials, taking into account techniques to assess the integrity of these materials, analysis of requirements to replace metallic structures with lightweight composites, different types of resins and fibres, as well as new alloys, joining methodologies for composite and metallic materials and assessing manufacturing improvements. The projects generally make use of computational tools for modelling micro and macro properties of the materials, and demonstrators and prototypes of components are frequently manufactured.

One area of focus has been on creating large one-piece structures to replace multi-part composites, reducing their overall weight whilst simultaneously increasing the strength and reducing the assembly time. This involved careful planning with multiple simulations to test the feasibility of the technological benefits. Another area of focus has been on the NDT methods to save significant time and costs during the development phase of projects. These have involved investigating optical methods, such as laser scanning vibrometer and active thermography, as well as sensor-based methods such as embedded optical fibre sensors or electrochemical impedance spectroscopy.

Projects have also focused on the environmentally friendly materials such as bio-based reinforcements and eco-composites. Projects have looked at using natural fibres as well as wood fibres mixed with bio based epoxy to maintain structural integrity standards.

6.2.2 R&I activities

A total of 94 projects were assigned to this sub-theme, with a large majority funded by Clean Sky, as shown in Table 10.
To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the structure field. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

Table 10: Sub-theme 2 research by parent programme summary

Parent programme	Number of projects	Total project value (million EUR)	Total EU contribution (million EUR)
FP7	14	130.45	84.78
H2020	11	31.16	30.42
Clean Sky	69	204.54	159.06

Source: TRIMIS.

The **MAAXIMUS** (More Affordable Aircraft through Extended, Integrated and Mature Numerical Sizing, 2008-2016) project partners aimed to demonstrate the viability of one-piece large structures to replace multiple composite parts and the use of simulation-based design to reduce costs and increase the speed of production. The project partners goals were to achieve a:

— 50% reduction in assembly time;

— 10% reduction in manufacturing and assembly recurring costs;

— 10% reduction in weight;

— 20% reduction in development time;

— 10% reduction in development costs.

The **EXTREME** (Extreme Dynamic Loading - Pushing the Boundaries of Aerospace Composite Material Structures, 2015-2019) project partners aimed to create innovative material characterisation methods along with measurements, materials and simulations to design and manufacture aerospace composite structures under extreme dynamic loadings. This would allow for a significant reduction of weight, design and certification costs.

The **ComBoNDT** (Quality Assurance Concepts for Adhesive Bonding of Aircraft Composite Structures by Advanced NDT, 2015-2018) project partners aimed to develop extended non-destructive testing (ENDT) methods for pre and post-bond inspection of carbon fibre reinforced polymer structures, often used in aircraft. The partners wanted the methods to:

— detect contaminations on surface before bonding, activating surface cleaning measures;

— detect poor quality bonds, triggering repair actions;

— improve the robustness of in-line inspections.

This technology has the potential to save up to 70% in time and 50% in costs related to production, maintenance, repair, overhaul and retrofitting.

The **CENTRELINE** (Concept Validation Study for Fuselage Wake-Filling Propulsion Integration, 2017-2020) project partners aimed to maximise the benefits of aft-fuselage wake-filling under realistic conditions. The concept was to fill the wake with a propulsive device installed at the fuselage aft-end to trap and energise the fuselage boundary layer flow. The partners wanted to mature this technology from TRL 1-2 to TRL 3-4 with a proof of concept and initial experimentation. Other targets also included an 11% reduction in CO_2 and NO_x emissions compared to a predicted reference aircraft from 2035.

The **IIAMS** (Innovative Infusion Airframe Manufacturing System, 2018-2020) project partners aimed to develop a system capable of manufacturing an integrated composite wing box. The new system could result in lower costs, reduced lead times and a reduced environmental footprint.

The **ECO-COMPASS** (Ecological and Multifunctional Composites for Application in Aircraft Interior and Secondary Structures, 2016-2019) project partners aimed to develop bio-based composites. Aircraft often use synthetic composites with negative environmental impacts, the use of bio-based reinforcements, resins and sandwich cores along with recycled synthetic fibres can help to negate these environmental impacts. The partners aimed to test the composite for structural integrity and perform a cradle to grave life cycle assessment to compare the eco-composites with state-of-the-art materials.

6.2.3 Achievements

The MAAXIMUS project partners improved acoustic models, composite data models and non-destructive investigation (NDI) data. The partners also completed a cost model, based on a generic fuselage design. The manufacturing test coupons have been used to compare experimental and calculated results, with all the NDI data available. The partners carried out comprehensive work on the development of models concerning damage from the micro to the macro scale, while ensuring effective coupling between the two and carefully controlling any errors. The ability to minimise errors is crucial to achieving the confidence required to translate the simulations into real world weight, cost and time savings. A software tool was developed to transfer the NDI data to an existing commercial simulation tool.

The EXTREME project partners designed a new resin system with improved energy absorption behaviour and built large scale structures to test under extreme loads. The partners created a robust physically based damage model for progressive damage in three dimensions three dimensions (3D) as well as a meso scale model for predicting the failure of composite materials. These models were optimised to reduce computational time. An impact detection system was developed and demonstrated at TRL 6. The ComBoNDT project partners defined, characterised and prepared test scenarios. Using these they developed ENDT techniques for quality assurance of surface parts and adhesive bondlines reaching the expected TRL 3-4.

The CENTRELINE project partners designed two fans to test the undistorted flow conditions and the specific inflow distortions for the propulsive fuselage concept (PFC). They successfully performed wind tunnel testing of the PFC in an unpowered state and established the architecture of the PFC turbo-electric power train. The partners matured the technology to TRL 3-4.

The IIAMS project partners successfully manufactured a full-scale dummy wing box in one piece, including the skin, six stringers, front and rear spacers and 24 stiffeners; completing the goal of reliable part integration whilst maintaining structural strength. These panels have since been tested to confirm robustness of the process and now the manufacturing system is ready.

The ECO-COMPASS project partners successfully tested various eco-composites, including natural fibres, flax and ramie, for reinforcements, green honeycomb sandwich cores with wood fibres and partly bio-based epoxy resins for secondary structures. The partly bio-based epoxy resin was considered to have the highest potential for successful application in aviation. The project partners were able to demonstrate a TRL 3-4 for the eco-reinforcements. The project has also reinforced a long-term relationship between China and Europe in aeronautics.

6.2.4 Implications for future research

The MAAXIMUS project partners did not succeed in building the structural sub-components to test the accuracy of their simulations. Further physical tests will be needed to verify the integrity of the simulation models produced during the project.

The EXTREME project partners developed a smart impact sensing concept, based on fibre-optics and piezo-sensors, for in-situ monitoring of extreme dynamic loading. This concept could be investigated further to produce a working example, allowing aircraft manufacturers to design more efficient and intelligent structural components.

The CENTRELINE project partners have now set out a pathway to mature wake-filling propulsion technology to TRL 6 by 2030. This technology is best utilised by medium-to-long range wide-body aircraft, but research could be extended into other aircraft segments.

The ECO-COMPASS project partners highlighted the weight saving potential of ramie, flax and sisal, but due to their natural aging their mechanical properties need to be improved. These could be improved with further research into computer numerically controlled (CNC) coating, hybridisation with recycled carbon fibre and plasma treatment.

6.2.5 Implications for future policy development

The research carried out with regards to NDT will need to meet the safety requirements of current testing methods to be certified for commercial use. The same applies to the simulation tools developed to facilitate the manufacture of aircraft structures. Many of these projects aim to improve the safety compared to current standards so future standards could become stricter.

These projects have also focused on significantly reducing the weight of aircraft which will help the aviation sector to achieve the SRIA target of a 50% reduction in aircraft fuel burn by 2050. They also go one step further by using materials with a reduced carbon footprint which will reduce the life-time emissions of aircraft. These environmentally friendly materials are often easier to recycle at the end of their service, further reducing life-time emissions.

6.2.6 Table of reviewed projects

Table 11 provides an overview of the projects undertaken in the structures field.

Table 11: Projects included in the review of sub-theme 2

Project acronym	Project name	Project duration	Source of funding
MAAXIMUS	More Affordable Aircraft Structure through Extended, Integrated, and Mature Numerical Sizing	2008-2016	FP7-Transport
EXTREME	Extreme Dynamic Loading - Pushing the Boundaries of Aerospace Composite Material Structures	2015-2019	H2020-3.4
ComBoNDT	Quality assurance concepts for adhesive bonding of aircraft composite structures by extended NDT	2015-2018	H2020-3.4
CENTRELINE	Concept Validation Study for Fuselage Wake-Filling Propulsion Integration	2017-2020	H2020-3.4
IIAMS	Innovative Infusion Airframe Manufacturing System	2018-2020	H2020-3.4
ECO-COMPASS	Ecological and Multifunctional Composites for Application in Aircraft Interior and Secondary Structures	2016-2019	H2020-3.4

Source: TRIMIS.

Box 6. Structures projects assessment summary

— The most important technologies researched include lightweight composite materials, focusing on material integrity, new types of fibres and resins and production methods

— Tools for research include modelling of materials in micro and macro scale and test coupons for strength measurements and damage detection

— Reduction of weight for the aircraft can help reduce fuel burn, with some projects suggesting 10% reduction in weight.

— TRLs for the projects are around 3 to 4

6.3 Sub-theme 3 - Propulsion

This sub-theme focuses on improving the efficiency and economic and environmental properties of propulsion systems in aircraft.

6.3.1 Overall direction of R&I

Projects have focused on several different areas of research regarding propulsion technology, which can be separated into two categories - propulsion technologies and alternative fuels. The first category includes electric and hybrid-electric propulsion, as well as improvements to the pressure ratio of engines to reduce pollutant emissions, while the second category uses novel fuels to power different aspects of aircraft and creating platforms to allow easy assessment of these new fuels. The projects identified that are investigating propulsion are funded by H2020, FP7 and Clean Sky.

Generally, topics within the sub-theme include research into innovative propulsion (e.g. counter rotating open rotor, hybrid electric propulsion), as well as the design of new generation (e.g. new generation TurboProp) and improvements to current propulsion systems (e.g. high bypass ratio turbofan), while also developing modelling tools and building prototypes. Research on alternative fuels (or sustainable alternative fuels (SAFs)) includes evaluation of potential benefits of using new fuel candidates, as well as building a knowledge base on these new fuels, for use in predicting impact of their adoption.

One area of focus has been increasing the overall pressure ratio (OPR) of engines to improve their thermal efficiency. This helps to reduce CO_2 emissions but counter productively increases NO_x emissions, so research has also involved lean combustion methods to reduce NO_x emissions.

Another area of focus has been on the fuels used in aircraft, for powering the engines and powering the on-board electrical systems. Project partners have investigated hydrogen as an alternative fuel to power non-essential applications as well as producing a full value chain for hydro-processed esters and fatty acids (HEFA) to replace conventional kerosene with SAFs.

Complementing the research into alternative fuels some projects have investigated platforms to assess the benefits and costs involved with switching fuels. This can provide stakeholders with essential information to make the fuel switch as seamless as possible.

6.3.2 R&I activities

A total of 94 projects are assigned to this sub-theme, with more than half of this number funded under Clean Sky, as shown in Table 12.

Table 12: Sub-theme 3 research by parent programme summary

Parent programme	Number of projects	Total project value (million EUR)	Total EU contribution (million EUR)
FP7	25	273.91	171.06
H2020	17	95.97	79.49
Clean Sky	52	395.31	285.32

Source: TRIMIS.

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the propulsion field. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

The **LEMCOTEC** (Low Emissions Core-Engine Technologies, 2011-2017) project partners aimed to improve core-engine thermal efficiency by increasing the OPR to 70. This will help to reduce CO_2 emissions but NO_x emissions increase with OPR so the partners wanted to improve combustion technologies to compensate for this effect. The project targets included:

— 50% reduction in CO_2 per passenger kilometre by 2020;

— 80% reduction in NO_x by 2020;

— Reduce other emissions including soot, carbon monoxide (CO), unburnt hydrocarbons (UHC), SO_x and particulates.

The project partners aimed to validate these technologies up to TRL 5.

The **ENOVAL** (Engine Module Validators, 2013-2018) project partners focused on the low-pressure system of high bypass ratio (BPR) propulsion systems between 12 and 20 in combination with high OPR between 50 and 70. These technologies could reduce fuel burn by 3% to 5% and engine noise by up to 1.3 effective perceived noise in decibels (EPNdB). The partners will focus on ducted geared and non geared turbofan engines, some of the best options for the next generation of short/medium and long range commercial flights.

The **ESPOSA** (Efficient Systems and Propulsion for Small Aircraft, 2011-2016) project partners aimed to develop a range of small gas turbine engines of up to 1,000 kW. The partners focused on propulsion unit efficiency, safety and pilot workload reduction. A key target was to reduce direct operating costs by 10% to 14%.

The **HYCARUS** (Hydrogen Cells for Airborne Usage, 2013-2018) project partners aimed to design a proton-exchange membrane (PEM) fuel cell system compatible of powering two non-essential applications (NEAs) and demonstrate this technology up to TRL 6. The partners also aimed to investigate how to capture and reuse the by-products of the technology.

The **JETSCREEN** (Jet Fuel Screening and Optimization, 2017-2020) project partners aimed to create a platform to assess the risks and benefits of alternative fuels, optimise alternative fuels for maximum energy per kilogram and maximum reduction of pollutant emissions. The technology utilised low cost small-scale experiments and model-based testing to predict the impact of the fuel. This would reduce the risk for investors and fuel producers when deciding on a new fuel type or blend.

The **ITAKA** (Initiative Towards Sustainable Kerosene for Aviation, 2012-2016) project partners aimed to develop a full value chain in Europe for producing sustainable drop-in HEFA with a large enough volume (4 000 tonnes) to test in existing systems. Camelina oil was targeted as the most appropriate sustainable feedstock, although used cooking oil was also considered.

The **BIO4A** (Advanced Sustainable Biofuels for Aviation, 2018-2022) project aims to accelerate the deployment of sustainable biofuels, targeting tom move the full value chain from TRL 6 to 7. Special attention is given to cost targets, as the price gap is considered the main barrier for commercial uptake.

6.3.3 Achievements

The LEMCOTEC project partners were able to produce a lean combustion sub-system that reduced NO_x emissions by 65% to 70%. The improvements in the engine sub-systems led to an environmental footprint reduction to 2 litres of fuel (equivalent to approximately 5 kg CO_2) per passenger per 100 kilometres. The partners developed advanced structures and thermal management up to TRL 4-5.

The ENOVAL project partners successfully validated the low-pressure system technologies up to TRL 5. They were able to demonstrate CO_2 reductions of 5% alone with a cumulative CO_2 reduction of 26% for long range applications. For short/medium range turboprops they achieved a CO_2 reduction of 3% alone and 24% cumulatively. The partners reduced engine noise by 1.3 EPNdB alone and 9 EPNdB cumulatively. The CO_2 improvements come from the 5% higher propulsive efficiency and 1.5% module efficiencies, overcoming the 1.5% increase due to weight and drag. These technologies can be applied to approximately 90% of the commercial aircraft market.

The ESPOSA project partners successfully carried out three test flights with two small aircraft and one helicopter using PBS TP100 and TS100 turboprops respectively. The partners were unable to confirm the cost reductions.

The HYCARUS project partners successfully demonstrated the generic fuel cell system (GFCS) in a cabin environment up to TRL 6. They defined, implemented and validated this system in compliance with aerospace standards and certification requirements. They demonstrated that a fuel cell is a feasible alternative source to power non-propulsive aircraft systems.

The JETSCREEN project partners tested a set of extreme fuels to capture the effects on thermodynamic properties, combustion kinetics, impact of polymer seals and storage stability. These results have been used to validate the fuel sensitivity of models and have been combined into a fuel screening and optimisation platform.

The ITAKA project partners successfully demonstrated that it was feasible to implement the value chain at large scale. The partners used Camelina oil due to the quantities and lack of competition with other crops for land. They built an installation at Oslo airport to directly supply the bio-kerosene mixed with conventional fuel using the existing fuel hydrant system. The fuel was used on 18 long haul and 80 short haul flights with no detrimental effects observed. It was also estimated to reduce CO_2 emissions by 66% and particulate matter by up to 50%.

The partners of the ongoing BIO4A project are engaged in producing and using SAFs at large industrial scale. The project has identified a biorefinery capable of producing Hydrotreated Esters and Fatty Acids, which is a component of SAFs. Moreover, following up on the ITAKA project, Camelina varieties are being cultivated and tested for bio-kerosene production, with an environmental analysis being carried out. Expected GHG savings are around 60 to 70%.

6.3.4 Implications for future research

The LEMCOTEC project partners predict that with improvements to propulsion combined with airframes, a consumption of 1 litre per passenger per 100 kilometres is possible in the long term. The technology did not surpass TRL 5 so more research is needed to use this technology commercially.

The technologies investigated within ENOVAL can now be advanced to a higher TRL with technology demonstrators. The partners expect an entry into service date between 2025 and 2030.

The HYCARUS project partners contributed to a change in public perception and acceptance of hydrogen on board aircraft. They also developed guidelines for hydrogen fuel cell systems on aircraft. These can be utilised to research the project's TRL 6 achievement further and bring this technology to commercial aviation.

The FLHYSAFE (Fuel Cell Hydrogen System for Aircraft Emergency Operation) project is now investigating fuel cell systems to power critical safety systems in aircraft.

The JETSCREEN platform is based on only a few select fuels, international collaboration can help improve the robustness of the tool with more experiments to refine the models.

The ITAKA model of supplying blended aviation fuel directly to an airport has already been adopted by Los Angeles International airport so, as long as supply is available, implementation at airports can progress. Research is required into different supply routes to create bio-kerosene, as using solely Camelina oil for the whole aviation industry could prove difficult. These implications are followed-up by the BIO4A project, where larger scale demonstration of the sustainable fuels is foreseen.

6.3.5 Implications for future policy development

There is a lot of potential from a number projects involved in this technology theme, proposing innovative propulsion systems. Their results suggest reduction to noise, CO_2, NO_x, CO, UHC, SO_x, soot and particulate matter emissions. While there are technology demonstrators and high TRLs, their implementation and use in real world is still limited. Bringing the most promising technologies to use can help reduce emissions and in turn achieve the SRIA emission reduction targets.

Projects have also investigated alternative fuel technologies which can further reduce the emissions from the aviation sector. Some of these technologies focus on fuels to replace kerosene whilst others focus on fuels to power non-essential applications. While SAFs are more mature and already in use, there is still a lot of potential from new alternative fuels which can be brought to use to further decrease emissions in the sector.

As engines become more efficient and less polluting and the use of SAFs becomes the standard, and thus emissions from the use-phase of aircraft are lowered, the impact from their production and end-of-life will become more evident and thus research could see a shift in focus to eco-design methodologies, taking into account the whole life-cycle of aircraft.

6.3.6 Table of reviewed projects

Table 13 provides an overview of the projects undertaken in the propulsion field.

Table 13: Projects included in the review of sub-theme 3

Project acronym	Project name	Project duration	Source of funding
LEMCOTEC	Low Emissions Core-Engine Technologies	2011-2017	FP7-Transport
ENOVAL	Engine Module Validators	2013-2018	FP7-Transport
ESPOSA	Efficient Systems and Propulsion for Small Aircraft	2011-2016	FP7-Transport
HYCARUS	Hydrogen cells for Airborne Usage	2013-2018	FP7-JTI
JETSCREEN	Jet Fuel Screening and Optimization	2017-2020	H2020-3.4
ITAKA	Initiative Towards Sustainable Kerosene for Aviation	2012-2016	FP7-Energy
BIO4A	Advanced Sustainable Biofuels for Aviation	2017-2020	H2020-3.3

Source: TRIMIS.

Box 7. Propulsion projects assessment summary

— Propulsion technologies include electric and hybrid-electric, as well and innovative propulsion technologies such as counter rotating open rotor

— Some projects aim to improve currently used technologies, such as improved engine thermal efficiency and high bypass ratio

— Alternative fuel research projects concentrate on the assessment of benefits, including the full value-chain

— Projects show that more efficient engines can reduce NO_x by 65%, and CO_2 by 20%

— Adoption of alternative fuels can lead to reduction in CO_2 emissions by more than 60% and particulate matter by up to 50%

6.4 Sub-theme 4 - Systems

This sub-theme focuses on the improvement of systems in aircraft including electrical, fuel and construction systems.

6.4.1 Overall direction of R&I

There have been several areas of research investigating different technologies to improve the systems in aircraft. Some of these projects have focused on mechanical actuators used for flight control, door operating, etc. Other projects have investigated robotics in the assembly phase of aircraft. Some have looked at tank storage systems for novel fuels. The projects identified that are investigating systems are funded by H2020, FP7 and Clean Sky.

Projects in this sub-theme emphasise the optimisation of energy consumption of auxiliary systems, as well as replacing hydraulic actuators with more efficient electric drives, and applying improved energy storage and energy management systems. Simulation tools and demonstrators and prototypes are used to prove the concepts.

One focus area has been on improving the reliability and reducing the costs of actuators by making them modular, scalable and standardised. This also has the added benefit of reducing the aircraft weight, resulting in reduced fuel burn. Projects have investigated actuators used in all aspects of the aircraft, including landing gear and thrust reversers.

Another area of investigation has been robotics, including the implementation of human-robotic collaboration. This can help to reduce the assembly time significantly, particularly with heavy structure manoeuvring in small spaces. Projects have also designed new streamlined assembly methods using technologies that save weight and recurring costs.

Accompanying the ongoing research into high-speed aircraft has been research into cryogenic tank technologies to house the propellants – liquid hydrogen and methane – necessary for high-speed (supersonic and hypersonic) flight. These projects have investigated the effects on fuel during in-flight situations such as sloshing and created lightweight tanks to combat these.

6.4.2 R&I activities

A total of 86 projects were assigned to this sub-theme. The great majority was funded by Clean Sky, as shown in Table 14.

