



Delft University of Technology

## A new dawn of aviation

Werij, Henri

### Publication date

2019

### Document Version

Final published version

### Published in

Skyline

### Citation (APA)

Werij, H. (2019). A new dawn of aviation. *Skyline*, (28), 5-5.

### Important note

To cite this publication, please use the final published version (if applicable).  
Please check the document version above.

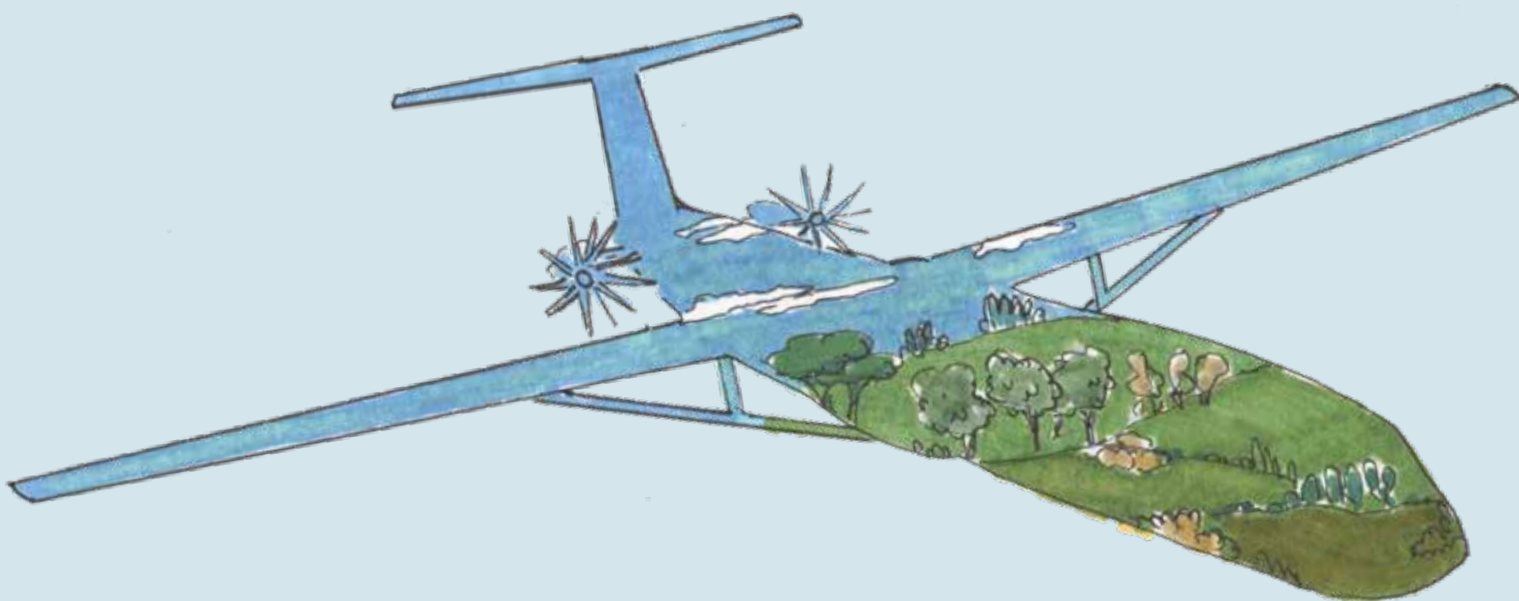
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## Powering Partnerships Towards Innovation Architecture



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## Delivering Electrification Through Partnership



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**Axel Krein**

*Executive Director, Clean Sky 2 Joint Undertaking*



## Powering Partnerships Towards Innovation Architecture

By the time you read these lines, the European Union will have in place a new European Parliament and a newly-appointed European Commission will soon take office. They have on their shoulders the formidable challenge of legislating to improve the life of Europeans at a time of huge societal change, economic uncertainty and rising awareness of the urgency of addressing climate change.

A key priority on their agenda to help fulfil that objective is impact-driven European research and innovation. Building on the Horizon 2020 research programme, Horizon Europe will provide an even greater opportunity to steer further excellence into European research, making sure that more actors have a chance to contribute and that outcomes are impactful, meeting far-reaching objectives such as mitigating damage to the environment.

A major step towards a potential future Clean Aviation Partnership under Horizon Europe took place at the Paris Air Show - Le Bourget in June 2019. Led by Airbus CEO Guillaume Faury, Safran CEO Philippe Petitcolin, Rolls-Royce CEO Warren East and Leonardo CEO Alessandro Profumo, twenty-three Aeronautics Industry leaders, Research Organisations and University Associations across Europe signed a Joint Declaration to express their strong commitment to a future European partnership that can lead the way towards a deep decarbonisation of aviation by 2050. The Joint Declaration made it clear that the partnership should build on the progress made under the Clean Sky programmes, and develop further-reaching innovations and concrete roadmaps for their implementation in a new breed of aircraft from 2030 and beyond. To highlight that these ambitious aims can only be achieved through cooperation between the public and private sectors, the Declaration

was handed over to Jean-Eric Paquet, Director-General for Research and Innovation, European Commission.

In that respect, the universities, research organisations and industrial companies continue to work on the technical proposal for a new Clean Aviation Partnership programme, which will aim to drive towards a deep decarbonisation of aviation, supporting the European Green Deal, leading to a carbon-free society by 2050, and taking European aviation and aeronautics to the forefront globally in this transition.

Initial analysis has identified a number of ambitious zero- and low-emission concepts. These include full electric and hybrid-electric solutions applicable to regional and short-range categories. Hydrogen or low-carbon fuel-powered architectures using ultra-efficient gas turbines and advanced aircraft configurations will cover the medium and long-range segments.

As a consequence, substantial research activity will need to be actively aligned with and connected to the future Partnership, ranging from Member States' national innovation funding initiatives in aeronautical fields to synergy areas within Horizon Europe, all supported by commonly agreed goals and objectives within an integrated and comprehensive roadmap.

It is now becoming increasingly clear that a future Clean Aviation Partnership would build an effective European 'innovation architecture' for aviation, ensuring shared roadmaps and enabling synergies with other European Partnerships and EU research programmes, national research and innovation programmes, and European structural investment funds and financial instruments.

Combining resources and funding will produce a substantial leverage effect and help reach the challenging objective of deep decarbonisation.

The overall resource requirement to meet this challenge inside the Horizon Europe timeframe is likely to exceed a staggering figure of €12 billion for European and Member States aeronautics research. This includes research, technology development and demonstrations only, as the implementation of the results will be yet again a multiple of this amount in terms of developing and certifying the new aircraft, engines and systems.

We are not talking about a mere continuation from Clean Sky 2 to a future Clean Aviation Partnership. This is a vital and necessary transformation to successfully take on the challenge ahead.

In parallel, Clean Sky 2 is still running with full steam ahead! In this Skyline issue you will find examples of Clean Sky 2 projects such as CORNET, which aims to improve understanding of engine noise in order to provide industry with new computer-based methods to predict noise in future engines; and ALC (Aircraft Light Communication), which is exploring the use of LiFi (a high-speed wireless communications system using light) in the cockpit for safer, more efficient data exchanges; and iBearing, an advanced sensor-enabled monitoring system that gauges the health of critical bearings in high-temperature environments, enabling aero-engine starter generators to operate safely at higher speeds and reduce fuel burn. You will also get an insight into what the next generation of engineers is working on from the winners of our Clean Sky Academy PhD Award.

I thank Paul Stein of Rolls-Royce, Henri Werij of TU Delft, and Maxime Hardouin of the SME AeroSpline for the views on what the future Partnership could look like and what this means for the industry's big players, SMEs and universities.

Please stay updated on the Clean Sky website for results, news and key events.

# DELIVERING ELECTRIFICATION THROUGH PARTNERSHIP

**Paul Stein**

*Chief Technology Officer, Rolls-Royce plc*



Looking to the future we may expect by 2030 8.6 billion people on Earth; 6 billion of those will be annual flyers and 5 billion will reside in cities. In 2019 global annual emissions of CO<sub>2</sub> created by humans will reach 33 billion tonnes, with aviation representing approximately 2%.

To support the rising demand for air travel and achieve CO<sub>2</sub> emissions reduction targets, the aviation industry is developing environmentally friendly technologies and practices. Clean Sky 2 is the leading R&T programme bringing forward solutions to these challenges and Rolls-Royce is proud to have been part of this community since the start of Clean Sky in 2008.

Rolls-Royce has an environmental strategy for aviation that has three strands: increasingly fuel-efficient products; encouraging the development of sustainable aviation fuels; and pursuing breakthrough technologies especially electrification. On efficiency, our UltraFan® demonstrator programme, supported by Clean Sky 2 funding in the Engines Integrated Technology Demonstrator Programme brings a new architecture to the market for medium to large engines and is targeted to reduce CO<sub>2</sub> emissions by 25% relative to the first Trent engine (mid 1990s). The fuels industry is developing sustainable aviation fuels based on several processes and we expect to see significant volume production with time. While gas turbines will power large aircraft for some time; electrification will play an increasing role via new propulsion configurations and with larger aircraft through more electric systems.

Electrification is one of the key enablers towards sustainability for many transportation systems because of its ability to power pure electric and hybrid machines with lower CO<sub>2</sub> footprints. It is possible that we will see a new type of regional air transport, being more fuel efficient and quieter than current turboprops, which could bring a new approach to mass mobility. For larger aircraft electrification will enable simplification of gas turbine internal design, unlock new methods of managing aircraft drag, and open new benefits to an aircraft at platform level.

In hybrid electric propulsion, we are leading the propulsion challenges in the E-Fan X project, which when flying in 2021 will demonstrate hybrid electric propulsion at megawatt scale. Working in partnership with Airbus we are integrating several key techno-bricks in power generation, thermal management and electrically driven thrust generation with one engine converted on a four engine Bae 146. Clean Sky 2, via the Large Passenger Aircraft Innovative Aircraft Demonstrator Platform, is specifically supporting our E-Fan X megawatt-class electrical development activities and in partnership with Airbus, a ground test of the entire E-Fan X electrical system. A key milestone was achieved in August when our engineers started ground testing of our compact 2.5-megawatt generator for E-Fan X. More broadly, our Clean Sky 2 activity has also identified several challenges that need further detailed study – we have launched 5 projects under call for proposals on electrification topics and are very pleased to be working with 16 different organisations to better understand the technical solutions required.

In parallel to Clean Sky 2, we are working in partnership with other organisations and agencies. In the UK we are working on ACCEL with the Aerospace Technology Institute to solve challenges of energy storage capacity and powertrain performance towards setting new records for an electrically powered aircraft. In Germany, we look forward to new opportunities to strengthen kilowatt-class hybrid electric power and propulsion research and development activities in Brandenburg.

Whilst challenges include the technology for very high power to weight machines, power electronics and batteries, thermal management, and systems integration complexity we can see a path towards solving these issues. This will require government support in research and technology, test infrastructure, and legislation. Academia, research organisations and industry will also have to join efforts to develop key knowledge, technology and effective supply chains. And fundamental to all of this is the need to develop global standards to accommodate new technologies where required.

This year's Paris Air Show saw two announcements that set foundations for future-focussed activity; the common theme in both is partnership. Firstly, seven of the leading aviation companies' CTOs collectively confirmed their commitment to sustainability of aviation. Secondly, the European Aviation community, represented by 23 Aeronautics Industry leaders, Research Organisations and University Associations indicated to the European Commission their strong focus on deep decarbonisation and a recommendation that this is best addressed by establishing a strong and robust public-private partnership within Horizon Europe.