Table 14: Sub-theme 4 research by parent programme summary

Parent programme	Number of projects	Total project value (million EUR)	Total EU contribution (million EUR)
FP7	12	43.79	28.96
H2020	7	11.11	10.94
Clean Sky	67	530.09	387.77

Source: TRIMIS.

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the systems field. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

The **ACTUATION2015** (ACTUATION2015: Modular Electro Mechanical Actuators for ACARE 2020 Aircraft and Helicopters, 2011-2016) project partners aimed to develop a set of standardised, scalable electro-mechanical actuators (EMAs) for all types of actuators (high lift, flight control, door, main landing gear, thrust reverser) and all types of aircraft, including regional/business/commercial aeroplanes and helicopters. When used on an Airbus A320, this technology will improve reliability by 30%, reduce life cycle costs by 30% and reduce aircraft weight by 500 kg. The partners aimed to mature EMA technology to TRL 5.

The **CHATT** (Cryogenic Hypersonic Advanced Tank Technologies, 2012-2015) project partners aimed to design, manufacture and test four different cryogenic fuel tanks in CFRP with and without a liner. These will pave the way for future hypersonic aircraft that will use new propellants such as liquid hydrogen and liquid methane. The partners also aimed to screen cryogenic insulation systems and study tank pressurisation, fuel location/retention, nucleation, horizontal sloshing, stratification and boiling subject to surface heat.

The **ACASIAS** (Advanced Concepts for Aero-Structures with Integrated Antennas and Sensors, 2017-2020) is a project which researches innovative systems (antennas, sensors, wiring and acoustic control) which can help reduce drag and facilitate the integration of novel efficient propulsion systems, in particular contra-rotating open rotor (CROR) engines. These engines are capable of fuel and CO_2 savings of 25% but integrating them into the airframe creates significant cabin noise which must be reduced, while antennas create undesirable drag and thus loss of efficiency.

The **EPICEA** (Electromagnetic Platform for Lightweight Integration/Installation of Electrical Systems in Composite Electrical Aircraft, 2016-2019) project partners aimed to develop a computer environment integrating a complete understanding of electromagnetic (EM) problems on composite electric aircraft (i.e. aircraft with combined composite and electric technologies flying at high altitude/latitude). These problems include interconnects, EM coupling and cosmic radiation interference. The partners aimed to increase the TRL from 3 to 4.

The **CALITO** (Cabin Lining Automation, 2017-2020) project partners aimed to redesign cabin and cargo lining parts and their mounting systems to create a basis for automated installation. The partners focused on optimisation for robotics and human-robot collaboration, using the latest materials and manufacturing processes, creating a highly customisable modular solution and self-adjustment solutions to minimise installation effort.

The **EURECA** (Enhanced Human Robot Cooperation in Cabin Assembly Tasks, 2017-2020) project partners aimed to create robotics for human-robotic collaboration to assist in cabin assembly. The partners' target was to develop:

— A lightweight mobile arm (LMA) to assist in the assembly of light components;

— Wearable upper arms exoskeleton to assist in handling and assembling heavy parts;

— A continuous update and adaption of the aircraft cabin map with camera sensors mounted on the LMA;

— A software platform to assist the human-robot cooperation.

6.4.3 Achievements

The ACTUATION2015 project partners successfully developed and validated a set of standardised, scalable and modular EMA modules meeting cost and reliability requirements. The partners designed four standard modules, power drive electronics, mechanics, motors and sensing. Prototypes were manufactured and assessed with test rigs. They also established virtual demonstrators for the main landing gear and nose-wheel steering.

The CHATT project partners successfully manufactured four different demonstrator tanks. These were a large tank using a CFRP shell with a polymer liner, a smaller tank with dry-winding technology, a liner-less tank and a multi-bubble tank for non-circular fuselage cross-sections. The partners discovered that thin-ply laminates can minimise microcracking in cryogenic environments, allowing designs of liner-less ultra-lightweight CFRP tanks. The liner was found to reduce the tank's structural integrity and prove leak paths. The partners also developed high-fidelity simulations to assess the effect of sloshing on aircraft control, aeroelastics and structural sizing. They also tested a ceramic heat-exchanger, increasing knowledge on ceramic materials for cryogenic heat-transfer and revealing critical issues.

The ACASIAS project partners have successfully integrated Ku-band antenna tiles in the fuselage panel for enabling satellite communications (SATCOM) on aircraft, smart layers in the lining panel for the reduction of transmitted noise, very high frequency (VHF) communication antenna in winglet and antennas in fibre metal laminate (FML) fuselage panel and with further testing are expected to mature these technologies from TRL 2 to TRL 4-5.

The EIPCEA project partners successfully created a modelling platform integrating EM coupling modules, computer modules and related modelling scenarios. They also manufactured low profile antennas integrated into composite structures. The partners carried out laboratory and flight tests to assess the cosmic radiation effects on electronics with a frequency band large enough to cover lightning and high intensity radiated fields.

The CALITO project partners successfully created a simplified installation process consisting of three components: a rail on the floor, a self-adjusting mounting system on the window and an light-emitting diode (LED) cover under the hat rack. It uses a bracket-less design that – when combined with the self-adjusting interface – is five times faster to install compared to conventional processes. The lining also weighs 20% less as it is made of high-performance foam, resulting in lower fuel consumption and less pollution.

The EURECA project partners successfully created prototype robotics, one capable of light lifting and the other heavy lifting. They address the problems of limited manoeuvring space and weight allowed on the cabin floor whilst reducing lead time and recurring costs. The robotics rely only on self-mounted sensors, so they can be used in plants with no modification or retrofitting required.

6.4.4 Implications for future research

The ACTUATION2015 project partners highlighted the need for additional testing to complete the full range of expectations, mainly the dynamic performances and qualitative evaluation of the cost, performance, integration and reliability targets. The virtual demonstrators can also be made into real life demonstrators.

The CHATT project has shown that further research into thin-ply laminate tank structures would prove very beneficial in making future tanks ultra-lightweight. Their work on ceramic heat-exchangers can also be expanded upon to overcome the critical issues.

The EURECA project has successfully shown the use of robotics in space and weight limited environments; this technology can be utilised in areas in which the assembly of bulky and heavy objects is currently done manually, such as building trains and tracks. Research into other use cases could be create significant benefits.

6.4.5 Implications for future policy development

While aircraft systems and equipments account for a lower emission footprint, reducing their weight and efficiency can still lead moderate reductions in emissions. Moreover, as aircraft become more efficient through the use of improved aerodynamics, lightweight structures and better engines, aircraft systems should also be improved to keep emissions low.

6.4.6 Table of reviewed projects

Table 15 provides an overview of the projects undertaken in the systems field.

Table 15: Projects included in the review of sub-theme 4

Project acronym	Project name	Project duration	Source of funding
ACTUATION2015	Actuation 2015: Modular Electro Mechanical Actuators for ACARE 2020 Aircraft and Helicopters	2011-2016	FP7-Transport
CHATT	Cryogenic Hypersonic Advanced Tank Technologies	2012-2015	FP7-Transport
ACASIAS	Advanced Concepts for Aero-Structures with Integrated Antennas and Sensors	2017-2020	H2020-3.4
EPICEA	Electromagnetic Platform for lightweight Integration/Installation of electrical systems in Composite Electrical Aircraft	2016-2019	H2020-3.4
CALITO	Cabin Lining Automation	2017-2020	H2020-3.4.5.1
EURECA	Enhanced Human Robot cooperation in Cabin Assembly tasks	2017-2020	H2020-3.4.5.1

Source: TRIMIS.

Box 8. Systems projects assessment summary

— Projects researching systems focus on optimal architectures and energy consumption for auxiliary systems

— Technologies include efficient electric drives, improved energy management systems and sensors

— Emissions can be reduced by reducing the aircraft weight, while improved systems are essential to support new propulsion technologies

6.5 Sub-theme 5 - Operations

This sub-theme focuses on optimising operational activities in aviation, including ATM and flight trajectory planning.

6.5.1 Overall direction of R&I

Several areas of research have emerged as focal points during the development of operational systems in aviation. These have ranged from improvements to ATM systems to efficient planning of flight trajectories. Some research has also focused on improving the maintenance operations in the aviation industry. The projects that have been identified as investigating operations are funded by SESAR, H2020, FP7 and Clean Sky.

One area of research has been on improving the ATM systems with a focus on dynamic air configurations, aimed at accommodating an increasing air traffic diversity. Other projects have focused on increasing the range of communications to adjust flight paths earlier and reduce the carbon and noise emissions of aircraft circling runways awaiting a landing time.

Another area of focus has been on free routing, allowing airspace users to fly as close as possible to their preferred trajectory (usually the great circle trajectory between the departure and destination airports). This involved using real-time simulations in highly complex environments as well as adjusting altitudes to find the most efficient routes (e.g. with tailwinds), whilst maintaining safety and capacity.

Projects have also investigated virtual maintenance platforms to create a portal for accessing expert advice in short timeframes. This can greatly reduce the maintenance, repair and overhaul times associated with aircraft which carry significant costs.

6.5.2 R&I activities

A total of 64 projects were assigned to this sub-theme; the greatest project values come from SESAR, as shown in Table 16.

Table 16: Sub-theme 5 research by parent programme summary

Parent programme	Number of projects	Total project value (million EUR)	Total EU contribution (million EUR)
FP7	11	30.09	21.37
H2020	15	60.07	32.24
Clean Sky	22	12.51	10.01
SESAR	16	76.01	42.76

Source: TRIMIS.

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the operations field. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

The **PJ08 AAM** (Advanced Airspace Management, 2016-2019) project partners aimed to address the issue of increasing air traffic diversity. The partners focused on dynamic airspace configurations (DACs) and dynamic mobile areas (DMAs) to provide flexible solutions capable of adapting dynamically to traffic demand. The partners aimed to validate the feasibility of DACs/DMAs and assess their potential impact.

The **PJ06 ToBeFREE** (Trajectory Based Free Routing, 2016-2019) project partners explored the concept of free routing enabling airspace users to fly as close as possible to their preferred trajectory, without being diverted due to fixed airspace structures or fixed route networks. The partners aimed to validate the benefits to airspace users and impact on ATM of free airspace routing into complex airspace and lower vertical limits, using modelling and real-time simulations.

The **INTERACTION** (Innovative Technologies and Researches for a New Airport Concept Towards Turnaround Coordination, 2013-2016) project partners aimed to produce a fully integrated and coordinated system of passenger, baggage, freight and ramp operations to reduce turnaround time and improve customer experience.

The **PJ25 XSTREAM** (Cross Border SESAR Trials for Enhanced Arrival Management, 2017-2019) project partners aimed to reduce airborne delays near the destination airport by extending trajectories or slowing down aircraft in flight. These help to reduce the carbon and noise emissions in the vicinity of airports that come from aircraft circling because of landing delays due to runway capacity. The partners aimed to test these systems on aircraft arriving at Paris Charles de Gaulle and Orly, London Heathrow and Gatwick, and Zurich airports.

The **WISE** (A Novel Approach to Remote and Real-Time Aircraft Maintenance, 2017-2019) project partners aimed to create a platform to connect any airport or maintenance, repair and overhaul (MRO) to a remote maintenance expert. They aim to provide this assistance with training and equipment leasing services in a single offer to MRO organisations.

The **ATM4E** (Air Traffic Management for Environment, 2016-2018) project partners aimed to expand on the research carried out in REACT4C to include an assessment covering climate, air quality and noise. The partners aimed to create a new metric for environmental assessment and use this to plan flight trajectories mitigating environmental impact and finally a roadmap to implement these strategies.

6.5.3 Achievements

The PJ08 AAM project partners demonstrated the workability of the DAC concept and tools from the perspective of air traffic controllers. They were able to use AI techniques to define new DACs and confirmed the feasibility in a free-route environment at a regional and local level. The DMAs were not addressed.

The PJ06 ToBeFREE project partners validated concepts enabling airspace users to plan free flight paths in highly complex environments supporting the implementation of European Regulation IR No 716/2014 (Pilot Common Project supporting the implementation of the European Air Traffic Management Master Plan). The partners also investigated the impact of expanding the free routing concept to the lowest altitude possible while accommodating airspace users concerns. The project confirmed that these bring significant benefits to airspace users with no negative impacts on safety and capacity.

The INTERACTION project partners characterised the relationship between airport turnaround processes. This enabled the partners to analyse the different processes in the same system to identify and predict the impact of disruptions in one area on the overall turnaround process. From this they were able to develop 20 solutions for each airport process, grouped into three categories: advanced procedures and new operational concepts; innovative technologies and techniques; and enhanced information management and decision-support tools. The partners also carried out a cost benefit analysis to identify the most promising improvements.

The PJ25 XSTREAM project partners successfully extended the arrival management systems (AMANs) between 200 and 350 nautical miles to adjust for delays earlier in the flight and at higher altitudes, which is more fuel efficient. The operational benefits included fuel saving in the arrival phase of up to 30 kg per flight, with 90 kg reductions in CO_2 per flight. The technology also reduces congestion and complexity in the terminal control area (TMA) and reduced air traffic flow and capacity management (ATFCM) constraints by 5%.

The WISE project partners validated the prototype system integrated with communication, maintenance features and certified tools. They performed tests to assess the usability of the system and created a WISE database that provides predictive insights of maintenance use cases.

The ATM4E project partners successfully developed an algorithm-based environmental change function and used it to optimise flight trajectories to minimise environmental impacts in a test run on 18 December 2015.

The partners have evaluated the routes with daily route analysis to verify the climate effects of the optimised routes.

6.5.4 Implications for future research

The PJ08 AAM project partners did not successfully investigate DMA concepts so further research in this area would be required to advance the technology. An initial feasibility study could decide if any further research is required.

The PJ06 ToBeFREE project partners successfully demonstrated concepts which can now be applied to real-world tests to verify the potential economic and environmental benefits of more efficient flight trajectories.

The ATM4E project partners have made progress towards a multi-dimensional environmental assessment framework, more research could improve this framework and would enable comprehensive analysis of the environmental performance of aircraft operations and trajectories.

6.5.5 Implications for future policy development

A significant number of these projects looked at improving the efficiency of ATM systems, leading to fewer delays and fewer aircraft taking inefficient flight trajectories. These will help reduce the carbon footprint of both old and new aircraft so can have significant immediate benefits if successfully implemented.

The increased efficiency of ATM operations will help achieve the 10% CO_2 reduction in this area set out by SRIA, whilst the innovative on-the-fly route planning will help achieve the 50% CO_2 reduction from aircraft fuel burn.

6.5.6 Table of reviewed projects

Table 17 provides an overview of the projects undertaken in the operations field.

Table 17: Projects included in the review of sub-theme 5

Project acronym	Project name	Project duration	Source of funding
PJ08 AAM	Advanced Airspace Management	2016-2019	SESAR
PJ06 ToBeFREE	Trajectory based Free Routing	2016-2019	SESAR
INTERACTION	Innovative Technologies and Researches for a new Airport Concept towards Turnaround Coordination	2013-2016	FP7-Transport
PJ25 XSTREAM	Cross Border SESAR Trials for Enhanced Arrival Management	2017-2019	SESAR
WISE	A novel approach to remote and real-time aircraft maintenance	2017-2019	H2020-3.4/2.1.1/2.3.1
ATM4E	Air Traffic Management for environment	2016-2018	SESAR

Source: TRIMIS.

Box 9. Operations projects assessment summary

— Projects researching operations focus on optimal trajectory and planning, reducing emissions by adjusting flight paths

— Assessment of the emission impact of trajectory planning is also an important topic

— Reduction in emissions can be achieved by lower time circling airports, as well as reduction in the fuel weights per flight

6.6 Sub-theme 6 – Eco-design

This sub-theme focuses on technologies to reduce the environmental impact of aircraft, particularly the construction and end-of-life phases.

6.6.1 Overall direction of R&I

Several areas of research have emerged from the advances in technologies related to the eco-design of aircraft. These include methods to improve the resource efficiency when manufacturing aircraft as well as the design of innovative materials for the aircraft structures to reduce weight and lifetime emissions. The projects identified that are investigating structures are funded by H2020, FP7 and Clean Sky.

One of the areas of focus has been increasing the resource efficiency using additive layer manufacturing (ALM). Projects have investigated automated ALM processes to manufacture lightweight and efficient structures with a reduced carbon footprint.

Another area of focus has been on novel materials with accompanying production processes to reduce the carbon footprint during the manufacturing process. The materials are often lighter in weight than conventional counterparts so help to reduce fuel burn and therefore emissions throughout the life of the structure.

Other projects have expanded research on life cycle assessments to include the environmental effects beyond aircraft operation alone. Ranging from the initial acquisition of raw materials to their end of life recycling.

6.6.2 R&I activities

A total of 35 projects were assigned to this sub-theme, with the majority of funding being from Clean Sky as shown in Table 18.

Table 18: Sub-theme 6 research by parent programme summary

Parent programme	Number of projects	Total project value (million EUR)	Total EU contribution (million EUR)
FP7	2	12.62	8.89
H2020	3	13.75	12.20
Clean Sky	30	24.00	19.37

Source: TRIMIS.

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the eco-design field. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

The Bionic Aircraft (Increasing Resource Efficiency of Aviation Through Implementation of ALM Technology and Bionic Design in All Stages of an Aircraft Life Cycle, 2016-2019) project partners aimed to investigate ALM which can be used to manufacture 'bionically' optimised lightweight structures in a resource efficient way. Key developments planned include:

— Automated ALM design process to reduce time and costs for bionic lightweight design;

— Energy efficient and productive ALM process to lower costs and emissions during manufacture;

— High strength ALM materials to increase lightweight potential;

— NDT and repair methods;

— Recycling method for ALM parts.

The **MMTech** (New Aerospace Advanced Cost Effective Materials and Rapid Manufacturing Technologies, 2015-2019) project partners aimed to investigate the use of the γ-TiAl alloy, a strong, stiff and lightweight material that could lead to weight savings of 50% compared to common Ni based alloys. The partners aimed to reduce the production costs, time and raw materials used in γ-TiAl alloys to encourage their use in industrial application. To achieve this aimed to address the:

— Production of powders with stable physical properties

— Reduction of rapid manufacturing costs

— Improvement of machining processes

— Development of multi-scale models of the manufacturing process chain

— Integration of MMTech systems in real, industrial components

The **NHYTE** (New Hybrid Thermoplastic Composite Aerostructures Manufactured by Out of Autoclave Continuous Automated Technologies, 2017-2020) project partners aimed to demonstrate concepts of hybrid thermoplastic matrix composite material with multifunctional capabilities. The material is based on PEEK-Carbon Fibre Prepreg with the addition of amorphous polyetherimide (PEI) films. This material will have reduced weight as well as reduced manufacturing and operational costs. The partners set a target weight saving of no less than 5% for primary structures.

The **ENDAMI** (Environmental Data Models and Interface development in Aviation, 2011-2014) project aimed to improve and take forward the adoption of life cycle analysis (LCA) and life cycle inventory (LCI) methods in aviation. Objectives included the creation of environmental data models with the purpose of assessing environmental impacts of production, maintenance and end-of-life, while also developing a methodological framework for future LCA studies in the aviation sector.

The **FastCan** (Light Weight, Impact Resistant, Canopy for Fast Compound Rotorcraft, 2017-2020) project partners are aiming to develop an innovative canopy structure with a total weight of less than 60 kg, whilst meeting requirements of structural demands, pilot view capabilities and aerodynamic drag.

The **MISSP** (Manufacturing of Integral Stiffened Skin Panels, 2017-2020) project partners aimed to develop cheaper and greener structures as an alternative to CFRP doors that could also be applied for any stiffened skin panel structure. To achieve this the partners aimed to replace expensive and polluting chemical milling processes with flat mechanical machining as well as multi-part riveted components with integrated structures.

6.6.3 Achievements

The Bionic Aircraft project partners successfully simplified and automated the design process for biomimetic lightweight structures (i.e. ones that mimic biomechanical systems), producing a toolset for 3D computer-aided design (CAD) software. The share of powder usable for the ALM process increased from 63% to 74%. The partners demonstrated a productivity increase of 35% for new high strength AlSiSc material using novel beam shaping optics.

They also developed an in-line integrity system to check the quality of the ALM parts after manufacture, checking below the surface and outer geometry simultaneously, and an ultrasonic NDT system for checks during manufacture. Thermal spraying was found to be the most resource efficient and cost competitive repair strategy. The project partners were able to achieve a weight saving of 27.5% with their bionic aircraft demonstrators, leading to a potential 625 kg saving per aircraft. The partners have already developed business plans to transfer this technology for industrial application.

The MMTech project partners developed low-cost γ-Ti powders for the additive manufacturing process but discovered these led to increased porosity and cracks on the blown powder machine. They then designed a new machine architecture to reliably deposit the new material. The partners used active and passive damping to improve the machining process and integrated multi-scale models of the process chain. The technologies were tested in three case studies, each found to reduce component weight by 45%. Part cost was reduced by 45% and production time by 10% for the aerospace blade and 80% and 64% for the laser-cut automotive exhaust flanges.

The NHYTE project partners created a highly automated, greener and more cost-effective manufacturing process of complex thermoplastic aerostructures. They utilised a continuous press method and induction welding technology. The partners performed life cycle assessments regarding the cost, quality and environmental impact of the processes developed in NHYTE. They successfully manufactured a novel hybrid thermoplastic material.

The ENDAMI project developed a scaling-up methodology for LCA, where missing data related to components can be extrapolated by scaling-up data from reference components. Such a methodology allows for estimating environmental impact of aircraft production without having complete data availability. A web tool for LCA was also developed, which aims to enable non-expert users to assess different design options and their impact on the environment.

The FastCan project partners developed the canopy design and manufacturing concept, completing component tests for the material properties. They have passed the critical design review and closed all major actions until the end of the reporting period.

The MISSP project partners carried out numerical modelling to calculate residual stresses and geometrical form of the prototype after creep-forming and simulated high energy hydroforming (HEHF) and creep age relaxation tests. Surface stress measurements were taken on small scale models which were manufactured with three different HEHF production methods. Machining pattern trials were also performed on these models to highlight geometrical defects. Forming and machine tools were designed and manufactured for the small-scale model as well as the forming die for the full-scale model.