In conclusion, Partnership is required firstly at a macro level to establish the frameworks and pillars of activities with all relevant stakeholders; this then unlocks the second form of partnership – collaboration. We can then collectively bring all our capabilities to bear on pulling technology forward that lays foundations to deliver the environmental targets that the aviation industry has set itself.





# A NEW DAWN OF AVIATION

**Henri Werij**

*Dean Aerospace Engineering, TU Delft*



To counter the climate effects of flying, we must start a revolution in aviation. Solutions must and will be found. I believe we're at a new dawn of aviation.

Everybody who takes a closer look at aviation will see that there has been an incredible improvement in fuel efficiency of commercial planes. Despite the fact that modern aircraft at first sight very much resemble their predecessors (a tube with wings), the fuel consumption per passenger kilometre has decreased significantly, due to vast improvements in propulsion, aerodynamics and materials. However, as we all know air travel has become so common that these improvements are completely nullified by the exponential growth of global passenger-kilometres. Emission of CO<sub>2</sub> from aviation currently amounts to 2.5% of the total global emission and this number will rise fast if we do not act. It is also important to realise that CO<sub>2</sub> is only half the story: high-altitude emission of NO<sub>x</sub> leading to ozone (not at the very high altitudes where we need it for protection against harmful solar radiation) and formation of contrails/thin cirrus clouds also contribute to an increased greenhouse effect.

The aviation community has realised that a change is required and therefore adopted the ambition to lower the overall CO<sub>2</sub> emission in 2050 to 50% of the amount produced in 2005. In Clean Sky we are trying to further improve fuel efficiency. We also look at alternatives for fossil fuel, including electric propulsion. The latter seems promising for the shorter range and a small number of passengers, but the limited energy density of batteries prevents long-haul mass transportation. Using hydrogen and fuel cells is another option that is studied. The challenge we are facing with (hybrid) electric propulsion becomes daunting when we think of the amount of power needed by current long-haul aircraft. This is comparable to the energy produced by roughly ten of the largest wind turbines at sea, each having blades larger than the wingspan of our biggest planes. Think about the cabling, and the thermal issues we will encounter.

As a result, the current prediction is that aircraft/engine developments will allow for a 100% reduction of CO<sub>2</sub> emission up to a range of 500 km, but above that things will become increasingly harder. For ranges above 3000 km the expectation is that we will only see a 15-30% improvement per passenger-kilometre. With a sector that shows a doubling every 15 years (4.5%/year) and assuming an optimistic year of introduction of the required next-generation of commercial aircraft, I fear that with the improvements currently envisioned we will see a continuing growth of CO<sub>2</sub> emission until 2040, followed by some stabilisation at best, and then a growth again. In 2050 the gap to the "50% of 2005" goal will be bigger than the total emission we have today. This will most probably have to be offset by using sustainable aviation fuels, if we want to adhere to the 2050

target. And by the way, today we use a billion litres of kerosene per day.

Continuing in the current way is unacceptable and we must start a revolution, which I consider comparable to the developments at the dawn of aviation a little over 100 years ago. The challenges are enormous, but solutions must and will be found. The question is: how soon? For sure it will require radical improvements in nearly every aspect of aviation, be it aircraft designs, materials, propulsion systems, batteries/fuel cells/sustainable fuel, and routing. It will require a concerted international collaboration based upon added value of each partner and stakeholder. It requires dedication, commitment to a long battle and a drastic change of mindset. I am ready for it. You too?



# DIVERSE TALENTS ON BOARD FOR AEROSPLINE'S CORDIAL PROJECT

**Maxime Hardouin**

*Director, AeroSpline*



We at AeroSpline have been coordinating Clean Sky 2's CORDIAL project, part of the Airframe technology platform, since early 2017. The overall objective of the CORDIAL project is to develop a disruptive One Way Assembly system that will involve a pair of collaborative robots and new compact drilling and fastening units.

AeroSpline is an SME, and back in 2017 we had only 3 employees. This has since grown to 15. This is not just a simple question of growth: it is an improvement with the recruitment of complementary talents. We were, at the start, two general engineers working in the field of aerospace manufacturing and robotics. Now, we have a wide range of diverse talents on board – even two cognitive engineers and a biologist-anthropologist. I am proud to say that our participation in the Clean Sky 2 programme has been a real attraction for new highly-qualified people. We are inclusive, with 5 women out of 15 employees, and a broad geographical spread: we are an international team bringing together talented engineers from across Europe, including Belgium, Poland, France, Italy and Spain – Clean Sky quickly projected us on a European scale!

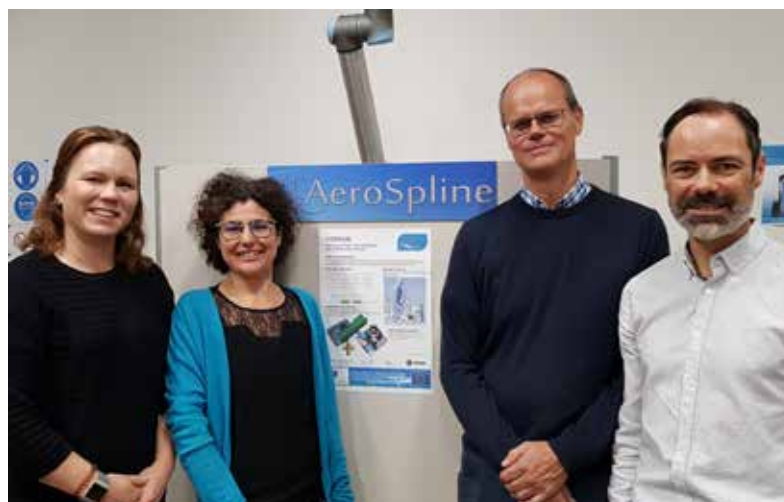
In terms of collaboration, it is thanks to Clean Sky that we have been able to work across Europe, with major industrial groups and

industry leaders. We all share, regardless of the size of the companies and partner laboratories, the same idea of protecting and progressing qualified manual work, such as the assembly process of aerostructures. Our CORDIAL project aims to develop a light and collaborative robotics for the assembly of structures. The ambition of simplification and frugality must allow diffusion within the manufacturing ecosystem of subcontractors. The first benefit of the project is to make this new robotics accessible and to preserve know-how and local production in Europe. The second benefit is to accelerate the replacement of older generations of aircraft: we must reduce cycles to significantly reduce carbon emissions.