6.6.4 Implications for future research

The ENDAMI project contributed to the improvement of the Aviation Environmental Database (AED), enhancing the datasets and carrying out consistency checks. The tool developed by the project partners can also be further used with aggregated data.

Work conducted in the MISSP project can now be extended to full-scale models for further research and feasibility assessments.

Overall, research projects have worked with the goals of improving manufacturing methodologies, as well as implementing LCA methodologies and bringing the mindset to the aviation industry.

6.6.5 Implications for future policy development

These projects all focused on reducing the environmental footprint on different areas on aviation, ranging from using more environmentally friendly materials to more efficient production methods. Often these projects would also aim to reduce the weight of structures, improving the fuel efficiency during aircraft use. These technologies will become even more important as use-phase emissions of aircraft are reduced.

6.6.6 Table of reviewed projects

Table 19 provides an overview of the projects undertaken in the eco-design field.

Table 19: Projects included in the review of sub-theme 6

Project acronym	Project name	Project duration	Source of funding
Bionic Aircraft	Increasing resource efficiency of aviation through implementation of ALM technology and bionic design in all stages of an aircraft life cycle	2016-2019	H2020-3.4
MMTech	New aerospace advanced cost effective materials and rapid manufacturing technologies	2015-2019	H2020-3.4
NHYTE	New Hybrid Thermoplastic Composite Aerostructures manufactured by Out of Autoclave Continuous Automated Technologies	2017-2020	H2020-3.4
ENDAMI	Environmental Data Models and Interface development in Aviation	2011-2014	Clean Sky
FastCan	Light weight, impact resistant, canopy for fast compound rotorcraft	2017-2020	H2020-3.4.5.3
MISSP	Manufacturing of Integral Stiffened Skin Panels	2017-2020	H2020-3.4.5.4

Source: TRIMIS.

Box 10. Eco-design projects assessment summary

— Eco-design projects focus on the production aspects, novel materials and life cycle analysis (LCA)

— The creation of models and a database for the assessment of life cycles is important

— Reduction in emissions come from the use of more environmental friendly materials and improved manufacturing methodologies

6.7 Sub-theme 7 - Rotorcraft

This sub-theme focuses on improving the performance and efficiency of rotorcraft.

6.7.1 Overall direction of R&I

Several areas of research have emerged that focus on rotorcraft, in the form of technologies that aim to reduce emissions along with technologies to improve the service life of rotorcraft. Projects have also investigated low maintenance systems and sensors to alert aircraft users, who can then make in-flight adjustments. The projects identified that are investigating rotorcraft are funded by H2020, FP7 and Clean Sky.

One area of focus has been on improving the efficiency of engines used for rotorcraft, such as creating a high compression piston engine to reduce greenhouse gas and noise emissions. These technologies have the added benefit of simultaneously increasing the range of rotorcraft opening up novel trajectories. Other projects have examined morphing technologies to continuously keep the aerodynamic efficiency of rotorcraft at its maximum.

Another area of focus has been on sensors with an accompanying human-machine interface, warning aircraft users of noise pollution levels so they can immediately make adjustments to reduce their noise footprint.

Other projects have looked at replacing shaft and gearbox systems with electric drives which require less maintenance and have a higher service life. They can also improve the fuel efficiency of rotorcraft.

6.7.2 R&I activities

A total of 52 projects were assigned to this sub-theme, with the majority of funding provided by Clean Sky, as shown in Table 20.

Table 20: Sub-theme 7 research by parent programme summary

Parent programme	Number of projects	Total project value (million EUR)	Total EU contribution (million EUR)
FP7	12	100.07	63.63
H2020	3	6.18	6.13
Clean Sky	37	294.78	143.93

Source: TRIMIS.

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the rotorcraft field. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

The HIPE AE 440 (Diesel Powerpack for a Light Helicopter Demonstrator, 2011-2015) project partners aimed to create a high compression piston engine for rotorcraft with a high energy efficiency to reduce greenhouse gas and noise emissions. The partners aimed to align their goals with the Clean Sky targets of reductions in specific fuel consumption of 30%; CO_2 emissions by 40%; and NO_x by 53%.

The SABRE (Shape Adaptive Blades for Rotorcraft Efficiency, 2017-2021) project partners aim to develop helicopter blades with morphing technologies to reduce fuel burn, CO_2 and NO_x emissions by 5% to 10%, along with reductions in noise. They aim to mature concepts with modelling, design and experimental testing.

The 9eGEN (9eGEN - Development of Innovative Lightweight HVDC 9-phase Brushless/Generator for Clean Sky Rotorcraft, 2016-2020) project partners aim to develop a high voltage direct current high voltage direct current (HVDC) brushless/generator up to TRL 6.

The ELETAD (Electrical Tail Drive - Modelling, Simulation and Rig Prototype Development, 2010-2016) project partners aimed to investigate the feasibility of powering the tail rotor of a helicopter with an electric drive, replacing the current system of shafts and gearboxes. This would allow for reduced reliance on hydraulic and oil systems, low maintenance, high service life and improved fuel efficiency.

The FRCDoorDemonstrator (Flightworthy Flush Lightweight doors for unpressurized Fast Rotorcraft, 2015-2020) project partners aim to demonstrate that compound rotorcraft configurations open up new mobility roles unachievable with conventional helicopters and fixed wing aircraft. They aim to develop concepts up to TRL 6 demonstrators for four types of fast rotorcraft (FRC) project doors.

The MANOEUVRES (Manoeuvring Noise Evaluation Using Validated Rotor State Estimation Systems, 2013-2016) project partners aimed to demonstrate noise reduction in rotorcraft based on in-flight rotor measurements. The partners planned to use a sensor system combined with a human-machine interface to raise awareness of noise levels to the pilot who can adjust to reduce noise levels on the fly.

6.7.3 Achievements

The HIPE AE 440 project partners successfully integrated the high compression engine into a demonstrator helicopter and performed a test flight. They demonstrated a fuel consumption 40% less than a conventional turbine engine, resulting in significantly less noise and exhaust emissions whilst nearly doubling the range of the helicopter.

The SABRE project partners have created sophisticated analysis tools to fully explore the design space of morphing rotors, expanding the depth of the original targets to include aspects of rotor vibrations and acoustic emissions. These analysis tools have shown surrogate models of morphing concepts have CO_2 and NO_x reductions of 5% to 10%. The project partners have created a number of experimental demonstrators and are working on the design and delivery of the final wind tunnel and whirl tower demonstrators.

The 9eGEN project partners have developed a HVDC along with a generator control unit (GCU) to regulate the power output. The partners have addressed some issues found during the sub-assembly phase and now have a first working prototype ready to be implemented for testing.

The ELETAD project partners successfully developed a prototype electric tail rotor (ETR) with ultra-high efficiency permanent magnet rotors particularly matched to heavy-duty cycle operation. They also created a software suite with modelling tools to describe the thermal and electromagnetic behaviour of fault-tolerant electrical systems. This software suite can be utilised in electrical machine design for high-torque wheel motors and aircraft drive systems.

The FRCDoorDemonstrator project partners have designed four door systems using concept studies, sizing loops and feasibility studies with a focus on weight saving and geometry optimisation.

The MANOEUVRES project partners successfully created an on-board sensor system and accompanying graphical display (pilot acoustic indicator) of the noise signal to the pilot. These have been integrated and tested on a ground test vehicle, demonstrating a level of maturity up to TRL 6.

6.7.4 Implications for future research

The ELETAD project partners gained experience and knowledge that is highly relevant to future electric propulsion of fixed wing aircraft and other safety critical areas where electric drives could be used. The adoption of an ETR would require significant improvements to electrical generation capacity. With the intermittent power peaks of the ETR the excess capacity could be used to power other electrical equipment such as actuators and de-icing systems. Holistically using electrical systems for efficient power management could prove to be a disruptive technology.

The MANOEUVRES project partners created a demonstrator prototype of their noise sensor system, further research into certifying this technology would allow for its intended application on production helicopters.

6.7.5 Implications for future policy development

The projects investigating rotorcraft technology have produced some solutions that offer significant fuel consumption reductions, resulting in lower CO_2 and NO_x emissions. These will help the aviation sector achieve the SRIA target of 50% reduction in CO_2 emissions from fuel burn.

A number of projects have also achieved reductions in noise emissions, either through more efficient systems that do not need to work as fast or sensors that alert the rotorcraft user of noise levels so they can make immediate adjustments. With advancements in noise reduction future policy could include mandated maximum noise levels from rotorcraft.

6.7.6 Table of reviewed projects

Table 21 provides an overview of the projects undertaken in the rotorcraft field.

Table 21: Projects included in the review of sub-theme 7

Project acronym	Project name	Project duration	Source of funding
HIPE AE 440	Diesel Powerpack for a Light Helicopter Demonstrator	2011-2015	Clean Sky
SABRE	Shape Adaptive Blades for Rotorcraft Efficiency	2017-2021	H2020-3.4
9eGEN	9eGEN - Development of innovative lightweight HVDC 9-phase Brushless/Generator for Clean Sky Rotorcraft	2016-2020	H2020-3.4.5.3
ELETAD	Electrical Tail Drive - Modelling, Simulation and Rig Prototype Development	2010-2016	Clean Sky
FRCDoor Demonstrator	Flightworthy Flush Lightweight doors for unpressurized Fast Rotorcraft	2015-2020	H2020-3.4.5.4
MANOEUVRES	Manoeuvring Noise Evaluation Using Validated Rotor State Estimation Systems	2013-2016	Clean Sky

Source: TRIMIS.

Box 11. Rotorcraft projects assessment summary

— Projects in the rotorcraft sub-theme aim to reduce emissions and noise by improving engines and blades, as well as using lightweigh structures

— Improvements in engines can lead to reductions in fuel burn (30 %), CO_2 (40%) and NO_x (50%)

— Innovative blades can lead to CO_2 and NO_x emissions reductions of up to 10%

7 Publications, patents and technologies insights

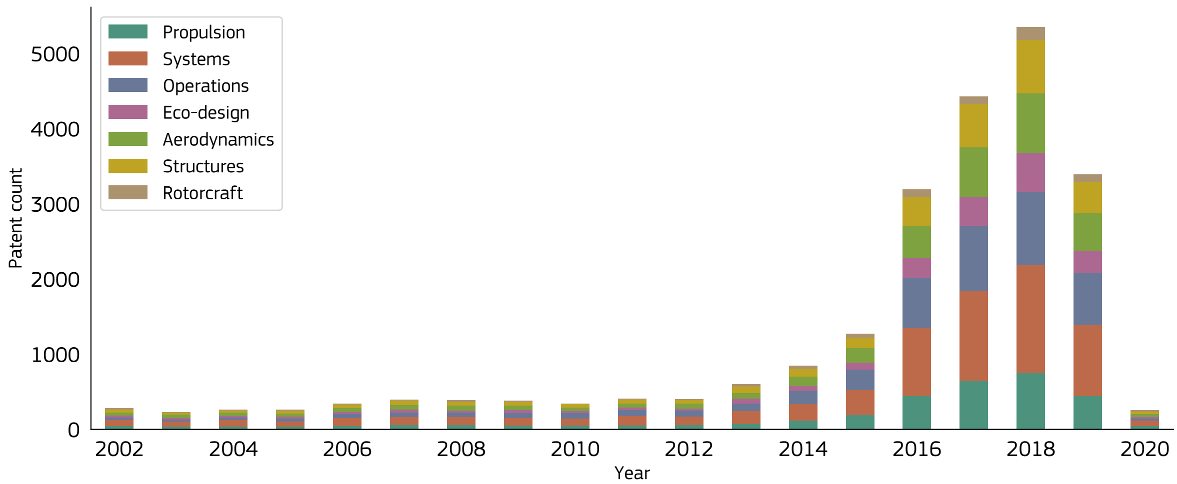
This chapter provides an overview of developed technologies related to aviation emissions reduction, as well as efforts beyond EU funded projects. For this purpose, analyses related to scientific publications and patents will be presented, followed by an assessment of technologies extracted from aviation projects focused on emissions reduction.

7.1 Patents

Patent analysis aims to provide additional insight into research outputs related to technological topics, which go beyond publicly funded research. This assessment focuses on the analysis of international patent applications related to the aviation transport research topics and sub-topics. For this purpose, Worldwide Patent Statistical Database (PATSTAT) was used, and a search using Cooperative Patent Classification (CPC) codes, patent title and abstract was carried out.

For this exercise, the search was restricted to the *B64 - AIRCRAFT; AVIATION; COSMONAUTICS* and *G08 - SIGNALLING* CPC codes, which comprise both aircraft design and air traffic patents. The search period was from 2002 to 2020 and the patents were restricted to emissions reduction topics, using the keywords presented in Annex 8.5. Similarly, for the sub-theme grouping for the patents, the keywords defined in the Annex were used. Figure 20 provides an overview of the granted patents per sub-theme based on application year.

Figure 20: Granted patent applications by year and sub-theme



Source: TRIMIS based on PATSTAT.

There has been a great rise in the number of patents since 2012, with the majority belonging to *systems*, *operations* and *propulsion*. The share of *eco-design* patents, although comparatively small, has been increasing since 2016. Moreover, *rotorcraft* patents are the least present, which can be explained by the way patents are usually described, in which they cover multiple areas, and thus specific rotorcraft patents are a minority. Finally, due to the lag between patent filing and grants, the most recent numbers are expected to increase.

7.2 Publications

The following exercise has as objective to mark the evolution of peer reviewed scientific publications in the area of air transport in the last years, focusing on decarbonisation, and providing also a perspective beyond Europe. For the exercise, the Scopus[24] citation database for scientific research has been used. The analysis was performed in April 2021 and is limited to journal and conference publications in the period of 2010 to 2019. These analyses focus on regular expressions (REGEX), representative of the sub-themes defined in air transport research relate to emissions reduction[25].

The complete list of REGEX used is reported in Annex 8.5, while Table 22 provides the connection between the sub-themes defined in this report and some of the keywords used in the query.

[24] www.scopus.com

[25] Regular expressions are intended to be representative of each sub-theme but not necessarily exhaustive.

Table 22: Aviation emissions reduction sub-themes and scientific research terms

Sub-theme	Text
Aerodynamics	aerodynamic, morphing, laminar, flutter, flaps, swirl, CFD, drag, Mach, aeroelastic
Structures	airframe, fuselage, thermoplastic, adhesive, composites, laminate, polymer, wing box, welding, lightweight
Propulsion	engine, propulsion, motor, cylinder, exjet, turbofan, propeller, inlet, nacelle, aero engine, combustion, electric aircraft
Systems	landing gear, electric power system, eps, power electronics, brakes, antenna, avionics, HVDC, cockpit, energy management
Operations	airport, delay, schedule, interline, crew, airline, trajectory, air traffic
Eco-design	LCA, LCC, life cycle, recycling, EOL
Rotorcraft	rotorcraft, tiltrotor, tilt rotor, compound rotorcraft, fast rotorcraft, helicopter blade, rotary wing, vertical take-off, VTOL

Source: TRIMIS.

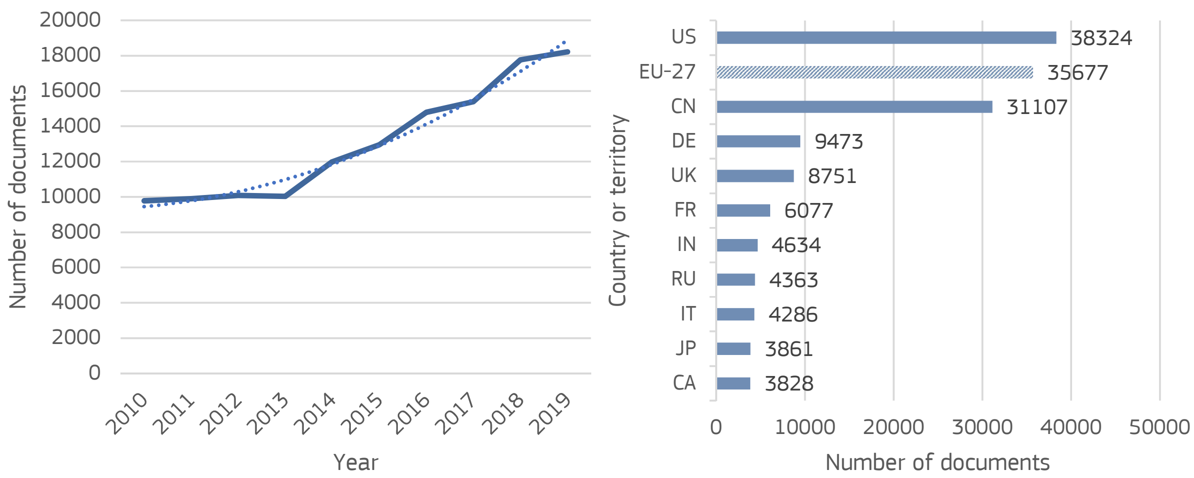
The following figures provide the results focusing on number of documents per year and their country of origin. A second order polynomial trend line has been added to the number of documents per year to highlight the trend. In the country of origin figures, the documents that come from the EU 27 countries are aggregated in a single bar.

Figure 21 sets the baseline for what regards scientific production in the field. As can be seen, the number of documents increased in 10 years by a factor of 1.85 (from 9 777 in 2010 to 18 215 in 2019). The US is leading the research, followed by China (CN), Germany the UK, France, India (IN), the Russian Federation (RU), Italy, Japan (JP) and Canada (CA).

Figure 22 shows the top 10 research affiliations. The Beihang University leads, followed by the Northwestern Polytechnical University and the Nanjing University of Aeronautics and Astronautics. Deutsche Zentrum für Luft- und Raumfahrt (DLR) is the only European research institute (fourth in the list).

Finally, Figure 23 shows the top 10 funding sponsors. The National Natural Science Foundation of China leads by a great margin, followed by NASA and the EC.

Figure 21: Research documents 2010-2019 (left) and top 10 countries (right) on air transport research

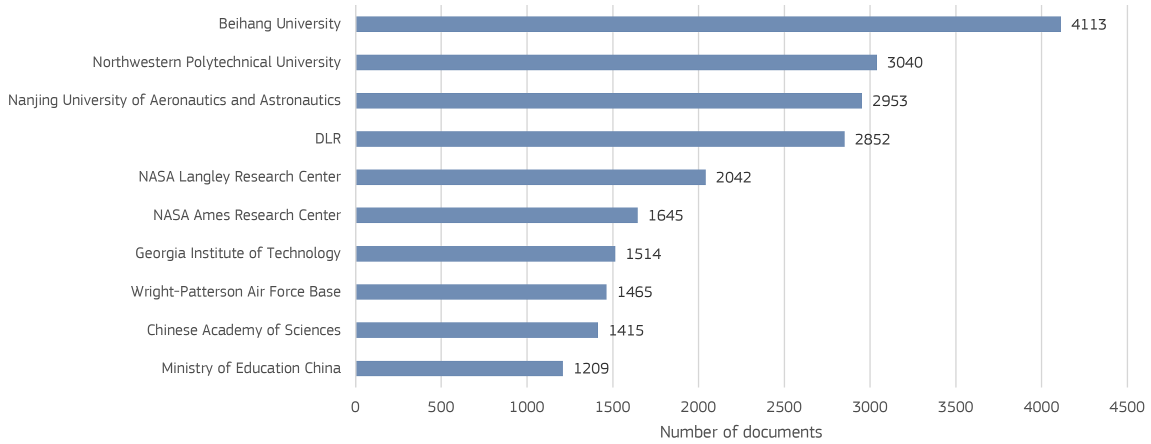


Source: TRIMIS elaborations based on Scopus.

On the *aerodynamics* sub-theme, as Figure 24 presents, the publication trend is positive, evolving from 1580 documents in 2010 to 3229 documents in 2019. The US is leading in terms of research outputs, while Germany and France are among the top 5 countries.

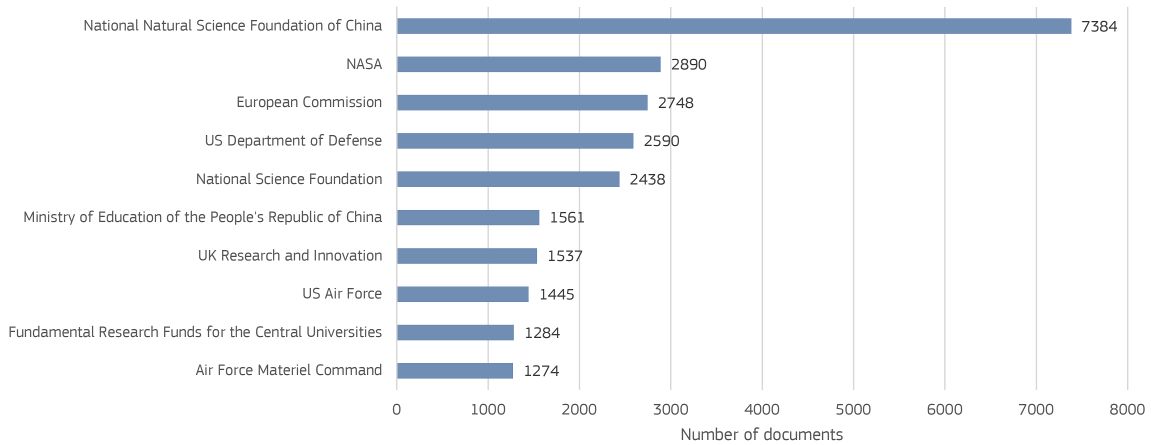
The *structures* sub-theme, as can be seen in Figure 25, identifies a positive trend, passing from around 1206 documents in 2010 to 2019 documents in 2019. Also, in this case, US is leading in terms of research outputs, with China and Germany following.

Figure 22: Top 10 affiliations of air transport research



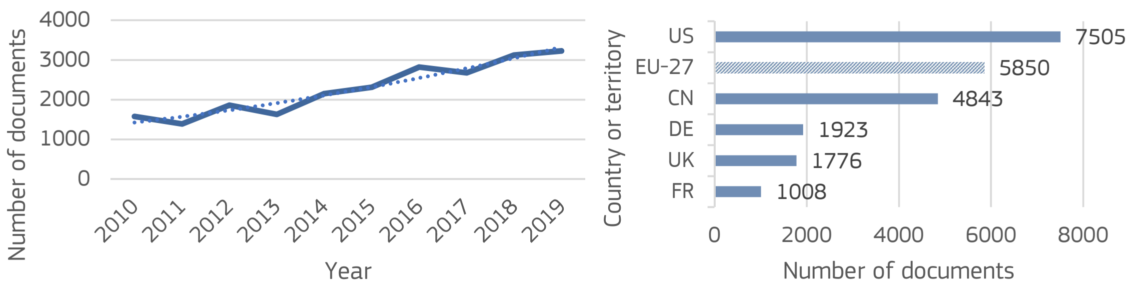
Source: TRIMIS elaborations based on Scopus.

Figure 23: Top 10 funding sponsors of air transport research



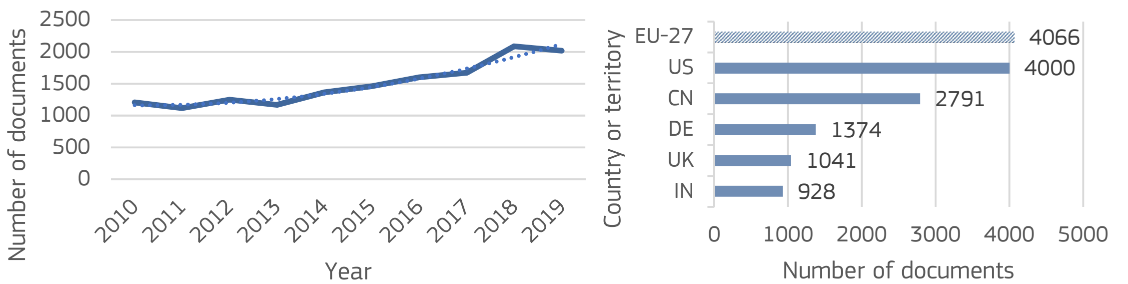
Source: TRIMIS elaborations based on Scopus.

Figure 24: Research documents 2010-2019 (left) and top 5 countries (right) on aerodynamics



Source: TRIMIS.

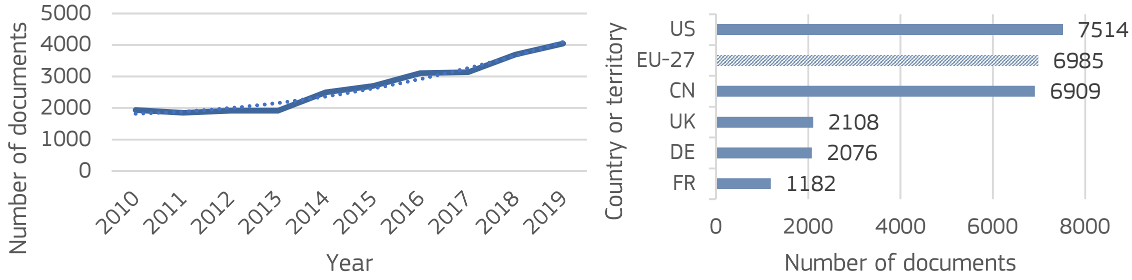
Figure 25: Research documents 2010-2019 (left) and top 5 countries (right) on structures



Source: TRIMIS.

On the *propulsion* sub-theme, in Figure 26, the trend is positive evolving from a low of 628 documents in 2011 to 999 documents in 2019. The US appears with the highest number of publications, followed by China. Germany and France are the two EU 27 countries in the top 5.

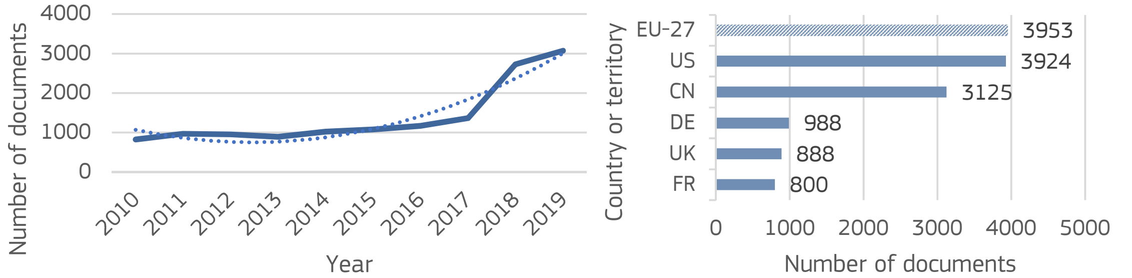
Figure 26: Research documents 2010-2019 (left) and top 5 countries (right) on propulsion



Source: TRIMIS.

When looking at the *systems* sub-theme, shown in Figure 27, a positive trend can be observed: from 824 documents in 2010 to 3072 documents in 2019. Also in this case, the majority of publications comes from: the US, followed by China. Germany and France are the two EU 27 countries present in the top 5.

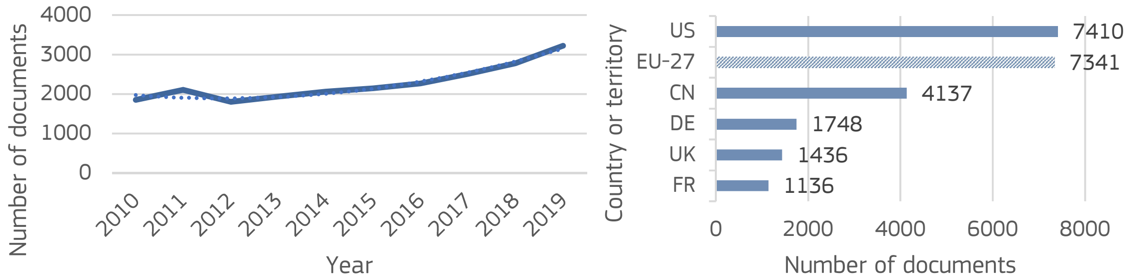
Figure 27: Research documents 2010-2019 (left) and top 5 countries (right) on systems



Source: TRIMIS.

The *operations* sub-theme, as can be seen in Figure 28, identifies a positive trend, passing from 1851 documents in 2010 to 3223 documents in 2019. Also, in this case, US is leading in terms of research outputs, with China and Germany following.

Figure 28: Research documents 2010-2019 (left) and top 5 countries (right) on operations

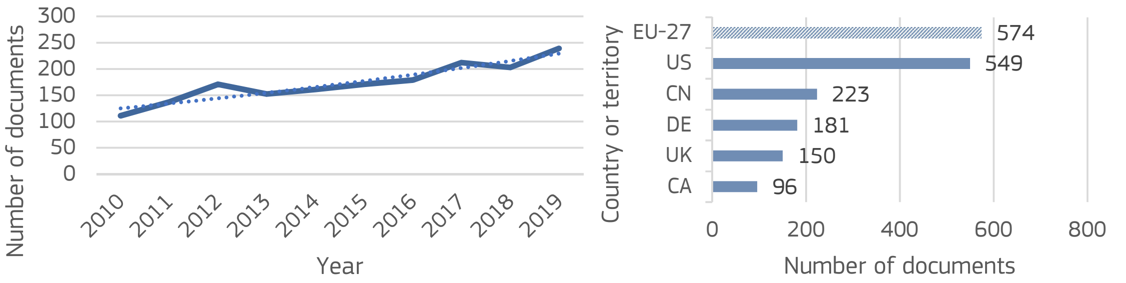


Source: TRIMIS.

On the *eco-design sub-theme*, in Figure 29, the trend is positive evolving from a low of 111 documents in 2010 to 239 documents in 2019. The US appears with the highest number of publications, followed by China. Germany is present in the top 5, together with the UK and Canada.

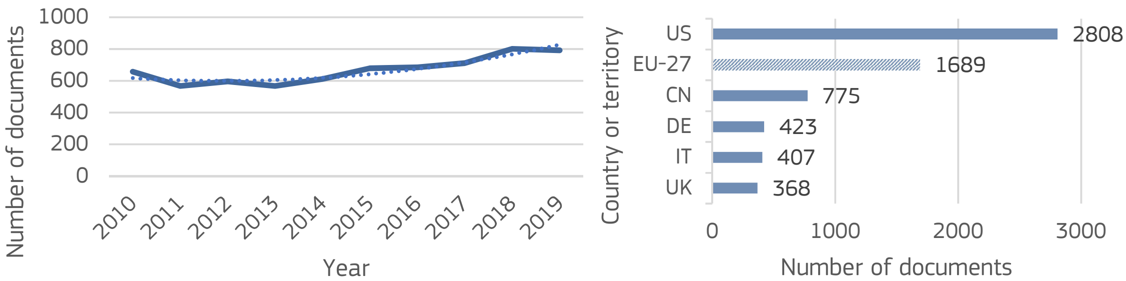
Finally, when looking at the *rotorcraft* sub-theme, shown in Figure 30, the trend is stable, passing from 657 documents in 2010 to 792 documents in 2019. The vast majority of publications comes from: the US, followed by China. Germany and Italy are the two EU 27 countries present in the top 5.

Figure 29: Research documents 2010-2019 (left) and top 5 countries (right) on eco-design



Source: TRIMIS.

Figure 30: Research documents 2010-2019 (left) and top 5 countries (right) on rotorcraft



Source: TRIMIS.

From the analysis, as a general remark, the US seems to dominate in air transport research in the last decade. However, Europe is strong with universities and research institutes being present among the top players in research. Also, if the EU 27 countries were considered all together, in three out of the seven cases would become the leading entity. Focusing on the individual sub-themes, research production on systems seems to increase swiftly after 2017, and observes the biggest increase over the 10 year period.

The results provide in this section need to be read with caution as the expression chosen with REGEX are prone to some limitation. The coverage provided is broad but not complete, while at the same time, results are likely to overlap between the different themes. Nevertheless, even if with limitations, they provide a meaningful analysis of research trends in air transport.

7.3 Technology assessment

A technology repository is included in the TRIMIS database, which is populated with technologies developed by projects funded under FP7 and H2020. A comprehensive methodology has been established within TRIMIS for identifying and extracting the technologies, assigned to overarching themes, to facilitate the comparison and analysis of various fields of transport innovation.

For this report, the analysis focuses on the top 20 technologies linked to aviation emissions reduction projects in TRIMIS, in terms of the total value invested per technology. These technologies are show in the radial structure of Figure 31, which highlights the key metrics.

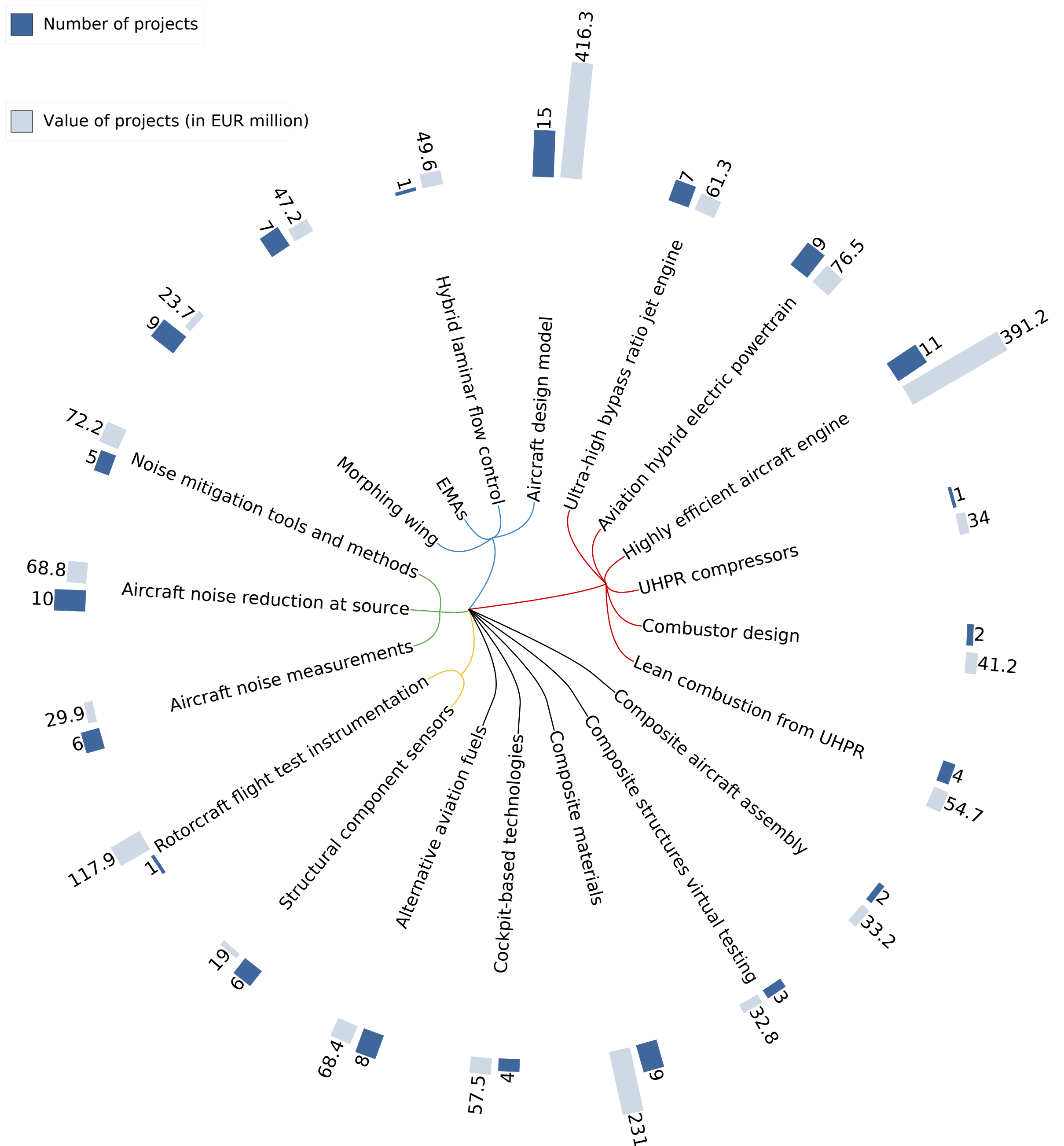
The technologies in the figure are grouped to the overarching technology themes and the metrics analysed are:

- Number of projects: the number of projects that have researched the technology;
- Value of projects per technology: the total value of all projects that have researched the technology (i.e. the total investment, by both the EU and project partners, in the development of the technology).

These metrics highlight the combined effort that has been put into the technology.
Four technologies (*Aircraft design model*, *Highly efficient aircraft engine*, *Composite materials*, and, *Rotorcraft flight test instrumentation*) have a total value of above 100 million euro each. Focusing on those:

- The *Aircraft design model* technology focuses on designing the aircraft for optimum performance across the full flight envelope, and includes advanced tools for aircraft design, integrating aerodynamics, structural design and stress analysis, aero-elastic simulation and control design with multi-objective optimisation.

Figure 31: Top 20 technologies for emissions reduction aviation projects[26]



Bars not in scale. Abbreviations: ultra-high pressure ratio (UHPR); electro-mechanical actuator (EMA). Clade colours represent higher nodes in the taxonomy (technology themes): light blue - Aircraft design and manufacturing; red - Aircraft propulsion; green - Noise testing, modelling and reduction; yellow – Sensor technologies
Source: TRIMIS.

The technology is researched in 15 projects but the majority of funding comes from two Clean Sky projects: SYS GAM 2018 and FRC GAM 2018.

— The *Highly efficient aircraft engine* technology focuses on increasing the overall engine efficiency and reducing fuel consumption and emissions, by means of improved design of aircraft gas turbine engines (for example higher pressure ratios, more efficient compressors, reduced turbine cooling requirements, etc.). The technology is researched in 11 projects (including one SME Phase 1 project) but the majority of funding comes from two the Clean Sky projects: ENG GAM 2018 and LPA GAM 2018.

— The *Composite materials* technology focuses on the development of design approaches for using composite materials (particularly carbon-fibre composites) for main structural parts of the aircraft, including the optimisation of the structural design to minimise weight and maximise strength. The technology is

[26]The figure is developed on the open and freely available interactive tree of life (Letunic and Bork, 2019), a web-based tool for the display, manipulation and annotation of phylogenetic trees.

researched in 9 projects, but the majority of the funding (210 out of 231 million euro) comes from the GAM AIR 2018 project.

— Finally, the *Rotorcraft flight test instrumentation* technology focuses on instrumentation systems for rotorcrafts to provide detailed information on the performance of the aircraft and of its systems during flight testing operations. The technology is researched in the GAM-2020-FRC project.

In addition, the technology maturity was assessed for all technologies researched within the projects. The assessment is based on technology Readiness Level s (TRLs), a method for estimating the maturity of technologies during the acquisition phase of a program, developed by the US NASA in the 1970's.

The EC advised that EU funded research and innovation projects should adopt the TRL scale in 2010; TRLs were then implemented for H2020 (Héder, 2017), although in practice TRLs are not consistently assigned to all H2020 projects. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology.

Table 23 provides the description for each of the nine TRLs, as taken from Annex G of the Horizon 2020 work programme (2014-2015) (European Commission, 2014) and the corresponding development phases used in TRIMIS. In TRIMIS, the nine TRLs have been consolidated into four development phases: research, validation, demonstration/prototyping/pilot production, and implementation.

Table 23: Technology Readiness Levels and TRIMIS development phase allocation

TRL	Description	TRIMIS development phase
1	Basic principles observed	Research
2	Technology concept formulated	
3	Experimental proof of concept	Validation
4	Technology validated in lab	
5	Technology validated in relevant environment	Demonstration/prototyping/pilot production
6	Technology demonstrated in relevant environment	
7	System prototype demonstration in operational environment	
8	System complete and qualified	Implementation
9	Actual system proven in operational environment	

Source: (Gkoumas et al., 2020); TRL scale based on (European Commission, 2014).

For this exercise to be meaningful, focus was given to those technologies researched in the highest number of projects. Table 24 provides the Top 10 technologies in terms of number of projects that research them, and, the projects that research them identified by the development phase.

The majority of projects are researched under the Research phase, and a good number under the Validation and Demonstration/prototyping/pilot production phases. There are only two technologies that have reached higher maturity (researched under the Implementation phase): Aircraft design model and Aircraft noise reduction at source.

Even though there are limitations linked to the approach followed for clustering technologies in technology themes and building a taxonomy, the exercise of linking several technology metrics with organisational data can be useful for identifying technology value chains, including opportunities, as well as providing indications on the most relevant projects and programmes which support these technologies and topics.

Table 24: Top 10 technologies and projects according to development phase

	Technology and ranking	Research	Validation	Demonstration	Implementation
1	Aircraft design model	ATAAC, CODE-TILT, FRC GAM 2018, GAM-2020-REG, GAM-2020-SYS, GLOWOPT, NEXTWING, NextGen Airliners, SAT GAM 2018, SMAES, UNIFIER19	-	INTFOP, LOSITA, SYS GAM 2018	ALEF
2	Highly efficient aircraft engine	ENG GAM 2018, GAM-2020-ENG, HIGHER, InVIGO, TRANSCEND, UTOPEA	ERICKA, LPA GAM 2018, STARTGENSYS, TETRA	E-BREAK	-
3	Aircraft noise reduction at source	ADOCHA, ARTEM, DJINN, ENOVAL, EVIS	GRAIN, NLFFD, PPSMPAB, TEENI	-	OPENAIR
4	Composite materials for structural purposes in the aircraft	ACID, GAM AIR 2018, GRAPHICING, IMAC-PRO, INFUCOMP, LIFT, SHERLOC QSP, STEADIEST	-	ADVITAC	-
5	Aviation hybrid electric powertrain	ACCURATE, AHEAD, ASuMED, DISPURSAL, HECARRUS	LPA GAM 2018	ACEP, H3PS, MAHEPA	-
6	Morphing wing	DEMMOW, NOVEMOR, SABRE, SABRE, SADE, SMS	-	AMuLET, GRETEL, LeaTop	-
7	Electric aircraft	ICEPASS, MISSION, TAUPE	AERTECVTI, EPICEA, RETAX, SEPDC, SIMEAD	-	-
8	Alternative aviation fuels	ALFA-BIRD, ALTERNATE, FlexJET, GRAIN 2, JETSCREEN, TRANSCEND	ITAKA	BIO4A	-
9	Ultra-high bypass ratio jet engine	ASPIRE, BIRAN, ORBIT	AvAUNT, INAFLOWT, LPA GAM 2018, SKOPA	-	-
10	Electro-Mechanical Actuators	ACTUATION2015, ARMLIGHT, E-BRAKE, GREENAIR, ACCOMIM	-	FASE-LAG, TAIRA	-

Source: TRIMIS.

Box 12. Patents, publications and technology assessment summary

— There has been a great rise in the number of patents relevant to aviation since 2012, with the majority belonging to *systems*, *operations* and *propulsion*

— The share of *eco-design* patents has been increasing since 2016

— The US appears as dominant in air transport research in the last decade with Europe being strong with universities and research institutes among the top players

— When taking into account EU 27 countries together, the EU is leader in publications for some sub-themes: *structures*, *systems* and *eco-design*

— The top technology themes are: *aircraft design and manufacturing*, *aircraft propulsion*, *noise testing, modelling and reduction* and *sensor technologies*

— The majority of researched technologies are in research phase, with *Aircraft design model* and *Aircraft noise reduction at source* being also present in implementation phase

8 Summary and conclusions

8.1 Report summary

The aviation sector faces challenges to reduce emissions in order to be able to reach the European Green Deal targets. For this reason, R&I has a very important role to play by creating new technologies which can tackle the emissions problems. In this context, this report assessed the status of R&I in Europe, related to emissions reduction in aviation.