In the end, the CORDIAL project will offer a demonstration with a level 6 TRL. We are really satisfied with the technological advances and we really believe in the industrial and commercial value of the CORDIAL innovation. We also know that the next steps towards an industrial product are important. This is why we plan to promulgate a maturity project using, for example, an SME Instrument programme.

Regarding the evolution of the future Clean Sky programme, I think as an SME manager that the simplification and reduction of the number of requirements and paperwork must be the rule. I believe well-formatted and editable document templates with LibreOffice, for example, could be helpful. For reasons of universality and computer security, we should no longer be dependent on a private office suite. Finally, and this is really important to me, we should always have on the front page of collaborative European research sites a map of Europe with useful drivers. We must have an overview of our common European projects at all times.

In summary, the Clean Sky programme is a challenge that is certainly leading to a higher level of maturity in many terms: scientific, human, culture, enterprise, life. And while we were hesitant and a bit shy at first, we found out that we could always count on the astonishing empathy of the Clean Sky officers. We know we should never hesitate to ask for help when needed, and our good cooperation with the Joint Undertaking staff has fostered a great atmosphere leading to the best possible results for our project.



## CORDIAL

### Drilling and Ergo-Tech Installation with Collaborative Robots

**Aim and objectives**  
Develop a light weight, flexible robotic demonstrator for the structural assembly of an aircraft door using the one-way-assembly process (OWA) for drilling and installation of ERGO-TECH fasteners. Provide an innovative demonstrator cell where flexible robots will collaborate with operators to make production smarter.

**One Way Assembly**

**Mobile Platform**  
Flexible with Human present in the workstation  
Safe and efficient

**CORDIAL End-effector**  
Multifunctional - Drill and countersink  
Arconic Ergo-Tech fastener installation with sealant on head  
Quality vision control

**Light Weight Robotics**  
From classical heavy automation to light-weight robots working with human in a common workstation

Email: contact.cordial@aerospline.eu

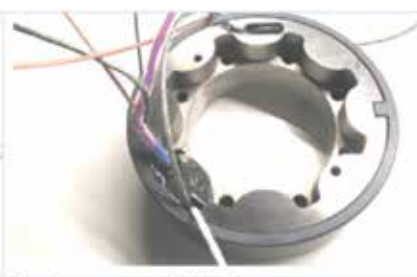
# ZOOM IN CLEAN SKY 2 RESULTS

## iBearing maximises service life for starter-generator bearings

**An advanced sensor-enabled monitoring system that accurately gauges the health of critically important bearings that operate within harsh high-temperature environments will enable aero-engine starter generators to operate safely at higher speeds, thereby reducing fuel burn and contributing to ACARE goals. Clean Sky's iBearing project brings real-time monitoring intelligence to bearings, making European aviation safer and more environmentally friendly.**



The iBearing mock-up used for proof-of-concept validation.



The iBearing sleeve with the sensors embedded.

Bearing condition monitoring is vital when it comes to rotary machine applications – indeed the consequences of bearing failure in mission-critical applications in aircraft can be catastrophic.

But it's difficult to predict when they are likely to fail because of their small size and inaccessibility once installed in an engine. Clean Sky's iBearing (Instrumented Bearing For Oil Cooled Starter/Generator) 26 month project, coordinated by Active Space Technologies with support from Cranfield University and Schaeffler Technologies, focused on assessing fly-by-wire enabled technologies and smart sensors to monitor the integrity of bearings in real-time.

The project concluded last May after various candidate solutions had been designed, implemented and tested on the Schaeffler test rigs, resulting in a final iBearing product which is a miniaturized and integrated piece of equipment that can be installed in any bearing using minimal adaptation.

The ultimate aim of iBearing was to monitor the bearing in real-time while being subjected to a representative harsh environment characterized by oil lubricant and high temperatures. The proposed system applies an advanced data fusion algorithm capable of integrating sensorial data from several sources simultaneously, including temperature, low frequency accelerations, acoustic emission waves, and quality of the lubricant, in order to calculate the most reliable prediction of the time to failure, without intervention of any testing operator.

The project enables more accuracy in understanding the optimal window for servicing or changing engine starter-generator bearings, and aligns with the aero-industry shift in maintenance strategies which sees less reliance on fixed timeframes or operation cycles between maintenance procedures and a move towards sensor-based solutions, whereby component condition and wear become the determining factors for overhaul or replacement.

With iBearing, data collected from sensors embedded within the engine during flight allows operators to check temperature, pressure, vibration as well as acceleration and noise at any given moment which makes it viable to witness bearing degradation and mechanical wear and the onset of micro-cracking. Using live data to monitor the status of bearings in this way makes it possible to take appropriate pre-emptive maintenance measures.

Compact size, standalone operation and resilience to the aeroengine environment were essential to the design of a condition monitoring system able to measure the safe lifetime of the bearing and predict failure at least 100 hours in advance (with a statistical significance of 0.997 (i.e., 3 sigma), and the iBearing team succeeded in developing a prototype device for in situ monitoring of bearings able to endure the whole spectrum of rotational speed values throughout the different phases of flight – typically from 10,000 to 30,000 RPM. The prototype performance was tested in temperatures

ranging between 150°C and 200°C and demonstrated encouraging results.

"The project is important for European aviation for several reasons" says António Santos of Active Space Technologies' Research and Development department, the coordinator of the iBearing project. "Firstly, more electrical power implies that generators must be larger or rotate at higher speeds. To mitigate the impact in the environment, the latter is recommended albeit high speed often implies more mechanical stress. Europe is leading environmental issues in the aviation sector and this project is a small contribution to keep the trend".