A methodological approach to this assessment was given in Chapter 2, while Chapters 3 and 4 give an overview of market and policy contexts.

In turn, Chapters 5, 6 and 7 provide insights into R&I in the EU by different means. First, an overall assessment of aviation research projects and specifically emissions reduction projects is carried out, followed by an in-depth analysis of selected research projects. Finally, technological advances are assessed by means of patents, scientific publications and a technology analysis.

8.2 Database assessment

Following the thorough assessment carried out using the TRIMIS database, the following main points can be concluded:

— there are in total 1967 projects labeled under the air transport mode in TRIMIS, with a steady increase since 1995. Most projects have a duration of 3 or 4 years and fall under the vehicle design and manufacturing (VDM) and network and traffic management (NTM) roadmaps;

— the majority of projects started in the FP7 and H2020 FPs and funding peaked in 2019 with approximately 600 million EUR project values and over 500 active projects;

— emissions reduction projects were categorised under 7 sub-themes: *aerodynamics*, *structures*, *propulsion*, *systems*, *operations*, *eco-design* and rotorcraft;

— the sub-themes with the highest number of projects are *structures*, *propulsion*, *systems* and *aerodynamics*, and the ones with with the highest project costs are *propulsion*, *systems*, *rotorcraft* and *structures*;

— Clean Sky projects are on the top of the list of projects with highest funding while French entities received the highest amount of funding, followed by German and Italian entities, with a high proportion of collaboration between the first two;

— The 5 most present organisations are: Deutsche Zentrum für Luft- und Raumfahrt (DLR), Office National d'Etudes et de Recherches Aérospatiales (ONERA), Nederlands Lucht- en Ruimtevaartcentrum (NLR), Technische Universiteit Delft (TU Delft) and Centro Italiano Ricerche Aerospaziali (CIRA)

8.3 Project analysis

— *Aerodynamics* projects research methods to improve efficiency by increasing lift and decreasing drag, reporting a potential to decrease emissions by up to 10%

— *Structures* projects aim to use lightweight materials to decrease aircraft emissions. Research focuses on production, development structural integrity of such materials. Potential emissions reductions are expected at up to 10%, with higher savings in production and maintenance costs.

— *Propulsion* projects focus innovative propulsion systems by proposing new solutions and improving the current engines, while also researching alternative fuels. Emissions reductions can vary between the different technologies, with the highest decrease in CO_2 consumption coming from the use of sustainable alternative fuels (SAFs) (66% reduction) and the potential of NO_x emissions reduction by over 60% using improved engine sub-systems.

— *Systems* projects can help integrate or mitigate drawbacks of newer technologies, while proposing new architectures for avionics. Emissions reductions from innovative systems are not as high when compared to other sub-themes, but the emissions gain comes from supporting other sub-themes through improved energy management, noise reduction and use of electro-mechanical actuators (EMAs)

— *Operations* projects aim to reduce emissions by optimal trajectory planning, while also decreasing costs in maintenance operations. There is possibility of reducing emissions by reducing aircraft circling times around airports, as well as decreasing fuel weight by better flight planning

— *Eco-design* projects research impacts beyond the use-phase of the aircraft, and aim to improve resource efficiency and reduce life cycle emissions. The life cycle analysis (LCA) methodology and mindset is less present in the aviation industry but research is meant to bring it up-to-date.

— *Rotorcraft* projects research new engines and innovative blades to reduce rotorcraft emissions. New propulsion technologies have achieved higher efficiency (up to 40% less fuel consumption) while innovative blades can lead to reductions in CO_2 and NO_x emissions from 5% to 10%.

8.4 Publications, patents and technology analysis conclusions

— granted patents related to emissions reduction have risen greatly since 2012, with the highest share belonging to systems, operations and propulsion.

— the US is the leader in terms of publications in the aviation field, followed by China and Germany. From the top 10 affiliations in aviation publications, 5 are Chinese, 4 are from the US and one is German;

— overall, the US has the highest number of publications in aviation in the last decade. European research institutes are present among the top publishing institutions. When taking into account EU 27 countries together, the EU is leader for some sub-themes: *structures*, *systems* and *eco-design*;

— most technologies from EU research projects are in the *research* phase and the top technology themes are *aircraft design and manufacturing*, *aircraft propulsion*, *noise testing, modelling and reduction* and *sensor technologies*.

8.5 Policy and research recommendations

The diverse types of assessments in this report have been carried out with the purpose of setting the scene and understanding the current state of R&I in the EU, related to emissions reduction in aviation. With this analysis, conclusions and recommendations related to future policy and research can be given:

— sustainable alternative fuels (SAFs) have the potential to reduce CO_2 emissions by a considerable amount, without the need of extensive or revolutionary technology improvements. Adoption of these alternative fuels can be a short/mid-term solution to reduce GHG effects in aviation;

— the potential for reduction of other pollutants (such as NO_x) comes in great part from the improvement of current engine technologies (such as achieving high bypass ratio, improving core engine efficiency). Improving the efficiency of engines is a solution that can be achieved faster than creating and validating new engine technologies, and as such is suitable as means of transition to highly efficient and cleaner technologies;

— the aerodynamic properties of aircraft are quite close to optimal and for this reason gains in reducing emissions can be limited. Therefore, new solutions suffer the risk of not making it to market due to cost and risk of implementation when compared to the actual gains. One path that can be taken is to investigate completely novel and disruptive aircraft architectures (at very low TRLs) which could bring benefits in a much longer horizon;

— while air transport can be time and cost efficient for long distances, there can be more effective and less polluting solutions for shorter routes. Integrating air and other types of transport modes for proper multimodal solutions, while clearly defining the best options for routes, can help mitigate pollutant emissions;

— it is also clear from the assessments that there is no clear best solution, with gains being restrictive in some cases. Therefore, efforts in the technological side should be integrated with non-technological solutions (multimodality, emissions trading schemes) as a means to reduce the environmental footprint of aviation;

— there is a limited number of research projects which investigate non-technological solutions. Therefore, further research in this area is encouraged to discover possible benefits and innovative solutions (e.g. improved emissions trading systems, citizen acceptance related to taxing aviation emissions, encouragement of multimodality use);

— for technological research, promising technologies with high TRL should be encouraged, to put into market the proposed solutions which could reduce emissions. However, the development of highly innovative ideas (at lower TRLs) should also be stimulated, as a means to give way for future disruptive technologies and concepts;

— finally, as the impact of use-phase emissions diminishes, more attention should be given to the full life-cycle of the aircraft, as emissions due to the production and end-of-life of aircraft become more significant.

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List of abbreviations and definitions

3D	three dimensions
ACARE	Advisory Council for Aviation Research and Innovation in Europe
AED	Aviation Environmental Database
AFC	active flow control
AI	artificial intelligence
ALT	low-emission alternative energy for transport
ALM	additive layer manufacturing
AMAN	arrival management system
AT	Austria
ATFCM	air traffic flow and capacity management
ATM	air traffic management
BE	Belgium
BG	Bulgaria
BPR	bypass ratio
CA	Canada
CAAC	Civil Aviation Administration of China
CAD	computer-aided design
CAT	connected and automated transport
CFD	computational fluid dynamics
CFRP	carbon fibre reinforced plastic
CH	Switzerland
CINEA	European Climate, Infrastructure and Environment Executive Agency
CIRA	Centro Italiano Ricerche Aerospaziali
CN	China
CNC	computer numerically controlled
CO	carbon monoxide
CO_2	carbon dioxide
CORDIS	Community Research and Development Information Service
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CPC	Cooperative Patent Classification
CROR	contra-rotating open rotor
CY	Cyprus
CZ	Czechia
DAC	dynamic airspace configuration
DE	Germany
DG MOVE	Directorate-General for Mobility and Transport

DG RTD	Directorate-General for Research and Innovation
DK	Denmark
DLR	Deutsche Zentrum für Luft- und Raumfahrt
DMA	dynamic mobile area
EASA	European Union Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
ECO	Eco-Design
EE	Estonia
EL	Greece
ELT	transport electrification
EM	electromagnetic
EMA	electro-mechanical actuator
ENDT	extended non-destructive testing
EPNdB	effective perceived noise in decibels
EPO	European Patent Office
ERC	European Research Council
ES	Spain
EU	European Union
EU 27	27 Member States of the EU
EUROCONTROL	European Organisation for the Safety of Air Navigation
Eurostat	European Statistical Office
ETIPS	electro-thermal ice protection
ETR	electric tail rotor
ETS	emissions trading system
FAA	Federal Aviation Administration
FI	Finland
FML	fibre metal laminate
FP	Framework Programme
FP7	7th Framework Programme for Research
FR	France
FRC	fast rotorcraft
GCU	generator control unit
GFCS	generic fuel cell system
GHG	greenhouse gas
GRA	Green Regional Aircraft
GRC	Green Rotorcraft

H2020	Horizon 2020 Framework Programme for Research and Innovation
HE	Horizon Europe research and innovation framework programme
HEFA	hydro-processed esters and fatty acids
HEG	high enthalpy shock tunnel Göttingen
HEHF	high energy hydroforming
HR	Croatia
HS	horizon scanning
HU	Hungary
HVDC	high voltage direct current
IADP	innovative aircraft demonstrator platform
ICAO	International Civil Aviation Organization
ICCT	International Council on Clean Transportation
IE	Ireland
IN	India
INF	transport infrastructure
INT	international
IS	Iceland
IT	Italy
ITD	integrated technology demonstrator
JP	Japan
JRC	Joint Research Centre
JTI	Joint Technology Initiative
JU	Joint Undertaking
KPI	key performance indicator
LCA	life cycle analysis
LCI	life cycle inventory
LED	light-emitting diode
LT	Lithuania
LMA	lightweight mobile arm
LU	Luxembourg
LV	Latvia
MPR	materials, processes and resources
MRO	maintenance, repair and overhaul
MS	Member State
MSCA	Marie Skłodowska-Curie actions
MT	Malta
NARP	National Aviation Research Plan

NASA	National Aeronautics and Space Administration
NDI	non-destructive investigation
NDT	non-destructive testing
NEA	non-essential application
NETT	new and emerging transport technologies and trends
NL	Netherlands
NLF	natural laminar flow
NLR	Nederlands Lucht- en Ruimtevaartcentrum
NO	Norway
NO_x	nitrogen oxides
NTM	network and traffic management
NUTS	nomenclature des unités territoriales statistiques
ONERA	Office National d'Etudes et de Recherches Aérospatiales
OPR	overall pressure ratio
PATSTAT	Worldwide Patent Statistical Database
PEI	polyetherimide
PEM	proton-exchange membrane
PFC	propulsive fuselage concept
PL	Poland
PM	particulate matter
PSP	pressure sensitive paint
PT	Portugal
R&I	research and innovation
R&D	research and development
REGEX	regular expressions
RO	Romania
RS	Serbia
RU	Russian Federation
SAF	sustainable alternative fuel
SAGE	Sustainable and Green Engines
SATCOM	satellite communications
SE	Sweden
SES	Single European Sky
SESAR	Single European Sky ATM Research
SESAR JU	SESAR Joint Undertaking
SETIS	Strategic Energy Technologies Information System
SGO	Systems for Green Operations

SI	Slovenia
SK	Slovakia
SFWA	Smart Fixed-Wing Aircraft
SMO	smart mobility and services
SO_x	sulphur oxides
SRIA	Strategic Research and Innovation Agenda
STRIA	Strategic Transport Research and Innovation Agenda
TE	Technology Evaluator
TMA	terminal control area
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	technology Readiness Level
TSP	temperature sensitive paint
TU Delft	Technische Universiteit Delft
UHC	unburnt hydrocarbons
UHPR	ultra-high pressure ratio
UK	United Kingdom
US	United States of America
VDM	vehicle design and manufacturing
VHF	very high frequency

List of boxes

List of figures

List of tables

Annexes

Annex 1. Keywords used for sub-theme definition

Keywords used for identifying emissions reduction projects: *decarbonization, decarbonisation, emissions, CO2, eco-design, eco design, green engine, green operation, green, nox, biofuel, environmental impact, low weight , high efficiency , environmental friendly , lightweight , pollution , aerodynamic efficiency , energy management , energy efficient*

Aerodynamics keywords: *wing, aerodynamics, aerodynamic, flight dynamics, morphing, edge, flaps, flow, laminar, lift, flutter, aeroelastically, aeroelastic, swirl, cfd, drag, mach*

Structures keywords: *structure, structures, airframe, configuration, lightweight, frame, weld, welding, fuselage, thermoplastic, alloy, adhesive, composites, laminate, composite, polymer, wing-box, wing box*

Propulsion keywords: *engine, propulsion, motor, fuel, cylinder, flexjet, inlet, nacelle, bypass, hydrogen, energy storage, battery, transmission, turbofan, power converter , hybrid, combustion, propeller, aero-engines, turbine, turbines, biofuel, biofuels, lignocellulosic, feedstock, electric aircraft*

Systems keywords: *control, icing, heat, sensing, landing gear, brake , antenna, electric power system, eps, power electronics, pe, connected, avionics, avionic, architecture, architectural, HVDC, Cockpit, cabin, power electronics module, energy management, energy*

Operations keywords: *airports, airport, aircraft delays, delay, schedules, schedule, interline , operations, operation, crew, airlines, trajectories, ats, air traffic service, forecast, trajectory, traffic, atm*

Eco-design keywords: *lca, lcc, life, ecodesign, waste, recycling, recyclability, eol*

Rotorcraft keywords: *helicopter , rotorcraft , tilt , tiltrotor , tilt-rotor , compound rotorcraft , compound , fast rotorcraft , helicopter blade, rotor blade , rotary wing , VTOL , Vertical Take-Off*

Annex 2. Project tables

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
16gAirTest-Phase2	Innovative EASA certified dynamic test method for 16g aircraft seat cushions	2016-2018	H2020		Main					
2050AP	The 2050+ Airport	2011-2014	FP7				Yes	Main	Yes	
9eGEN	9eGEN - Development of innovative lightweight HVDC 9-phase Brushless/Generator for Clean Sky Rotorcraft	2016-2020	H2020 Clean Sky				Yes		Yes	Main
AAS	Integrated Airport Apron Safety Fleet Management	2008-2011	FP7					Main		
ACASIAS	Advanced Concepts for Aero-Structures with Integrated Antennas and Sensors	2017-2021	H2020		Main	Yes	Yes			
ACCOMIM	ACtuator COmponents made by alternative Metal Injection Moulding	2014-2016	FP7 Clean Sky				Yes		Main	
ACCUBLADE	Low cost design approach through simulations and manufacture of new mould concepts for very high tolerance composite components	2013-2015	FP7 Clean Sky						Yes	Main
ACCURATE	Aerospace Composite Components - Ultrasonic Robot Assisted Testing (ACCURATE)	2017-2021	H2020 Clean Sky		Main	Yes				
ACEP	Airlander Civil Exploitation Project	2015-2017	H2020			Main				
ACFA 2020	Active Control for Flexible 2020 Aircraft	2008-2011	FP7	Yes	Yes		Main			
ACHEON	Aerial Coanda High Efficiency Orienting-jet Nozzle	2012-2014	FP7	Yes		Yes	Yes			Main

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
ACHIEVE	Advanced mechatronics devices for a novel turboprop Electric starter-generator and health monitoring system	2017-2021	H2020 Clean Sky			Main	Yes			
ACID	Advanced Composite Integrated Skin Panelstructural testing	2013-2014	FP7 Clean Sky		Main				Yes	
ACOTAAL	Automation COncepts and Technologies for Aircraft Assembly Lines in the Aircraft Factory of the Future	2016-2018	H2020 Clean Sky		Yes		Yes		Main	
ACTIonRCraft	Anti-Crash lightweight fuel bladder Tank Integrated on a new RotorCraft	2016-2020	H2020 Clean Sky		Yes	Yes				Main
ACTUATION 2015	ACTUATION 2015: Modular Electro Mechanical Actuators for ACARE 2020 Aircraft and Helicopters	2011-2016	FP7			Yes	Yes	Yes		Main
ACcTIOM	Advanced Pylon Noise Reduction Design and Characterization through flight worthy PIV	2012-2016	FP7 Clean Sky	Main		Yes	Main			
ADAVES	Advanced avionics equipment simulation	2011-2013	FP7 Clean Sky						Yes	
ADDAPTTA SEALS	ADDitive mAnufacturing oPTimized TAilored SEALS	2018-2021	H2020 Clean Sky	Main					Yes	
ADDSAFE	Advanced fault diagnosis for safer flight guidance and control	2009-2012	FP7	Yes	Yes		Main			
ADHERO	Aerodynamic Design Optimisation of a Helicopter Fuselage including a Rotating Rotor Head	2011-2014	FP7 Clean Sky	Yes	Yes					Main
ADOCHA	Acoustic Design Of High-lift Architectures	2010-2010	FP7 Clean Sky	Main	Yes					
ADORNO	Aicraft Design and nOise RatiNg for regiOnal aicraft	2018-2022	H2020 Clean Sky			Main				

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
ADVANCE	ADVANCE: Sophisticated experiments and optimisation to advance an existing CALPHAD database for next generation TiAl alloys	2018-2021	H2020 Clean Sky			Main				
ADVANCED	Advanced heating system and control mode for homogeneous high temperature curing of large composite repairs	2011-2012	FP7 Clean Sky		Yes		Main			
ADVENT	Advanced ventilation techniques for modern long-range passenger aircraft to promote future energy management systems	2017-2021	H2020 Clean Sky				Main			
ADVITAC	ADVance Integrated Composite TailCone	2009-2013	FP7		Main					
AEGART	AIRCRAFT ELECTRICAL GENERATION SYSTEM WITH ACTIVE RECTIFICATION AND HEALTH MONITORING	2011-2015	FP7 Clean Sky				Main			
AEON	Advanced Engine Off Navigation	2020-2022	N/A					Main		
AEROCHINA2	Prospecting and Promoting Scientifi c Co-operation between Europe and China in the Field of Multi-Physics Modelling, Simulation, Experimentation and Design Methods in Aeronautics	2007-2009	FP7	Yes	Yes		Yes			
AERODESIGN	AERODESIGN - Preliminary Design Methodologies	2010-2013	FP7 Clean Sky	Main		Yes	Yes			
AEROL-HP	Development, construction, integration, and progress toward to two-phase device monitoring and qualification on aircrafts	2011-2014	FP7 Clean Sky				Main			

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
AEROMUCO	AEROdynamic Surfaces by advanced MUltifunctional COatings	2011-2014	FP7	Main			Yes			
AEROPZT	Development of materials, processes, and means to enable the application of Piezoelectric materials in aero engine controls	2014-2016	FP7 Clean Sky			Main	Yes			
AERTECVTI	Test bench for endurance test and reliability prediction of avionics power electronic modules	2011-2013	FP7 Clean Sky				Main			
AFC4TR	Active Flow Control for Tilt Rotor	2020-2022	H2020 Clean Sky	Main						
AFCIN	Structural designs and tests for integration of active flow control concepts on a trailing edge high lift device	2011-2014	FP7 Clean Sky	Main	Yes		Yes			
AFDAR	Advanced Flow Diagnostics for Aeronautical Research	2010-2014	FP7	Main	Yes	Yes				
AFOOT	Advanced FOrging of an Optimized Turbine casing	2013-2016	FP7 Clean Sky		Yes	Main	Yes			
AFPMeT	Automatic Fiber Placement Metitalia Tooling	2018-2020	H2020 Clean Sky		Yes		Yes	Yes		Main
AGF	Active Gurney Flap	2012-2015	FP7 Clean Sky	Yes	Yes		Yes			Main
AHEAD	Advanced Hybrid Engines for Aircraft Development	2011-2014	FP7		Yes	Main	Yes			
AIR	Active and Isolated Rectifier unit for more electric aircraft: Design and Manufacturing of a 10KW AC-DC Converter Unit (AIR)	2013-2016	FP7 Clean Sky				Main		Yes	
AIRWISE	Hardware Development of Wireless Sensor Network Nodes for Operation in Airborne Environment	2009-2010	FP7 Clean Sky				Main	Yes		
ALBATROSS	ALBATROSS: The most energy efficient flying bird	2020-2022	N/A					Main		

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
ALEF	Aerodynamic loads estimation at extremes of the flight envelope	2009-2012	FP7	Main			Yes			
ALFA	Advanced Laminar Flow tAilplane	2016-2020	H2020 Clean Sky	Main	Yes				Yes	
ALFA-BIRD	Alternative Fuels and Biofuels for Aircraft Development	2008-2012	FP7			Main				
ALLEGRA	Advanced Low Noise Landing (Main and Nose) Gear For Regional Aircraft	2013-2015	FP7 Clean Sky		Yes					
ALMAGIC	Aluminium and Magnesium Alloys Green Innovative Coatings	2017-2019	H2020 Clean Sky		Main					
ALTD	Large 3-shaft Demonstrator - Aeroengine intake acoustic liner technology development	2011-2016	FP7 Clean Sky			Main				
ALTERNATE	ASSESSMENT ON ALTERNATIVE AVIATION FUELS DEVELOPMENT	2020-2022	H2020			Main				
AMBEC	Advanced Modelling Methodology for Bearing Chamber in Hot Environment	2018-2021	H2020 Clean Sky	Yes		Yes	Main			
AMEL	Advanced Methods for the Prediction of Lean-burn Combustor Unsteady Phenomena	2014-2016	FP7 Clean Sky	Yes	Yes	Main				
AMU-LED	Air Mobility Urban - Large Experimental Demonstrations	2021-2022	N/A					Main		
AManECO	ASSESSMENT OF ADDITIVE MANUFACTURING LIMITS FOR ECO-DESIGN OPTIMIZATION IN HEAT EXCHANGERS	2019-2022	H2020 Clean Sky						Main	
AMuLET	Advanced Control Unit for Morphing Leading Edge Management	2018-2021	H2020 Clean Sky	Main			Yes			
ANULOID	Investigation of novel vertical take-off and landing (VTOL) aircraft concept, designed for operations in urban areas	2013-2015	FP7	Yes	Yes		Yes			Main

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
APRIL	Advanced Preformmanufacturing for industrial LCM-Processes	2011-2013	FP7 Clean Sky		Yes				Main	
ARMLIGHT	Design, development and manufacturing of an electro-mechanical actuator and test rig for AiRcrafts Main LandIng Gear acTuation systems	2012-2016	FP7 Clean Sky			Yes	Main	Yes		
ARMONEA	Anotec Real-time MOdel for Noise Exposure of Aircraft	2012-2013	FP7 Clean Sky					Main		
ARTEM	Aircraft noise Reduction Technologies and related Environmental iMpact	2017-2021	H2020	Yes	Yes			Yes		
ASPIRE	Advanced Smart-grid Power dIstRibution systEm	2016-2020	H2020 Clean Sky				Main			
ASPIRE	Aerodynamic and acouStic for high-by-Pass ratIo tuRbofan intEgration	2016-2018	H2020 Clean Sky	Yes	Yes	Main				
ASuMED	Advanced Superconducting Motor Experimental Demonstrator	2017-2020	H2020			Main				
ATAAC	Advanced Turbulence Simulation for Aerodynamic Application Challenges	2009-2012	FP7	Main						
ATAEGINA	Airline TriAls of Environmental Green flIght maNAgement functions	2014-2016	FP7 Clean Sky					Main	Yes	
ATHENAI	Aerodynamic Testing of Helicopter Novel Air Intakes	2013-2015	FP7 Clean Sky	Yes	Yes	Yes				Main
ATLLAS II	Aero-Thermodynamic Loads on Lightweight Advanced Structures II	2011-2015	FP7	Yes	Main	Yes				
ATM4E	Air Traffic Management for environment	2016-2018	H2020					Main		
ATOS2012	International Air Transport and Operations Symposium 2012	2012-2012	FP7					Main		

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
AUTOW	Automated Preform Fabrication by Dry Tow Placement	2007-2010	N/A		Main				Yes	
AVERT	Aerodynamic Validation of Emission Reducing Techniques	2007-2010	N/A	Main			Yes		Yes	
AVIATOR	Assessing aViation emission Impact on local Air quality at airports: TOwards Regulation	2019-2022	H2020			Yes		Main		
AWAHL	Advanced Wing And High-Lift Design	2010-2012	FP7 Clean Sky	Main	Yes					
AdEPT	High Efficiency Fuel Pumping	2011-2013	FP7 Clean Sky			Main				
Aerowash II	InnovAtive automatic battERy pOwered WASHing robot for the aviation industry - Aerowash II	2015-2015	H2020			Yes		Main		
AiMeRe	Aircraft Metal Recycling	2012-2014	FP7 Clean Sky					Yes	Main	
Airport IQ	Situation-Aware Mobile Platform for Airport Collaborative Decision-Making	2015-2017	H2020					Main		
AssAssiNN	Development of a multifunctional system for complex aerostructures ASSembly, ASSisted by Neural Network	2020-2022	H2020		Main					
AvAUNT	AdaptiVe Area nozzle for Ultra high bypass Nacelle Technology	2017-2021	H2020 Clean Sky	Main	Yes	Main				
BESTT	Development, Construction and Integration of Bench Systems for Ground Thermal Tests	2011-2014	FP7 Clean Sky						Main	
BFCleaner	Borate Free Cleaners for Aluminum Alloys	2012-2013	FP7 Clean Sky						Main	
BIO4A	Advanced sustainable BIOfuels for Aviation	2018-2022	H2020			Main				
BIO_LCA_ TOOL	SIMPLIFIED LIFE CYCLE ASSESSMENT TOOL	2011-2013	FP7 Clean Sky						Main	

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
BIRAN	IP TurBIne Rear Stage Aero/Noise Rigs	2018-2019	H2020 Clean Sky	Yes		Yes				
BME Clean Sky 027	Development of an innovative bio-based resin for aeronautical applications	2012-2014	FP7 Clean Sky		Main					
BRACKETWELD	Development of an innovative welding process for the rapid assembly of thermoplastic brackets to thermoset-matrix composite structures	2016-2018	H2020 Clean Sky		Main		Yes			
BREEZE	HyBRid photocatalyitic air filtEr for rEmoving pollutants and odours from aircraft cabin ZonE	2017-2020	H2020 Clean Sky				Main		Yes	
BRIGHT	Bamboo Reinforced bIocomposite with High mecHanical properTies	2014-2015	FP7 Clean Sky		Main		Yes			
BUTERFLI	BUffet and Transition delay control investigated with European-Russian cooperation for improved FLIght performance	2013-2017	FP7	Main	Yes		Yes			
Bionic Aircraft	Increasing resource efficiency of aviation through implementation of ALM technology and bionic design in all stages of an aircraft life cycle	2016-2019	H2020		Yes				Main	
CALITO	CAbin LIning auTOmation	2017-2020	H2020 Clean Sky		Yes		Main		Yes	
CANAL	CreAting NonconventionAl Laminates	2013-2017	FP7		Main		Yes		Yes	
CANNAPE	Canadian Networking Aeronautics Project for Europe	2011-2013	FP7				Main	Yes		
CARD	Contribution to Analysis of Rotor Hub Drag Reduction	2010-2014	FP7 Clean Sky	Yes						Main
CARGOMAP	Air Cargo Technology Road Map	2011-2013	FP7	Yes	Yes			Yes		Main

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
CARHAY2011	"Design, Manufacturing and Impact Testing of Advanced Composite Materials"	2012-2014	FP7 Clean Sky		Main				Yes	
CARING	Contribution of Airlines for the Reduction of Industry Nuisances and Gases	2010-2011	FP7 Clean Sky					Main		
CENTRELINE	ConcEpt validatioN sTudy foR fusElage wake-filLIng propulsioN intEgration	2017-2020	H2020	Yes	Main	Yes				
CERFAC	Cost Effective Reinforcement of Fastener Areas in Composites	2010-2014	FP7		Yes		Yes		Yes	Main
CF-THREAD	Composites under Fatigue: Temperature and Humidity Related Environmental Ageing Damage	2011-2014	FP7 Clean Sky		Main					
CHATT	Cryogenic Hypersonic Advanced Tank Technologies	2012-2015	FP7		Main	Yes	Yes			
CHAiRLIFT	Compact Helical Arranged combustoRs with lean LIFTed flames	2019-2022	H2020 Clean Sky			Main				
CIDAR	Combustion species Imaging Diagnostics for Aero-engine Research	2018-2020	H2020 Clean Sky			Main				
CLAIRPORT	Clean Sky 2 - Airport Environmental Impact Assessments for Fixed-wing Aircraft	2017-2021	H2020 Clean Sky					Main		
CNMD	Development of nanofilled prepreg for aircraft composite structures	2010-2010	FP7 Clean Sky		Main					
COBRA	Innovative Counter Rotating Fan System for High Bypass Ratio Aircraft Engine	2013-2017	FP7	Yes		Main		Yes		
COCTA	Coordinated capacity ordering and trajectory pricing for better-performing ATM	2016-2018	H2020					Main		

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
CODE-TILT	Contribution to design optimization of tiltrotor components for drag reduction	2010-2013	FP7 Clean Sky	Yes	Yes	Yes				Main
COFRARE 2020	Out of autoclave technologies for frame and shear tie of Regional Aircraft	2018-2021	H2020 Clean Sky		Main					
COLTS	Casting of Large Ti Structures	2010-2013	FP7		Main	Yes	Yes			
COMBUSS	Composite tooling for business jet lower wing stiffened panel manufacturing	2018-2020	H2020 Clean Sky		Yes		Yes		Main	
COMPASS	Fuctional laminates development. Components compatibility and feasibility assessment. Industrialization	2010-2013	FP7 Clean Sky		Main					
CONCERTO	Cabin nOise reductioN ground Checked by nEw loudspeakeR exciTatiOn	2020-2021	H2020				Yes			
CONCORDE	Flight Operations for Novel COntinuous DEscent - cONCOrDE	2014-2015	FP7 Clean Sky				Yes	Main		
CONDUCTOR	Flexible Conductive Composite Repair Heaters	2011-2014	FP7 Clean Sky		Main		Main			
CORDIAL	Collaborative OWA robots for drilling and fasteners insertion in assembly lines	2017-2020	H2020 Clean Sky		Main					
CORE-JETFUEL	Coordinating research and innovation of jet and other sustainable aviation fuel	2013-2016	FP7			Main	Yes	Yes		
CORNET	CORE NOISE ENGINE TECHNOLOGY	2016-2019	H2020 Clean Sky	Yes		Main				
CORSAIR	Cold Spray Radical Solutions for Aeronautic Improved Repairs (CORSAIR)	2013-2016	FP7		Yes			Yes	Main	
CRASHING	Characterization of Structural Behaviour for High Frequency Phenomena	2014-2016	FP7 Clean Sky		Main					

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
CREATE	INNOVATIVE OPERATIONS AND CLIMATE AND WEATHER MODELS TO IMPROVE ATM RESILIENCE AND REDUCE IMPACTS	2020-2022	N/A					Main		
CROP	Cycloidal Rotor Optimized for Propulsion	2013-2014	FP7	Yes	Yes	Yes				Main
CSSA	Clean Sky Support Action	2007-2008	FP7	Main	Yes					
Co2Team	Cognitive Collaboration for Teaming	2019-2021	H2020 Clean Sky					Main		
CoPoCo	Optimizing power density of aircraft inverter by optimized topology and PWM-pattern	2014-2016	FP7 Clean Sky				Main			
ComBoNDT	Quality assurance concepts for adhesive bonding of aircraft composite structures by extended NDT	2015-2018	N/A		Main				Yes	
Corvid	AI-based autonomous flight control for the electric passenger aircraft of the nearest future	2017-2018	H2020				Yes			Main
DAEDALOS	Dynamics in Aircraft Engineering Design and Analysis for Light Optimized Structures	2010-2014	FP7		Main	Yes	Yes			
DAFNE	Development of gamma-TiAl forgings in a low-cost near conventional hot-die process and process evaluation	2011-2014	FP7 Clean Sky			Main				
DAHLIAS	Development and application of hybrid joining in lightweight integral aircraft structures	2018-2021	H2020 Clean Sky		Main	Yes				
DARGOS	Definition of ATM Requirements for GRA Operations and Simulations	2011-2013	FP7 Clean Sky					Main		
DEAMAK	Design And Manufacture of Krueger Flaps	2010-2016	FP7 Clean Sky	Main	Yes					

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
DEFLECT	DEvelopment of Functionalizable materiaLs for Electrical CabineTs	2018-2020	H2020 Clean Sky		Main				Yes	
DELASTI	DEvelopment of advanced LASer based technologies for the manufacturing of TItanium HLFC structures	2016-2018	H2020 Clean Sky	Yes	Main	Yes				
DELILAH	Diesel engine matching the ideal light platform of the helicopter	2011-2013	FP7 Clean Sky			Yes	Yes			Main
DEMMOW	Detailed Model of a Morphing Wing	2017-2021	H2020 Clean Sky	Main			Yes			
DENOX	Innovative Technologies of Electrochemical Suppression and Electromagnetic Decomposition for NOx Reduction in Aeroengines	2019-2022	H2020 Clean Sky	Yes		Main				
DEPART2050	Design Evaluation and Performance Assessment of Rotorcraft Technology by 2050	2017-2021	H2020 Clean Sky					Yes		Main
DEfcodoor	Development of a Ecological friendly final consolidation step using Thermoplastic Fibre Placement for a helicopter door	2011-2013	FP7 Clean Sky		Yes		Yes		Yes	Main
DIGESTAIR	A novel anaerobic DIGESTer solution in AIR transport for on-board safe and efficient waste management	2019-2021	H2020 Clean Sky				Yes		Main	
DILECO	DIgitalization of ground-testing Life cycle with ECO design criteria	2018-2020	H2020 Clean Sky				Yes		Main	
DISPURSAL	Distributed Propulsion and Ultra-high By-pass Rotor Study at Aircraft Level	2013-2015	FP7	Yes	Yes	Main				
DJINN	Decrease Jet-Installation Noise	2020-2023	H2020	Yes						

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
DREAm-TILT	Assessment of tiltrotor fuselage drag reduction by wind tunnel tests and CFD	2013-2015	FP7 Clean Sky	Yes	Yes					Main
DSOT300-125S	Development and manufacturing of programmable electrical load and advanced PSM for electrical energy management testing in flight demo	2012-2016	FP7 Clean Sky						Yes	
DYNCAT	Dynamic Configuration Adjustment in the TMA	2020-2022	N/A					Main		
DevTMF	Development of Experimental Techniques and Predictive Tools to Characterise Thermo-Mechanical Fatigue Behaviour and Damage Mechanisms	2016-2021	H2020 Clean Sky			Main	Yes		Yes	
E-BRAKE	Design, Manufacturing and Qualification up to TRL5 of Innovative Electro-Mechanical BRAKE actuation System for SAT Application	2018-2021	H2020 Clean Sky				Main		Yes	
E-BREAK	Engine Breakthrough Components and Subsystems	2012-2017	FP7		Yes	Yes			Yes	Main
EASIER	Electric Aircraft System Integration Enabler	2020-2023	H2020				Main			
EC2S	ENVIRONMENT CONTROL SECONDARY SYSTEM	2019-2021	H2020 Clean Sky				Main			
ECEFA	Eco-efficient aluminium for Aircraft	2011-2014	FP7 Clean Sky		Main					
ECO GAM 2018	Eco-Design Transverse Activity GAM 2018	2014-2019	H2020 Clean Sky						Main	
ECO-COMPASS	Ecological and Multifunctional Composites for Application in Aircraft Interior and Secondary Structures	2016-2019	H2020		Main				Yes	

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
ECOLAND	Development of ECO-friendly protection procedures for LANDing gear aluminium alloys	2018-2020	H2020 Clean Sky		Main					
EDEC	Enhanced Diesel Engine Control	2017-2019	H2020 Clean Sky			Main	Yes			
EFAICTS	Ergonomic impact and new Functions induced by Active Inceptor integration in CockpiTS	2018-2021	H2020 Clean Sky					Main		
ELECTRA	Efficient and Light Electrical Compressor for Tilt-Rotor Aircraft	2019-2023	H2020 Clean Sky				Yes			Main
ELETAD	Electrical Tail Drive - Modelling, Simulation and Rig Prototype Development	2010-2016	FP7 Clean Sky			Main				
ELPOC	Electrical Power Control - More Electric Aircraft	2011-2015	FP7 Clean Sky				Main			
ELTESTSYS	ELECTRICAL TEST BENCH DRIVE SYSTEMS: MECHANICAL INTERFACES	2011-2013	FP7 Clean Sky		Yes		Yes			
ELUBSYS	Engine LUBrication SYStem technologies	2009-2012	FP7	Yes		Main	Yes			
ELWIPS	Electro-thermal Laminar Wing Ice Protection System Demonstrator	2012-2016	FP7 Clean Sky	Main			Yes			
ENABLEH2	Enabling cryogenic hydrogen based CO2 free air transport (ENABLEH2)	2018-2021	H2020	Yes		Main	Yes			
ENCOMB	Extended Non-Destructive Testing of Composite Bonds	2010-2014	FP7		Main		Yes		Yes	
ENDAMI	Environmental Data Models and Interface development in Aviation	2011-2014	FP7 Clean Sky						Main	
ENERGIZE	Efficient Energy Management for Greener Aviation	2017-2022	H2020 Clean Sky				Main			
ENG GAM 2018	Engine ITD - GAM 2018	2014-2018	H2020 Clean Sky			Main	Yes		Yes	

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
ENIGMA	Supervisor Control for ENhanced electrIcal enerGy MAnagement	2018-2021	H2020 Clean Sky				Main			
ENITEP	Experimental and Numerical Investigation of Turbulent Boundary Layer Effects on Noise Propagation in High Speed Conditions	2012-2016	FP7 Clean Sky	Yes	Yes	Yes				
ENODISE	Enabling optimized disruptive airframe-propulsion integration concepts	2020-2024	H2020	Main						
ENOVAL	Engine Module Validators	2013-2018	FP7	Yes	Yes	Main				
EPICEA	Electromagnetic Platform for lightweight Integration/Installation of electrical systems in Composite Electrical Aircraft	2016-2019	H2020		Main		Yes			
EPOCAL	EPOCAL: an Electrical POwer Center for Aeronautical Loads	2013-2015	FP7 Clean Sky				Main			
EPS55	Electric Propulsion System for the Air Transportation of Tomorrow	2019-2019	H2020			Yes	Yes			Main
ERAT	Environmentally Responsible Air Transport	2007-2010	N/A					Main		
ERICE	Super hydrophobic and erosion resistant coating for turbine scroll and downstream pipe	2018-2021	H2020 Clean Sky				Main			
ERICKA	Engine representative internal cooling knowledge and applications	2009-2014	FP7	Yes		Main	Yes			
ESCaPE	A game-changing light aircraft enabled by advanced materials and novel production methods	2016-2016	H2020		Main					

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
ESICAPIA	Experimental Subsonic Investigation of a Complete Aircraft Propulsion system Installation and Architecture power plant optimization	2013-2017	FP7 Clean Sky	Yes	Yes	Main				
ESPOSA	Efficient Systems and Propulsion for Small Aircraft	2011-2016	FP7			Main	Yes			
ESTEEM	Advanced Energy STorage and Regeneration System for Enhanced Energy Management	2017-2021	H2020 Clean Sky				Main			
EULOSAM	Design and Manufacturing of Baseline Low-Speed, Low-Sweep Wind Tunnel Model	2013-2016	FP7 Clean Sky	Main	Yes				Yes	
EURECA	Enhanced Human Robot cooperation in Cabin Assembly tasks	2017-2020	H2020 Clean Sky		Yes		Main	Yes		
EVIS	Engine Mounting System (EMS) for Ground Test Turboprop Engine Demonstrator	2016-2021	H2020 Clean Sky			Main				
EXTREME	EXTREME Dynamic Loading - Pushing the Boundaries of Aerospace Composite Material Structures	2015-2019	H2020		Main		Yes			
FACTOR	Full Aero-thermal Combustor-Turbine interactiOn Research	2010-2017	FP7	Yes	Yes	Main				
FAMEC	Failure analysis and damage mechanisms of newly developed, gamma-prime strengthened Ni - based superalloy	2014-2016	FP7 Clean Sky		Main	Yes				
FASE-LAG	FAil-Safe Electro-mechanical actuation for LAnding Gear	2017-2021	H2020 Clean Sky				Main			
FASTDISC	Disconnect device for jam tolerant linear actuators	2013-2016	FP7 Clean Sky				Main			
FASTOP	FAST OPtimiser for continuous descent approaches	2012-2014	FP7 Clean Sky			Yes		Main		

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
FFAST	Future Fast Aeroelastic Simulation Technologies	2010-2013	FP7	Main	Yes	Yes				
FIRST	Fuel Injector Research for Sustainable Transport	2010-2014	FP7	Yes	Yes	Yes				Main
FITCoW	Full-scale Innovative integrated Tooling for Composite material Wing-box	2019-2021	H2020 Clean Sky		Main				Main	
FLHYSAFE	Fuel CellL HYdrogen System for AircraFt Emergency operation	2018-2022	H2020			Main	Yes			
FLIP	Automatic FLIght Plan management tool	2014-2015	FP7 Clean Sky					Yes		
FLOWSENSYS	Flow sensor system for the separation detection at low speed in view of flight	2011-2014	FP7 Clean Sky	Main			Yes	Yes		
FLY-BAG2	Advanced technologies for bomb-proof cargo containers and blast containment units for the retrofitting of passenger airplanes	2012-2015	FP7		Main		Yes	Yes		
FLYSEC	Optimising time-to-FLY and enhancing airport SECurity	2015-2018	H2020					Main		
FRARS	Future Regional Aircraft Requirements Study	2010-2010	FP7 Clean Sky					Main		
FRC GAM 2018	Fast Rotorcraft	2018-2019	H2020 Clean Sky							Main
FRCDoor Demonstra-tor	Flightworthy Flush Lightweight doors for unpressurized Fast Rotorcraft	2015-2020	H2020 Clean Sky		Yes					Main
FUSETRA	Future Seaplane Traffic - Transport Technologies for the Future	2009-2011	FP7					Main		
FUSINBUL	Full scale innovative pressure bulkheads for Regional Aircraft Fuselage barrel on-ground demonstrators	2019-2021	H2020 Clean Sky		Main				Yes	
FUTURE	Flutter-free Turbomachinery Blades	2008-2013	FP7	Main	Yes	Yes				

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
FastCan	Light weight, impact resistant, canopy for fast compound rotorcraft	2017-2020	H2020 Clean Sky	Yes	Main				Yes	
FlexJET	Sustainable Jet Fuel from Flexible Waste Biomass	2018-2022	H2020			Main			Yes	
Flight-Noise-II	Turboprop and Propfan-Equipped Aircraft Noise Emission Model	2011-2014	FP7 Clean Sky		Yes	Yes		Yes		
FloCoTec	FLOw COntrol TEChniques Enabling Increased Pressure Ratios in Aero Engine Core Compressors for Ultra-High Propulsive Efficiency Engine Architectures	2018-2022	H2020 Clean Sky	Main		Yes	Yes			
FlyATM4E	Flying Air Traffic Management for the benefit of environment and climate	2020-2022	N/A					Main		
GABRIEL	Integrated Ground and on-Board system for Support of the Aircraft Safe Take-off and Landing	2011-2014	FP7		Yes	Main		Yes		
GAGARIN	GAlileo-Glonass Advanced Receiver INtegration	2009-2011	FP7				Main	Yes		
GALAHD	General and Light Aviation Head-up Display	2016-2016	H2020				Main			
GAM AIR 2018	AIRFRAME ITD	2014-2018	H2020 Clean Sky		Main					
GAM-2020-ENG	H2020-IBA-CS2-GAMS-2020-2021	2020-2021	H2020 Clean Sky			Main				
GAM-2020-FRC	Fast Rotorcraft	2020-2021	H2020 Clean Sky							Main
GAM-2020-REG	REGIONAL AIRCRAFT 2020-2021	2020-2021	H2020 Clean Sky	Yes		Main				
GAM-2020-SAT	Small Air Transport (SAT) - GAM 2020	2020-2021	H2020 Clean Sky		Yes	Main	Yes			
GAM-2020-SYS	SYSTEMS ITD GAM 2020	2020-2021	H2020 Clean Sky	Yes			Main			
GAM-2020-TE2	TA Technology Evaluator (GAM-2020-TE2)	2020-2021	H2020 Clean Sky	Yes	Yes	Yes	Yes		Yes	Yes