"Secondly, the aviation sector is steadily reducing maintenance costs, but at no expense of safety. Through-life engineering services is contributing to this effort, where state-of-the-art technologies and know-how assure that components are fully exploited within the context of their effective life span".

"Third, prediction of bearing failure in advance contributes to improve safety and maintenance planning, because monitoring can be performed not only on the ground but also during flight. Information of critical systems performance is important to further improve safety standards and reduce operational costs".

"Finally," concludes Santos, "by expanding the lifetime of vital systems, the aviation industry can safely expand the operational time of aircraft, thus reducing materials disposal and recycling needs".



# ZOOM IN CLEAN SKY 2 RESULTS

## ALC – pilot communications at the speed of light

Li-Fi (Light-Fidelity — a high speed, bidirectional and fully networked wireless communications system using light) could become a successor to Wi-Fi, transmitting data faster and consuming less energy. Clean Sky's ALC project is exploring the possibilities of this nascent technology in the cockpit to see whether Li-Fi could provide flight crew with a more impenetrable and more energy-efficient means of exchanging data.

"The objective of ALC is to develop a more secure wireless communications solution to replace Wi-Fi or Bluetooth because these are very easy to hack, with the aim to successfully operate connected devices in the highly demanding environment of a cockpit, and if you want to deploy more and more wireless solutions in the aircraft then we need to find ones that are immune to potential hacking or external intervention" says Sebastien Dubois, Project Officer for Large Passenger Aircraft at Clean Sky. "Li-Fi is safer, because you can only interact with the source of data in the area where the light source carrying the information is emitted, which means it's a more isolated system. So someone, for example in the cabin, will not be able to hack the communication".

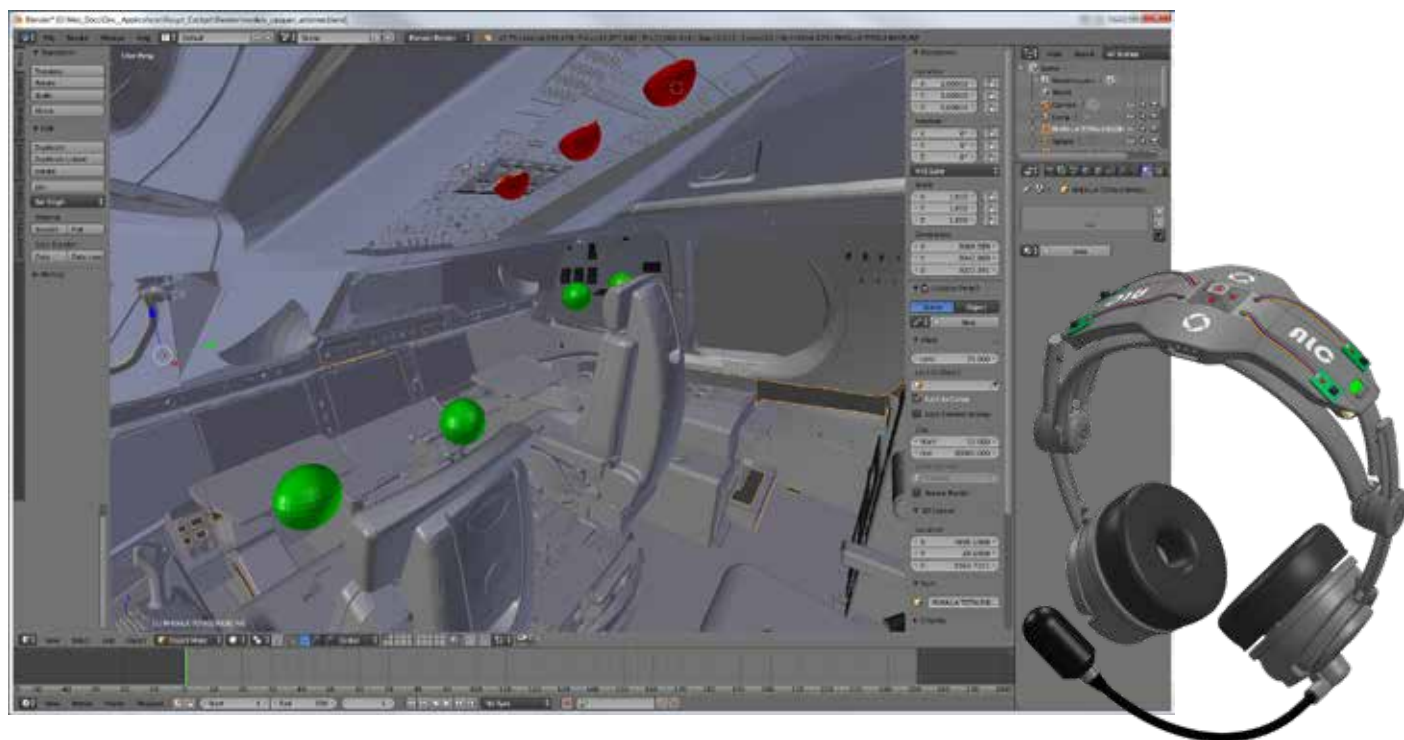
The full scope of the project is to realise secure wireless Li-Fi for the flight crew's EFB (Electronic Flight Bag), headset and other pilot-connected devices and to show evidence that Li-Fi connection solutions can successfully address current RF transmission drawbacks, and are mature enough to successfully operate connected devices in the highly demanding environment of a cockpit. The main participants in the project are FACTEM, Pure Lifi Ltd, and XLIM.

"The point of investing in Li-Fi technology is to assess the benefits and develop standards and to prove that such a communication channel is beneficial, and to provide the pilot with a headset and/or associated mobile devices which could be used through Li-Fi communication" says Dubois. "The objective is to reach TRL5, and one of the challenges is to ensure that the dongle, which is used to operate that Li-Fi, can be matured in terms of power efficiency and autonomy because if we're talking about long-haul flights we need to ensure that all mobile devices can operate for at least 10 to 12 hours without any interruption".