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
GARDEN	GNSS-based ATM for Rotorcraft to Decrease Emissions and Noise	2009-2015	FP7 Clean Sky					Yes		Main
GBSSD(2)	Design & Manufacture of a ground based structural/systems demonstrator (Phase 2)	2010-2012	FP7 Clean Sky	Main						
GBSSD(3)	Ground Based Structural & Systems Demonstrator Phase 3 - Component and sub-system manufacture	2012-2014	FP7 Clean Sky	Main						
GLAMOUR	Gust Load Alleviation techniques assessment on wind tUnnel MOdel of advanced Regional aircraft	2014-2016	FP7 Clean Sky	Main			Yes			
GLOWOPT	Global-Warming-Optimized Aircraft Design	2019-2022	H2020 Clean Sky					Main		
GRA3M	Green Regional Aircraft Avionics Architecture for Mission and Trajectory Management	2010-2011	FP7 Clean Sky				Main	Yes		
GRAIN	GReener Aeronautics International Networking	2010-2012	FP7	Main	Yes	Yes				
GRAIN 2	GReener Aeronautics International Networking-2	2013-2016	FP7	Main	Yes			Yes		
GRAPHICING	Application of graphene based materials in aeronautical structures for de-icing, lightning strike protection, fire barrier and water absorption prevention purposes	2020-2023	H2020		Main					
GREAT	Greener Air Traffic Operations	2020-2023	H2020					Main		
GREEN-WAKE	Demonstration of LIDAR-based Wake Vortex Detection System Incorporating an Atmospheric Hazard Map	2008-2012	FP7		Yes	Yes		Main		

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
GREENAIR	Generation of Hydrogen by Kerosene Reforming via Efficient and Low Emission new Alternative, Innovative, Refined Technologies for Aircraft Application	2009-2013	FP7			Main	Yes			
GREEN BARRELS	Contra-Rotating Open Rotor (CROR) Propeller barrels	2012-2016	FP7 Clean Sky			Main				
GRETEL	GREen Turboprop Experimental Laminar Flow Wind Tunnel Testing	2017-2022	H2020 Clean Sky	Main	Yes				Yes	
GUM	Active GUrney on Main Rotor blades	2012-2015	FP7 Clean Sky	Yes	Yes					Main
GeoVar	Non-rigid geometry variation for fabricated aero structure	2014-2016	FP7 Clean Sky		Main					
GyroWing	Highly integrated ultra-low-noise Gyrometer solution for Smart Fixed Wing Aircraft	2012-2014	FP7 Clean Sky				Main			
H3PS	H3PS - High Power High Scalability Aircraft Hybrid Powertrain	2018-2021	H2020			Main				
HAIRD	Hybrid AIRcraft seating requirement specification and Design	2017-2017	H2020 Clean Sky			Main				
HARVEST	Hierarchical multifunctional composites with thermoelectrically powered autonomous structural health monitoring for the aviation industry	2018-2021	H2020		Main		Yes			
HDSPC	High dense smart power capacitor	2014-2016	FP7 Clean Sky				Main			
HECARRUS	Hybrid ElectriC smAll commuteR aiRcraft conceptUal deSign	2019-2022	H2020 Clean Sky			Main				
HELI-COMFORT	Adaptable power density coating for energy efficient heating of cockpit and cabin	2014-2016	FP7 Clean Sky			Yes	Yes			Main

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
HEPODIS	HVDC Electrical Power cOnversion and DIstribution System	2016-2020	H2020 Clean Sky				Main			
HEXAFLY	High-Speed Experimental Fly Vehicles	2012-2014	FP7	Main	Yes	Yes				
HEXAFLY-INT	High-Speed Experimental Fly Vehicles - International	2014-2019	FP7	Main	Yes	Yes				
HICOMP	Development and Manufacture of High Temperature Composite Aero Engine Parts	2011-2014	FP7 Clean Sky		Main	Main				
HICTAC	High performance composites for demanding high Temperature applications	2013-2015	FP7 Clean Sky		Main				Yes	
HIGHER	HIGHER: High performance Engine for Light Sport Aircraft	2015-2016	H2020			Main				
HIKARI	High speed Key technologies for future Air transport - Research and Innovation cooperation scheme	2013-2015	FP7			Main				
HIPE AE 440	Diesel Powerpack for a Light Helicopter Demonstrator	2011-2015	FP7 Clean Sky			Yes				Main
HISVESTA	High Stability Vertical Separation Altimeter Instruments	2009-2011	FP7	Yes			Main			
HITCOMP	High Temperature Characterization and Modelling of Thermoplastic Composites	2019-2021	H2020 Clean Sky		Main					
HITEAS	High Temperature Energy Autonomous System	2014-2016	FP7 Clean Sky				Main			
HITECAST	High temperature Ni-based super alloy casting process advancement	2012-2014	FP7 Clean Sky		Main	Yes				
HIVOLA	High Voltage amplifier for MEMS-based Active Flow Control (AFC) Actuators	2012-2013	FP7 Clean Sky				Main			
HLFC 4.0	Hybrid Laminar Fluid Control 4.0	2019-2022	H2020 Clean Sky	Main					Yes	

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
HOT	Humidity Optimisation Tool	2014-2016	FP7 Clean Sky	Main			Yes			
HPEM	Development of key technology components for high performance electric motors	2012-2014	FP7 Clean Sky			Main				
HYBRIA	Hybrid laminates. Industrialization for aircraft nose fuselage	2012-2014	FP7 Clean Sky		Main	Yes				
HYCARUS	HYdrogen cells for AiRborne Usage	2013-2018	FP7			Main				
HYPNOTIC	HYbridization via Parallelization based on NOvel Topologies for Innovative Converters	2020-2022	H2020 Clean Sky				Main			
HYPSTAIR	Development and validation of hybrid propulsion system components and sub-systems for electrical aircraft	2013-2016	FP7			Main	Yes	Yes		
HiReLF	Transonic High Reynolds Number Testing of a Large Laminar Wing Half Model	2012-2012	FP7 Clean Sky	Main						
HiTNiFo	Development of an advanced design and production process of High Temperature Ni-based Alloy Forgings	2011-2014	FP7 Clean Sky			Main				
HiTemComFil	Manufacturing of high temperature composite parts for air cooling unit (e.g. cyanate ester / carbon fibres) by filament winding	2013-2015	FP7 Clean Sky		Main				Yes	
HighPMAAC	High Performance Modular Architecture of Acquisition and Control command system dedicated to test Electrical systems for Aeronautics	2011-2014	FP7 Clean Sky				Main			

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
HyPoGA	Feasibility study of a superefficient hybrid power train as a replacement unit for existing engines - Hybrid Power for General Aviation (HyPoGA)	2015-2015	H2020			Main		Yes		
IASS	Improving the Aircraft Safety by Self Healing Structure and Protecting Nanofillers	2012-2015	FP7		Yes		Yes		Yes	Main
ICARO	In-field CFRP surfaces Contamination Assessment by aRtificial Olfaction tool	2011-2013	FP7 Clean Sky		Main					
ICEPASS	innovative ICE Protection And Shielding System for HLFC Demonstrator	2020-2023	H2020 Clean Sky	Main						
ICOA.10.09	International Conference on Airports, October 2009 Paris	2008-2010	FP7					Main		
IDEN	Innovative Distributed Electrical Network	2018-2021	H2020 Clean Sky			Yes	Main			
IDOHAP	INNOVATIVE DESIGN OF HUBS AND PROPELLERS	2010-2011	FP7 Clean Sky			Yes				
IFARS	International Forum for Aviation Research Support Action	2011-2014	FP7		Yes		Yes	Main		
IIAMS	Innovative Infusion Airframe Manufacturing System	2018-2020	H2020 Clean Sky	Yes	Main				Yes	
IMAC-PRO	Industrialisation of Manufacturing Technologies for Composite Profiles for Aerospace Applications	2008-2012	FP7		Main		Yes		Yes	
IMAGINE	Integrated Approach to Manage Glass Fiber Aircraft Insulation Waste	2012-2014	FP7 Clean Sky		Yes				Main	
IMAGINE	Integrated Models of Airlines for a Green Impact on the New Economy	2013-2014	FP7 Clean Sky					Main		
IMBALS	IMage BAsed Landing Solutions	2018-2022	H2020 Clean Sky				Main			

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
IMPSHIELDA	Impact Shield A	2013-2015	FP7 Clean Sky		Main	Yes			Yes	
IMPSHIELDB	IMPact SHIELD Design B	2013-2015	FP7 Clean Sky		Main	Yes				
IMPSHIELDC	IMPact SHIELD design C	2013-2015	FP7 Clean Sky		Main	Yes			Yes	
IMPTEST	Impact test campaign	2013-2015	FP7 Clean Sky		Main	Yes				
INAFLOWT	INnovative Actuation Concepts for Engine/Pylon/Wing Separation FLOw Control (Design, Build and Wind Tunnel Test)	2017-2020	H2020 Clean Sky	Main		Yes	Yes			
INFUCOMP	Simulation based solutions for industrial manufacture of large infusion composite parts	2009-2013	FP7		Main				Yes	
INMA	Innovative Manufacturing of complex Ti sheet aeronautical components	2010-2014	FP7		Yes		Main		Yes	
INSTEP	INnovative SmarT Electric Power Distribution	2017-2023	H2020 Clean Sky				Yes			Main
INTELLICONT	Development and Manufacturing of Intelligent Lightweight Composite Aircraft Container	2018-2021	H2020 Clean Sky		Main		Yes	Yes		
INTERACTION	INnovative TEchnologies and Researches for a new Airport Concept towards Turnaround coordinatION	2013-2016	FP7			Yes		Main	Yes	
INTFOP	Integrating Forging and Process Simulation for turbine disks	2011-2014	FP7 Clean Sky			Main				
IRECE	INDUSTRIAL RECYCLING OF CFRP BY EMULSIFICATION	2013-2014	FP7 Clean Sky		Main				Yes	
IRIDA	Industrialisation of Out-of-Autoclave Manufacturing for Integrated Aerostructures	2012-2014	FP7 Clean Sky		Yes				Main	

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
ITAKA	Initiative Towards sustAinable Kerosene for Aviation	2012-2016	FP7			Main	Yes	Yes		
IVANHOE	Installed adVAnced Nacelle uHbr Optimisation and Evaluation	2019-2022	H2020 Clean Sky			Main				
InVIGO	INtake Vortex Ingestion on Ground Operations	2019-2022	H2020	Main						
InductICE	Efficient, Modular and LightWeight Electromagnetic Induction Based Ice Protection System	2016-2019	H2020 Clean Sky	Yes	Yes		Main			
JETSCREEN	JET Fuel SCREENing and Optimization	2017-2020	H2020			Main	Yes			
JIF2LAND	Jigs and Fixtures for Assembly of the Laminar Wing at the BLADE flight test demonstrator Final Assembly Line	2014-2016	FP7 Clean Sky	Main						
JIF4FLIGHT	Final Assembly Line Assembly Jigs and Fixtures for flight test demonstrator	2012-2016	FP7 Clean Sky	Main						
KEROGREEN	Production of Sustainable aircraft grade Kerosene from water and air powered by Renewable Electricity, through the splitting of CO2, syngas formation and Fischer-Tropsch synthesis	2018-2022	H2020			Main				
KIAI	Knowledge for ignition, acoustics and instabilities	2009-2013	FP7	Yes		Main		Yes		
KLEAN	Knowledge-based EFB for green flight trajectory decision aid	2012-2014	FP7 Clean Sky				Yes	Main		
LAMBLADE	Development and provision of a numerical model to solve laminar-turbulent boundary-layer transition and boundary-layer velocity profiles for unsteady flow conditions	2011-2012	FP7 Clean Sky	Main						

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
LAPCAT-II	Long-term Advanced Propulsion Concepts and Technologies II	2008-2013	FP7	Yes	Yes	Main				
LEAFINNOX	Development of the Lean Azimuthal Flame as an Innovative aviation gas turbine low-NOX combustion concept	2019-2022	H2020 Clean Sky			Main				
LEMCOTEC	Low Emissions Core-Engine Technologies	2011-2017	FP7		Yes	Main	Yes			
LETS DOHOP	Leveraging the Environment of civil air TranSport with DOHOP	2017-2017	H2020					Main		
LIFT	Lightweight Innovative Generator for Future Air Transportation	2018-2021	H2020 Clean Sky	Yes	Main	Yes				
LIGHT-TANK	Feasibility study and prototypes manufacturing of oil tank in thermoplastic for Helicopter Engine	2012-2014	FP7 Clean Sky						Yes	Main
LIGHTBOX	LIGHTWEIGHT COMPOSITE BUS SYSTEM HOUSING FOR EXTREME ENVIRONMENTS	2012-2014	FP7 Clean Sky		Main		Yes		Yes	
LIGHTWELD	Development of welding technologies for light alloys aircraft structures	2013-2015	FP7 Clean Sky		Main					
LOSITA	LOw Subsonic Investigation of a large complete Turboprop Aircraft	2013-2017	FP7 Clean Sky						Main	
LOSPA	Model Design and Manufacturing of the Turbofan Configuration for Low Speed Aerodynamic and Acoustic Testing	2011-2014	FP7 Clean Sky	Main	Yes	Yes				
LPA GAM 2018	Large Passenger Aircraft	2014-2019	H2020 Clean Sky		Yes	Yes	Main			

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
LRI-HiT	Investigations of liquid resin impregnation and out-of-autoclave curing of composites for the high temperature aerospace applications	2012-2014	FP7 Clean Sky		Main				Yes	
LeaTop	Leading Edge Actuation Topology Design and Demonstration	2011-2013	FP7 Clean Sky	Main						
LiBAT	Development of a High Voltage Lithium BATtery	2018-2020	H2020 Clean Sky			Main				
LightAir	Light weight airframe structures through combination with high performance materials	2018-2020	H2020 Clean Sky		Yes				Yes	Main
LubSEP	Test of advanced lubrication equipment	2012-2015	FP7 Clean Sky			Main				
MAAT	Multibody Advanced Airship for Transport	2011-2015	FP7			Yes	Yes	Yes		Main
MAAXIMUS	More Affordable Aircraft Structure through Extended, Integrated, and Mature Numerical Sizing	2008-2016	FP7		Main		Yes		Yes	
MACAO	Development of VOCs and ozone Micro-analysers based on microfluidic devices for Aircraft Cabin Air mOnitoring (MACAO)	2016-2020	H2020 Clean Sky				Main			
MADELEINE	Multidisciplinary ADjoint-based Enablers for LArge-scale INdustrial dEsign in aeronautics	2018-2021	H2020	Yes		Main			Yes	
MAEM-RO	Methodologies and applications of emission measurements on rotorcraft	2010-2013	FP7 Clean Sky			Yes	Yes	Yes		Main
MAGBOX	Aeronautical Magnetic Gear Box	2012-2014	FP7 Clean Sky					Main		

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
MAGNASENSE	Magnetostrictive sensor applications for self-sensing of composite structures	2012-2013	FP7 Clean Sky		Main		Yes			
MAHEPA	Modular Approach to Hybrid Electric Propulsion Architecture	2017-2021	H2020			Main	Yes			
MARQUESS	Multiscale Analysis of AiRframe Structures and Quantification of UncErtaintieS System	2017-2021	H2020 Clean Sky		Main					
MARS	Manipulation of Reynolds Stress for Separation Control and Drag Reduction	2010-2014	FP7	Main	Yes		Yes			
MAS_LAB	Multipurpose Aircraft Simulation Laboratory	2010-2012	FP7 Clean Sky				Main			
MAYA	MAnufacturing of the lining panel using hYbrid technologies; Additive manufacturing, injection moulding and thermoforming	2019-2021	H2020 Clean Sky		Main				Yes	
MEMS MATURITY	MEMS Gyro - Maturity assessment of performance and integration	2012-2015	FP7 Clean Sky		Main					
MEPAFUS	Metitalia prototype tooling for fuselage panel	2018-2019	H2020 Clean Sky		Main				Yes	
MERLIN	Development of Aero Engine Component Manufacture using Laser Additive Manufacturing	2011-2014	FP7			Yes	Yes		Main	
MICMEST	Microwave Clearance Measurement System for Low Pressure Turbines	2012-2015	FP7 Clean Sky			Main				
MICRO-IMU	MEMS-Accelerometer Miniaturisation of the analogue electronics in an Application Specific Circuit (ASIC)	2014-2016	FP7 Clean Sky	Main						
MICROFORM	FORMING OF MICROPERFORATED OUTER SKIN OF HLFC WINGS ASSISTED BY FEM SIMULATON	2020-2022	H2020	Main						

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
MIME	Market-based Impact Mitigation for the Environment	2007-2010	N/A				Yes	Yes		
MISSION	Multifunctional aIrcraft power network with Solid-State electrIcal pOwer SwitchiNg	2019-2021	H2020 Clean Sky				Main			
MISSP	Manufacturing of Integral Stiffened Skin Panels	2017-2020	H2020 Clean Sky		Yes		Yes		Main	
MMTech	New aerospace advanced cost effective materials and rapid manufacturing technologies	2015-2019	H2020						Main	
MORPHELLE	Morphing Enabling Technologies for Propulsion System Nacelles	2013-2015	FP7	Yes	Yes	Main				
NADiA	Novel Air Distribution Approaches	2019-2022	H2020 Clean Sky				Main			
NEMESIS	New trends and Market Survey for the end of life of aircrafts. Eco design Guideline	2013-2014	FP7 Clean Sky						Main	
NEXTWING	Numerical and EXperimental shock conTrol on laminar Wing	2011-2014	FP7 Clean Sky	Main	Yes		Yes			
NHYTE	New Hybrid Thermoplastic Composite Aerostructures manufactured by Out of Autoclave Continuous Automated Technologies	2017-2020	H2020		Main	Yes			Yes	
NICENAV	NICENAV Navigation-grade ITAR-free Certifiable Equipment for the Navigation of manned and unmanned Air Vehicle, based on FOG technology	2015-2015	H2020				Main			
NINHA	Noise Impact of aircraft with Novel engine configurations in mid- to High Altitude operations	2010-2013	FP7			Yes		Yes		
NLF-WingHiPer	NLF Wing High Speed Performance Test	2014-2015	FP7 Clean Sky	Main						

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
NLFFD	NLF Starboard Leading Edge & Top cover design & manufacturing Trials	2010-2014	FP7 Clean Sky	Main						
NOCONDES	Novel Continuous Descent Simulation Test Support	2011-2012	FP7 Clean Sky					Main		
NOGAP	Development of a rapid, multifunction, automated gap filler device	2013-2014	FP7 Clean Sky	Main						
NOVEMOR	Novel Air Vehicles Configurations: From Fluttering Wings to Morphing Flight	2011-2015	FP7	Main	Yes		Yes			
NextGen Airliners	Designing Next-Generation Aircraft via High-Fidelity Computational Models and Optimization	2015-2016	H2020	Main		Yes				
OASIS	Optimisation of Friction Stir Welding (FSW) and Laser Beam Welding (LBW) for assembly of structural aircraft parts	2018-2020	H2020 Clean Sky		Main	Yes			Yes	
OPENAIR	OPtimisation for low Environmental Noise impact AIRcraft	2009-2014	FP7					Yes		
OPTIMIZE	Design of Experiments to OPTIMIZE design solutions for a Power reduction Gearbox	2014-2016	FP7 Clean Sky			Main				
OPTOCOM	Optimal tooling system design for large composite parts	2012-2014	FP7 Clean Sky		Main					
ORBIT	Aerodynamic rigs for VHBR IP turbine	2017-2022	H2020 Clean Sky	Yes		Yes				
ORCA	Development of an optimized large scale engine CFRP annulus filler	2010-2013	FP7 Clean Sky		Main					
OREAT II	Open Rotor Engines Advanced Technologies II	2011-2013	FP7 Clean Sky			Main	Yes			

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
OWACSA	Autonomous Camera System validation and its installation on an in-service Aircraft for Leading Edge Photography	2014-2016	FP7 Clean Sky	Main						
OptiWind	Optimized cockpit windshield for large diameter business aircraft	2018-2023	H2020 Clean Sky				Yes			
PALACE	Pump Architecture Linked to Aircraft Cooling Expectations	2018-2021	H2020 Clean Sky				Main		Main	
PALAST	Assessment of the interaction of a passive and an active load alleviation scheme	2011-2012	FP7 Clean Sky	Yes	Main					
PEL-SKIN	PEL-SKIN: A novel kind of surface coatings in aeronautics	2013-2015	FP7	Main		Yes	Yes			
PERSEUS	Pulsed jEt actuatoRs for SEparation control of tUrbulent flowS	2020-2023	H2020	Main						
PHOBIC2ICE	Super-IcePhobic Surfaces to Prevent Ice Formation on Aircraft	2016-2019	H2020				Main			
PIPS	Passive Ice Protection System	2016-2020	H2020 Clean Sky			Yes	Main			
PJ06 ToBeFREE	Trajectory based Free Routing	2016-2019	H2020					Main		
PJ08 AAM	Advanced Airspace Management	2016-2019	H2020		Yes			Main		
PJ25 XSTREAM	Cross Border SESAR Trials for Enhanced Arrival Management	2017-2019	H2020				Yes	Main		
PJ37-W3 ITARO	INTEGRATED TMA, AIRPORT AND RUNWAY OPERATIONS	2021-2022	N/A					Main		
PJ38-W3-ADSCENSIO	ADS-C ENables and Supports Improved ATM Operations	2020-2022	N/A					Main		
PLASMAERO	Useful PLASMa for AEROdynamic control	2009-2012	FP7	Main	Yes		Yes			
PLEN OPTIMUM	MANUFACTURING OPTIMIZATION OF A PLENUM WITH GFRP CYANATE ESTER-BASED PREPREG	2014-2015	FP7 Clean Sky						Main	