"The weight and size of the devices and how the dongle equipment will be miniaturized and optimised are also on the project's checklist. The second objective is to improve the connection robustness to comply with severe environments", says Dubois:

"We need to ensure that when we have very intense light in the cockpit we do not saturate the device and we can keep operating safely. Conversely, during night flights, the absence of light might be prejudicial to the functioning of the Li-Fi connection — so there are two extreme scenarios which deserve specific attention for deployment and implementation in the cockpit. Ultimately, we need to clearly demonstrate the data security of the device and the different conditions to demonstrate that this is immune enough to go to the next stage of development of such a technology".

The project has many potential benefits in addition to the data security aspects. The removal of wires brings comfort to the crew, therefore reducing stress. Li-Fi could also lessen the amount of wiring required in the aircraft and therefore reduce weight, thereby



lowering fuel consumption. And on a strategic industrial level, there's a benefit to European aviation by pioneering and advancing this new science in the cockpit.

From a technical standpoint, there are also important issues of quality and communications clarity at stake, according to Simon Bazin, Head of Research & Innovation at FACTEM, the Bayeux-based company leading the project:

"The project is developing functional prototypes of wireless headsets and a tablet for cockpit crew that doesn't use conventional RF (radio frequency) technologies such as Bluetooth, WiFi, etc. Instead, the ALC project aims to use "Li-Fi", in response to challenges with current RF technologies. RF technologies are known to be unsecure, and susceptible to electromagnetic interferences, and these make them unsuitable for critical applications such as audio communications between pilot and Air Traffic Control. Li-Fi can be the solution to this. That's what we intend to demonstrate".

The project is divided into four technical work packages plus a separate package for evaluation of the technology:

- WP1 – Audio headset: the objective is to make a demonstrator of wireless headsets in a cockpit simulator
- WP2 – Tablet: the objective is to make a demonstrator of a wireless tablet in a cockpit simulator
- WP3 – Connected headset: similar to WP1, but the headset is equipped with sensors to monitor the pilot's health

- WP4 – Other applications: this WP aims at finding other applications for Li-Fi use in the cockpit or cabin
- WP5 – Evaluation of the technology

In terms of measurable results so far achieved, Bazin remarks that "In WP1 (audio headset) (FACTEM-XLIM) a proprietary protocol has been developed for two headsets that in the initial stages can communicate up to 1,4 metres. This can be extended with further work. Audio latency, which is the main technical issue for this use has been measured initially at below 2.5ms, which is very low in comparison to other wireless technologies which have an average latency of 20ms in this use case. Lowering latency greatly improves user experience and reliability of the set-up".

"The customized WP2 – tablet (pure Li-Fi) is the first in-lab prototype which demonstrates throughput of 36 Mbit/s downlink and 22 Mbit/s uplink when perfectly aligned with the Access Point" adds Bazin. "On top of that, one very interesting result is that XLIM managed to develop a 3D model of light

propagation in a real A350 cockpit. Now detection of the presence of smoke is being implemented, which will be very helpful for final integration in the cockpit simulator. In WP4 – other applications (pureLiFi – FACTEM – XLIM) 149 ideas were generated as part of this project. Through this process we have decided to produce a prototype of an optical wireless backbone for cabin use. This will result in reducing wires, complexity and increased reliability".

By the end of the project, FACTEM anticipates that all prototypes will perform as expected by Airbus and the partners. And Bazin assures that at the initial stages, "everything is on track to achieve these results," adding that "the first prototype of a connected headset is planned for the end of 2019, while the optical backbone is expected in 2020".

If WP4 is successful, FACTEM expects that the total weight of the aircraft can be reduced, thereby reducing fuel consumption. Calculation of this possible reduction is part of Work Package 5.



# ZOOM IN CLEAN SKY 2 RESULTS

## Aircraft noise: getting to the core of the issue with CORNET

**NOx, CO<sub>2</sub> ... and noise. Is it possible to tackle all three simultaneously? Aeroengines with lean burn combustors reduce NOx, but create noise concerns, and without optimised design there's the risk that low emission cores will cause aircraft engines to exceed the EU's targeted aviation noise thresholds. Clean Sky's CORNET project aims to improve understanding of the noise from engines with low emission combustors in order to provide industry with new computer-based methods to predict the noise when designing future engines. This, in turn, will provide Europe's aviation industry with the competitive advantage of being able to design quieter aircraft.**

It's not every day that all three of the main high level objectives of the Clean Sky 2 programme – mitigating CO<sub>2</sub>, NOx and also noise – present themselves in a single project. To contextualise the challenge, Europe's Flightpath 2050 targets specify a 75% reduction in CO<sub>2</sub>; 90% reduction in NOx and a reduction of 65% in perceived noise emissions, relative to the levels of a typical new aircraft in 2000. The convergence of these challenges has prompted considerable anticipation of the results of the CORNET (COrre Noise Engine Technology) project as it approaches its conclusion this April.

"Lean burn combustor technologies being introduced to reduce NOx emissions are proving to be inherently noisier than conventional combustors, generating broadband noise that can be heard external to the aircraft," says Professor Dame Ann Dowling at the Department of Engineering of the University of Cambridge. "Without careful design and optimisation, there is a danger that the low emission combustors will cause the aircraft engines to exceed the noise requirement".

The University is the primary coordinator of the CORNET project which aims to improve European aviation's understanding of flow physics associated with generation and propagation of combustion noise. This means analysing 'direct noise' of combustion, pressure waves generated directly by unsteadiness in the rate of combustion, and the 'indirect noise' generated as unsteady hot spots accelerate out of the combustor and through the turbine blade rows. The research is relevant to Rolls-Royce's ALECSys (Advanced Low Emissions Combustion System) engine, a demonstrator that is testing a lean-burn system that improves pre-mixing of fuel and air prior to ignition, delivering a more

complete combustion of the fuel, resulting in lower NOx and particulate emissions.