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
PLIT	Panel Liquid Infusion Technology	2013-2014	FP7 Clean Sky	Main	Yes				Yes	
POTRA	Parametric optimisation software package for trajectory shaping under constraints	2010-2012	FP7 Clean Sky					Main		
PPLANE	Personal Plane: Assessment and Validation of Pioneering Concepts for Personal Air Transport Systems	2009-2012	FP7			Yes	Yes	Main		
PPSMPAB	Piezo Power Supply Module for Piezo Actuator Bench	2011-2014	FP7 Clean Sky	Yes						Main
PRIMAE	Packaging of futuRe Integrated ModulAr Electronics	2010-2014	FP7		Yes		Main			
PULSAR PLANE	PulsarPlane: Worldwide Air Transport Operations	2013-2015	FP7		Yes		Main	Yes		
PUMA	PUMA	2012-2014	FP7 Clean Sky		Main				Main	
PercEvite	PercEvite - Sense and avoid technology for small drones	2017-2020	H2020					Main		
Project Sense	Enforcement of the environmental regulations on sulphur emissions from ships using drone technology.	2015-2015	H2020			Yes				
PyModSimA	PySimulator and Modelica Based Collaborative System Design Simulation Analysis Environment for Energy System Applications	2014-2016	FP7 Clean Sky				Main			
QUALIFY	Qualification of insulation materials to engine oils	2011-2015	FP7 Clean Sky			Main				
R-NOZZLE	Rotating nozzle	2013-2016	FP7 Clean Sky			Yes			Main	
RAPTOR	Research of Aviation PM Technologies, mOdelling and Regulation	2019-2021	H2020 Clean Sky					Main		

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
RBF4AERO	Innovative Benchmark Technology for Aircraft Engineering Design And Efficient Design Phase Optimisation	2013-2016	FP7	Main	Yes		Yes			
REACT4C	Reducing Emissions from Aviation by Changing Trajectories for the Benefit of Climate	2010-2014	FP7	Yes		Yes		Main		
RECEPT	RECEPTivity and amplitude-based transition prediction	2011-2015	FP7	Main		Yes	Yes			
RECORD	Research on Core Noise Reduction	2013-2015	FP7	Yes		Yes	Yes			Main
RECREATE	REsearch on a CRuiser Enabled Air Transport Environment	2011-2015	FP7			Yes	Yes	Main		
REDISH	CROR Engine Debris Impact SHielding. Design, manufacturing, simulation and Impact test preparation	2016-2018	H2020 Clean Sky		Yes	Main	Yes			
REG GAM 2018	Regional Aircraft	2014-2019	H2020 Clean Sky	Yes		Main				
REGENESYS	Multi-source regenerative systems power conversion - REGENESYS	2012-2015	FP7 Clean Sky				Main			
REMART	Recycling of Metallic Materials from Rotorcraft Transmissions	2013-2015	FP7 Clean Sky			Yes			Yes	Main
RENERGISE	Innovative management of energy recovery for reduction of electrical power consumption on fuel consumption	2011-2014	FP7 Clean Sky			Yes	Main			
RETAX	Rotorcraft Electric Taxiing	2011-2013	FP7 Clean Sky					Yes		Main
RETROFIT	Reduced Emissions of TRansport aircraft Operations by Fleetwise Implementation of new Technology	2010-2012	FP7			Main	Main	Yes		

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
RIBES	Radial basis functions at fluid Interface Boundaries to Envelope flow results for advanced Structural analysis	2014-2016	FP7 Clean Sky	Main						
RIFPA	Grooved paint surface manufacturing for aerodynamic drag reduction testing	2011-2013	FP7 Clean Sky	Main						
RTMGear	RealTime Monitoring Power Reduction Gearbox	2014-2016	FP7 Clean Sky			Main				
ReINTEGRA	Innovative End of Life procedures for REcycling INTEGRAl welded Al-Li Aerostructures	2020-2023	H2020 Clean Sky						Main	
SABRE	Shape Adaptive Blades for Rotorcraft Efficiency	2017-2021	H2020	Yes						Main
SABRE	Transforming the biodiesel industry to meet Europe's need for sustainable aviation fuel: business feasibility study, technical validation and real-world demonstration	2016-2016	H2020			Main			Yes	
SADE	Smart High Lift Devices for Next Generation Wings	2008-2012	FP7	Main	Yes			Yes		
SAFAR	Small Aircraft Future Avionics Architecture	2008-2012	FP7				Main	Yes		
SALAMANDER	Soakback Assessment using LAttice Boltzmann Method and Aerothermal Nodal-network for the Design of the Engine-bay Region	2018-2021	H2020 Clean Sky	Yes		Main				
SALUTE	Smart Acoustic Lining for UHBR Technologies Engines	2018-2022	H2020 Clean Sky	Yes	Yes	Main				
SANDIT	Design and manufacture of a flight worthy intake system (scoop/NACA divergent intake) SCOOP AND NACA DIVERGENT INTAKE TRIAL (SANDIT)	2013-2016	FP7 Clean Sky				Main		Main	

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
SAT GAM 2018	Small Air Transport (SAT) - GAM 2018	2014-2019	H2020 Clean Sky		Yes	Main	Yes			
SAVER	Smart Battery with Active Power Conversion	2013-2015	FP7 Clean Sky			Main	Yes			
SCALAiR	Scaled Test Aircraft Preparation and Qualification	2016-2021	H2020 Clean Sky	Yes		Yes	Yes			
SCOPUS	Smart Converters for Optimized Power Usage and Storage	2019-2021	H2020 Clean Sky				Main			
SEALEDBOX	AEROSPACE HOUSING FOR EXTREME ENVIRONMENTS	2013-2015	FP7 Clean Sky		Main				Yes	
SELFRAG CFRP	High Voltage Pulse Fragmentation Technology to recycle fibre-reinforced composites	2012-2014	FP7 Clean Sky		Main				Yes	
SENTRY	Sustainable Dismantling and Recycling of Metallic Aerostructures	2014-2015	FP7 Clean Sky						Main	
SEPDC	Smart Electrical Power Distribution Centre	2011-2014	FP7 Clean Sky				Yes			Main
SHEFAE	Surface Heat Exchangers for Aero-Engines	2013-2016	FP7		Yes	Main	Yes			
SHERLOC QSP	Quilted Stratum Processes (QSP) for low cost and eco thermoplastic manufacturing of complex composite parts	2017-2019	H2020 Clean Sky		Main				Yes	
SIEDIT	Development of a Slat with Integrated Electrical Deicers for Icing Wind Tunnel Tests	2011-2013	FP7 Clean Sky	Main						
SIMEAD	Suite of integrated models for electrical aircraft drives	2011-2013	FP7 Clean Sky				Main			
SIPAL	Development and Manufacture Scoop Intake and Channel incl. ice and debris protection and acoustic absorbers	2010-2011	FP7 Clean Sky		Main		Yes			
SKOPA	Skin friction and fiber-optics-based surface pressure measurements for aircraft applications	2018-2021	H2020 Clean Sky	Main		Yes	Yes			

Project acronym	Project name	lProject duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
SMAES	Smart Aircraft in Emergency Situations	2011-2014	FP7	Yes	Main					
SMART-FTI	Surface Module Approach for Rapid Testing in Flight Test Instrumentation	2020-2023	H2020 Clean Sky	Main						
SMARTER SHIELD	Smart erosion shield for electro-mechanical de-icers	2013-2015	FP7 Clean Sky	Yes			Main			
SMARTWISE	Smart Miniaturized and Energy Autonomous Regional Aircraft Wireless Sensor	2020-2023	H2020				Main			
SME-AERO-POWER	Empowering European Aeronautical SMEs to Participate in EU Research	2011-2013	FP7		Main			Yes		
SMS	Smart Morphing and Sensing	2017-2020	H2020	Main	Yes		Yes			
SOG PEERS	SOG Power Electronics with Energy Recycling System	2012-2015	FP7 Clean Sky			Yes	Main	Yes		
SOLAR-JET	Solar chemical reactor demonstration and Optimisation for Long-term Availability of Renewable JET fuel	2011-2015	FP7			Main	Yes	Yes		
SOPRANO	Soot Processes and Radiation in Aeronautical inNOvative combustors	2016-2021	H2020	Yes		Main	Yes			
SORCERER	Structural pOweR CompositEs foR futurE civil aiRcraft	2017-2021	H2020 Clean Sky		Main	Yes	Yes			
SPAIN	Smart Panels for SAT Aircrafts Cabin Insulation	2016-2019	H2020 Clean Sky		Yes		Main			
STARTGEN SYS	ADAPTATION KIT DESIGN & MANUFACTURING: APU DRIVING SYSTEM	2012-2015	FP7 Clean Sky		Yes	Yes	Yes			Main
STEADIEST	Design, development and flight qualification of a supercritical composite shaft drive line for tiltrotor main drive system	2019-2022	H2020 Clean Sky		Yes					Main

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
STRAINWISE	Hardware & Software Development of Wireless Sensor Network Nodes for Measurement of Strain in Airborne Environment	2010-2012	FP7 Clean Sky				Main			
STRONGR CRAFT	Safe, Technically Robust and Optical New Generation fuel system to be integrated on new RotorCRAFT	2018-2023	H2020 Clean Sky			Yes	Yes		Yes	Main
SUNSET	Storage energy UNit for Smart and Efficient operation on Tarmac	2018-2021	H2020 Clean Sky			Yes	Main	Yes		
SUPREMAE	A Supervised Power Regulation for Energy Management of Aeronautical Equipments	2011-2013	FP7 Clean Sky				Main			
SWING	Sonaca WING flap process Development	2019-2022	H2020 Clean Sky	Main	Yes					
SYS GAM 2018	Systems ITD	2014-2019	H2020 Clean Sky				Main			
SYS-ARCHITECTU-RE GRA	Development of an Advanced Software Tool for Aircraft-level Investigation of the Impact of new Architectures for Avionics and On-board General Systems for the Green Regional Aircraft	2009-2010	FP7 Clean Sky		Main					
SafeShore	System for detection of Threat Agents in Maritime Border Environment	2016-2018	H2020				Main			
Sealed withoUT aKiss	Non-destructive testing (NDT) of bonded assemblies	2019-2022	H2020 Clean Sky		Main	Yes				
SlotMachine	A Privacy-Preserving Marketplace for Slot Management	2020-2022	N/A					Main		
TACTIC	in flight Trajectory optimizAtion through advanCed simulation TechnICs	2013-2015	FP7 Clean Sky			Yes		Main		

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
TAIRA	Fault Tolerant Aileron Actuation System for Regional Aircraft	2017-2021	H2020 Clean Sky			Yes	Main		Yes	
TAUPE	Transmissions in Aircraft on Unique Path Wires	2008-2012	FP7			Yes	Main	Yes		
TE2 GAM 2018	Technology Evaluator 2 - GAM 2018	2014-2019	H2020 Clean Sky	Yes	Yes	Yes	Yes		Yes	Yes
TECC-AE	Technologies Enhancement for Clean Combustion in Aero-Engines	2008-2012	FP7	Yes		Main		Yes		
TEENI	Turboshaft Engine Exhaust Noise Identification	2008-2013	FP7	Yes		Yes			Yes	Main
TEMGIR	Thermal and electrical Mock-ups for Thermal Management of a Ground Integration Test Rig	2014-2016	FP7 Clean Sky				Main			
TEMPO	Thermal Exchange Modelling and Power Optimization	2011-2014	FP7 Clean Sky		Yes		Main			
TESTHEMAS	Design and Implementation of a Load Simulator Rig and Ground Test Bench Adaptation Kit for a HEMAS Test Rig	2013-2016	FP7 Clean Sky				Yes			
TETRA	TEst of Tilt-Rotor Air intakes	2014-2017	FP7 Clean Sky	Yes	Yes	Yes				Main
TFAST	Transition Location Effect on Shock Wave Boundary Layer Interaction	2012-2016	FP7	Main	Yes		Yes			
THERMICOOL	Thermoelectric cooling using innovative multistage active control modules	2014-2016	FP7 Clean Sky				Main			
TICOAJO	TItanium COmposite Adhesive JOints	2017-2019	H2020 Clean Sky	Main	Main	Yes				
TIDE	Tangential Impulse Detonation Engine	2013-2016	FP7			Main				
TIFAN	manufacturing by SLM of TItanium FAN wheels. Comparison with a conventional manufacturing process	2013-2015	FP7 Clean Sky		Yes				Main	

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
TMC Brake	Development of a titanium composite brake part for weight reduction and hence lower fuel burn and emissions on a large, long haul aircraft	2015-2016	H2020		Yes	Yes	Main			
TOD	Thermoplastic on Doors	2018-2021	H2020 Clean Sky		Main					
TOPMOST	Optimization two phases cooling solution using micro pump brick	2017-2019	H2020 Clean Sky				Main			
TRADE	Turbo electRic Aircraft Design Environment (TRADE)	2017-2020	H2020 Clean Sky	Yes	Yes	Main				
TRAIL	Design, manufacture and deliver a high performance, low cost, low weight Nacelle Structure for Next Generation Tilt-Rotor (NGCTR)	2019-2023	H2020 Clean Sky		Main	Yes				
TRANSCEND	Technology Review of Alternative and Novel Sources of Clean Energy with Next-generation Drivetrains	2019-2022	H2020 Clean Sky			Yes	Main			
TRAVEL	Tilt Rotor ATM Integrated Validation of Environmental Low Noise Procedures	2012-2015	FP7 Clean Sky					Yes		Main
TRIADE	Development of Technology Building Blocks for Structural Health Monitoring Sensing Devices in Aeronautics	2008-2012	FP7		Yes	Yes	Main			
TRINITI	Multi-Material Thermoplastic high pressure Nitrogen Tanks for Aircraft	2019-2021	H2020 Clean Sky		Main					
TSA	Telemharsh - Telemetric System Acquisition in Harsh Environment	2013-2016	FP7 Clean Sky			Main				
TURBOGAS	Advanced turbofan engine gaseous emissions model	2010-2011	FP7 Clean Sky			Main				
TecALSens	Advanced Load Sensing technology for Aerospace Application	2018-2020	H2020 Clean Sky						Main	

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
Thermoplastic scroll	Manufacturing and optimization of a PEEK scroll by fusible core injection moulding	2014-2015	FP7 Clean Sky		Main	Yes				
TurboNoiseBB	Validation of improved turbomachinery noise prediction models and development of novel design methods for fan stages with reduced broadband noise	2016-2020	H2020	Yes		Yes				
ULTIMATE	Ultra Low emission Technology Innovations for Mid-century Aircraft Turbine Engines	2015-2018	H2020			Main	Yes			
UNIFIER19	Community Friendly Miniliner	2019-2022	H2020 Clean Sky					Main		
UTOPEA	UHBR Engine Technology for aircraft OPeration, Emissions and economic Assessments	2020-2023	H2020 Clean Sky			Main				
VALEMA	VALidation tests of ElectroMechanical Actuators and its dedicated control units at TRL 6 level	2017-2022	H2020 Clean Sky				Main		Yes	
VALIDATETSAA	Validation of TSAA coating technology. Development of procedures and standards manual. Technical and economical study.	2013-2014	FP7 Clean Sky				Yes		Main	
VALORIE	Validate Operations to Reduce Impact on Environment	2013-2014	FP7 Clean Sky			Yes		Main		
VELOCIRAPTOR	Development of Synthetic Jet Actuator Hardware for the Green Regional Aircraft Low Noise Configuration	2010-2011	FP7 Clean Sky	Main						
VENUS	inVestigation of distributEd propulsion Noise and its mitigation through wind tUnnel experiments and numerical Simulations	2020-2023	H2020 Clean Sky			Yes				

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
VIAFUMA	VIbration Analysis methodology for FUel MAnifolds of lean burn engines	2014-2016	FP7 Clean Sky			Main				
VIPER	Valve hIgh PERformances for flow control separation in aircraft	2012-2016	FP7 Clean Sky	Main		Yes	Yes			
VLD2-W2 STAIRS	Surface Traffic Alerts Improve Runway Safety	2019-2022	H2020					Main		
VOCAL-FAN	VIRTUAL OPTIMIZATION CFD PLATFORM ALLOWING FAN NOISE REDUCTION	2011-2013	FP7 Clean Sky	Yes	Yes					
VOLT	Innovative high VOLTage network battery concept	2016-2021	H2020 Clean Sky			Yes	Yes			Main
VTAIL	Design and manufacturing of a business jet model for high and low speed tests	2014-2016	FP7 Clean Sky						Main	
WASIS	Composite fuselage section Wafer Design Approach for Safety Increasing in Worst Case Situations and Joints Minimizing	2011-2014	FP7		Main	Yes			Yes	
WELDMECS	Welding Metallurgy and Cracking in Superalloys	2013-2015	FP7 Clean Sky		Main	Yes	Yes			
WELDMINDT	Open rotor Engine WELDed parts inspection using MINiaturizable NonDestructive Techniques	2012-2015	FP7 Clean Sky			Main				
WEMACS	WEights and MAnufacturing Costs	2010-2011	FP7 Clean Sky		Yes					
WENEMOR	Wind Tunnel Tests for the Evaluation of the Installation Effects of Noise Emissions of an Open Rotor Advanced Regional Aircraft	2011-2013	FP7 Clean Sky	Yes	Yes	Yes				
WILDCRAFT	Wireless Smart Distributed End System for Aircraft	2012-2014	FP7 Clean Sky			Yes	Main	Yes		
WIMO	Outer Wing Metrology	2011-2016	FP7 Clean Sky	Main						

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
WINFC	Weather INformation Fusion and Correlation for weather and traffic situational awareness	2014-2015	FP7 Clean Sky	Yes				Main		
WINFRAME 4.0	Full scale innovative composite windows frames for Regional Aircraft fuselage barrel on-ground demonstrators	2018-2021	H2020 Clean Sky		Main					
WINGTECH _EVALUA-TION	Wing Box Technology Evaluation - Trade-Off Study for the Ranking of New Technologies Best Fitting Wing	2011-2012	FP7 Clean Sky	Main	Yes					
WINNER	smart WINg panels for Natural laminar flow with functional Erosion Resistant COATings	2016-2019	H2020 Clean Sky	Main	Yes					
WISE	A novel approach to remote and real-time aircraft maintenance	2017-2019	H2020					Main		
WISE	WISE - Wide Instantaneous Support Equipment	2015-2015	H2020					Main		
WITTINESS	WindTunnel Tests on an Innovative Regional A/C for Noise assessment	2014-2017	FP7 Clean Sky	Yes	Yes	Yes				
Wearable4 Work	Wearables for Workplace Productivity Safety	2016-2016	H2020						Main	
WiMCam	BLADE Wing Measurement Campaign	2015-2016	FP7 Clean Sky	Main						
Wimper	Windshield with improved bird-strike, erosion, de-fogging, de-icing and IR performance	2017-2021	H2020 Clean Sky		Yes		Yes			Main
X-WALD	Avionic X-band Weather signal modeling and processing vALidation through real Data acquisition and analysis	2014-2016	FP7 Clean Sky				Yes	Main		
Z DAMPER	Z-Coupled Full System for Attenuation of Vibrations	2014-2016	FP7 Clean Sky		Yes	Yes	Yes			

Project acronym	Project name	Project duration	Source of funding	Aerodynamics	Structures	Propulsion	Systems	Operations	Eco-design	Rotorcraft
cLEvER	Lightweight and rEliable Emergency exits and cabin footstep for fast Rotorcraft	2018-2023	H2020 Clean Sky	Yes	Yes		Yes			Main
extra-laser	EXTRApolation and technical and economic study of a LASER beam welding technology (extra-laser)	2013-2014	FP7 Clean Sky		Main				Yes	
iSSE	Improvement of numerical models for JTI/GRA Shared Simulation Environment	2012-2015	FP7 Clean Sky				Main			
windtunnel	DESIGN AND MANUFACTURE OF A WIND TUNNEL TEST HARDWARE	2011-2013	FP7 Clean Sky	Yes	Main		Yes			

Annex 3. Scopus database regular expression analysis keywords

REGEX (documents retrieved in April 2021)

Aviation emissions reduction sub-themes and scientific research terms

Sub-theme	Sub-theme description
Air transport (general)	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS-KEY ((aviation or aircraft* or rotorcraft*)) AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Aerodynamics	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS-KEY ((aviation or aircraft) and (aerodynamic* or morphing or laminar or flutter or flaps or swirl or cfd or drag or mach or aeroelastic)) AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Structures	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS-KEY ((aviation or aircraft) and (airframe or fuselage or thermoplastic or adhesive or composites or laminate or polymer or “wing box” or welding or weld or lightweight)) AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Propulsion	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS-KEY ((aviation or aircraft) and (engine or propulsion or motor or cylinder or exjet or turbofan or propeller or inlet or nacelle or “aero engine” or combustion or “electric aircraft”)) AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Systems	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS-KEY ((aviation or aircraft) and (“landing gear” or “electric power system” or eps or “power electronics” or brakes or antenna or avionic* or HVDC or cockpit or “energy management”)) AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Operations	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS-KEY ((aviation or aircraft) and (airport* or delay or schedule or interline or crew or airline* or trajectory* or “air traffic”)) AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Eco-design	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS-KEY ((aviation or aircraft or airport*) and (lca or lcc or “life cycle” or recycling or recyclability or eol)) AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Rotorcraft	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS-KEY ((rotorcraft or tiltrotor or “tilt rotor” or “compound rotorcraft” or “fast rotorcraft” or “helicopter blade” or “rotary wing” or “vertical take-off” or vtol)) AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))

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