"This project is a nice illustration of looking at the combined problem of low NOx combustor interaction with a high-pressure turbine, because the temperature profile of a lean burn combustor is completely different from a normal combustor," says Jean-François Brouckaert, Clean Sky Project Officer. "The CORNET consortium is looking at the interaction of noise, particularly noise propagation of these types of low NOx combustors, because going towards the new generation of engines – which are less noisy in terms of fan and bypass jet noise – the level of the core noise becomes relatively more important with respect to what existed before. Therefore there's benefit to Europe's

aviation industry in evaluating this in order to update aerodynamic combustion and acoustic models of the combustor and the turbine, validated by experiments – so, a beautiful academic project!"

In terms of work carried out and results achieved so far, Professor Dowling reports that the CORNET team at the University of Cambridge has predicted the turbulent reacting flow field inside a low-emission combustor operating at representative engine conditions.

"Large Eddy Simulations have been performed for a low-emission combustor operating at realistic engine conditions. These have been validated through comparison with experimental data. The results of these simulations have been used to investigate the validity of using OH-spectroscopy to determine unsteady temperatures at the conditions in a gas turbine combustor exit" she says, adding that all this has been achieved despite the fact that "modelling of turbulent combustion at elevated pressures to a satisfactory level of accuracy, reliability and robustness is challenging".





"The combustion model developed at the University of Cambridge and being used in this project does not treat the mixing and chemical reactions to be statistically independent, includes the finite-rate chemistry effects, and does not need tunable parameters. Implementation within a Large Eddy Simulation of a single sector of an aero engine combustor within the first 18 months of the CORNET project has enabled the characteristics of the combustion noise sources to be studied in partially premixed combustion. Subsequent work simulated a double sector with two fuel-injectors and this has been used to investigate additional physics such as burner-to-burner interaction that might be important in the annular combustor of an aeroengine gas turbine" she says.

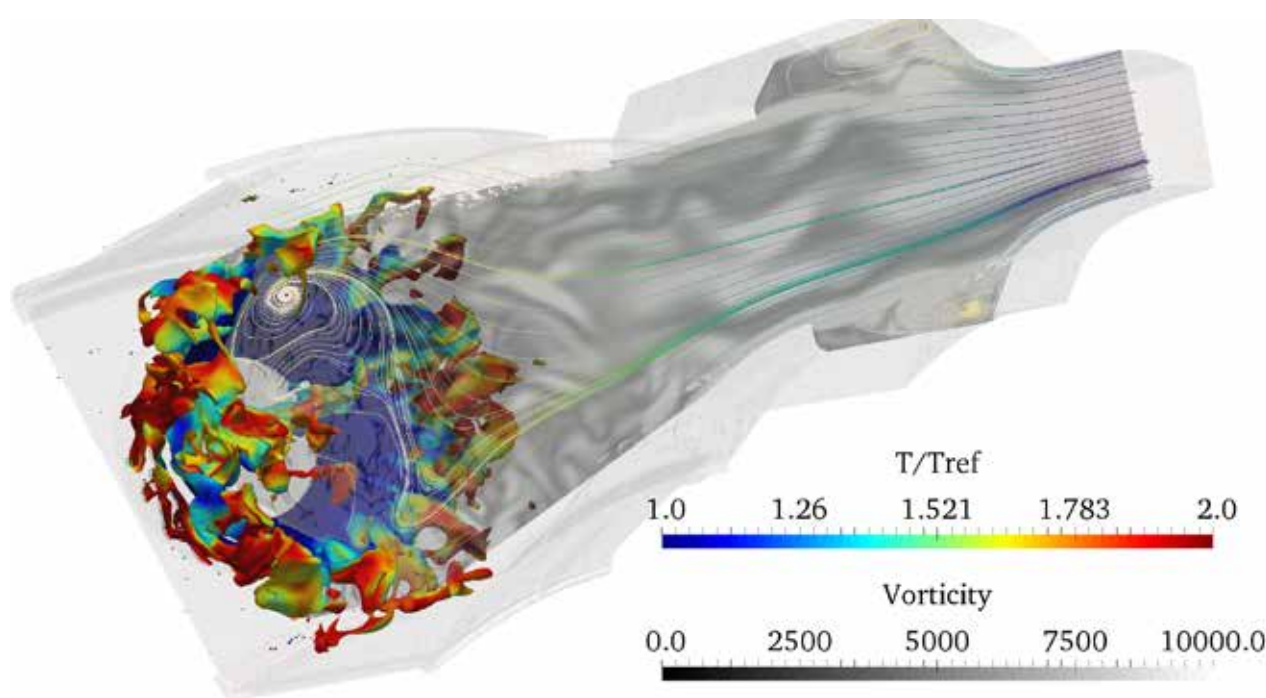
High-fidelity calculations of the propagation of flow unsteadiness through the turbine have been performed at the University of Cambridge, and the unsteady flow at combustor exit provides the inlet boundary conditions to these calculations.

"The temperature and flow profiles at combustor exit are highly unsteady and three-

dimensional. A novel way of using filtered Proper Orthogonal Decomposition to describe this unsteadiness has been developed and implemented in high-fidelity simulations of the unsteady flow through the turbine" says the Professor, pointing out that "The high-fidelity turbine flow modelling is giving physical insight but practical application by the industrial partners requires a quick way of capturing the important effects. The knowledge from the high-fidelity turbine modelling is being captured in an advanced, validated design tool that can be used by industry".

With regard to the high frequency temperature measurements in a high-pressure combustor, Professor Dowling explains that "the experimental campaign carried out at DLR Cologne as part of the CORNET project, with support from researchers at the Technical University Darmstadt, has demonstrated for the first time the feasibility of using high-speed OH-spectroscopy to obtain unsteady temperatures in the challenging operating environment of a high-pressure combustor facility. Data with sufficient signal-to-noise ratio was obtained at a high sampling rate".

"Laser combustion diagnostics have evolved into an indispensable tool for understanding and improving combustion technology. Data with sufficient signal-to-noise ratio was obtained from OH-spectroscopy at a sampling rate of 10kHz in the operating environment of a high-pressure combustor. Subsequently, laser absorption spectroscopy has been performed simultaneously with OH-LIF recorded along a one-dimensional probe volume to give absolute OH concentrations, which is being used to infer temperature at sampling rates of up to 1kHz" says Professor Dowling, concluding that all of this effort will directly produce tools that can be used for the design of lean-burn aero-engines: "These tools will be useful in building reliable estimates of the noise from a particular lean-burn combustor. What will make this possible is not only the improved accuracy of the models, but also the inclusion of important physics such as injector-injector interactions. Therefore it is expected that better combustors can be designed and the whole design process will be quicker and cheaper. This will obviously have a direct effect on the profitability of European engine manufacturers, and society will benefit from low noise aircraft, with low emissions".





# CLEAN SKY ACADEMY PHD AWARD CELEBRATES THE NEXT GENERATION OF INNOVATORS!

The fourth edition of the Clean Sky Academy Best PhD Award took place during Aerodays in Bucharest on 28 May 2019. The award recognises outstanding research work by young scientists in applied sciences and engineering for aeronautics. Meet our winners below!



## First prize: 'MICROPHONE ARRAYS FOR IMAGING OF AEROSPACE NOISE SOURCES'

*Dr. Roberto Merino-Martinez  
Delft University of Technology*



Aircraft noise emissions cause high annoyance and harmful health effects to hundreds of millions of people living around airports. It also costs the aerospace industry billions of euros due to strict noise regulations and night curfews. The continuous growth of air traffic (approximately 5% per year) is only making this situation worse for the future.

Aircraft are very complicated noise sources, with many different elements emitting noise in different ways. In order to reduce aircraft noise efficiently, the first step is to identify all noise sources on board accurately. This is an impossible task with using our ears or a single microphone, but using several microphones in an array (also called acoustic camera) simultaneously allows us to pinpoint noise sources in space. In other

words, we can literally see sound. We recorded several aircraft flyovers at Amsterdam airport and, using acoustic imaging techniques, we discovered that most aircraft during landing emit a very strong tonal sound between 1 and 2 kHz, which is perceived as particularly annoying by the human ear. A further investigation determined that open cavities in the nose landing gear (the wheels of the aircraft) caused this noise when interacting with the incoming flow, see the figure below. By simply closing these cavities, the annoyance around airports can be drastically reduced. This is just an example of the potential of microphone arrays, but these devices might be the key for reducing aircraft noise in the near future and making aviation more sustainable and environmentally friendly.

My research of my PhD thesis dealt with this topic. I received my PhD diploma cum laude in December 2018 at Delft University of Technology. For the next three years, I will be a part-time postdoctoral researcher in the same department I performed my PhD work (Aircraft Noise and Climate Effects) and a part-time consultant at Peutz BV (a consultancy company in the Netherlands). My main challenges will be to keep developing advanced acoustic imaging techniques and to design and construct an aeroacoustic wind tunnel facility. I am not certain about my next steps professionally, but (for now) I would like to stay in a research position.

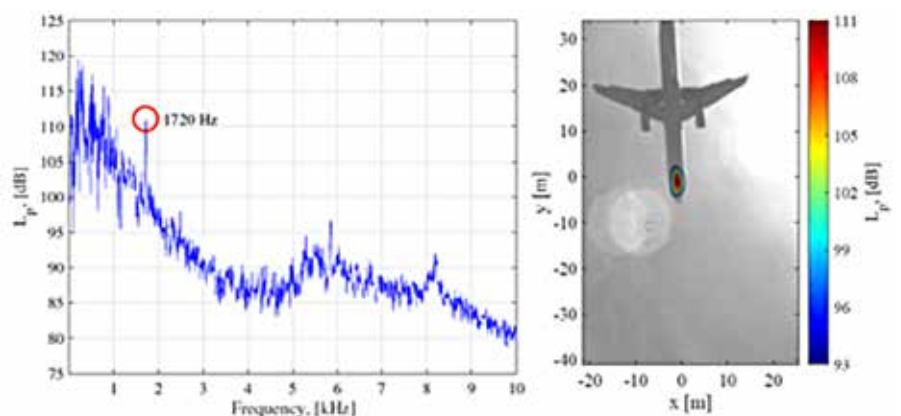


Figure 1 – (Left) Sound frequency spectrum of an aircraft flyover at the source position. (Right) Acoustic source plot of that flyover at 1720 Hz, showing that the tonal noise is generated at the nose landing gear.

**Second prize:  
'NUMERICAL AND EXPERIMENTAL  
INVESTIGATIONS ON TWO BAYS  
CRACKS PROPAGATION INTO  
CARBON/EPOXY COMPOSITES UNDER  
COMPLEX LOADINGS'**

*Dr. Joël Serra – Institut Clément Ader*



Composite structures are now well established in the field of civil and military

aeronautical structures. Their mechanical properties make it possible to have lighter aircrafts and therefore enable a reduction in both fuel consumption and CO<sub>2</sub> emission in the atmosphere. Their mass percentages for the Boeing 787 and the Airbus A350 XWB are greater than 50% and the one of the aerodynamic surfaces is close to 100%. In practice, the development and certification of these structures is still largely based on experimental validations in an approach known as the pyramid of tests. Even though these methods have the advantage of being robust, they are extremely costly (tens of thousands of tests per aircraft) and generate very long design cycles. Therefore, a major challenge for future programs is to significantly reduce the number of tests and design loops and thus shift towards "Predictive Virtual Testing". It is with this objective that the "VERTEX" program was funded by the French National Research Agency (ANR). VERTEX is the French acronym for "Experimental modelling and validation

of composite structures under complex loading". This project made it possible to elaborate and validate through multi-axial testing, a numerical model simulating the failure of notched composite plates of structural dimensions (400x400 mm<sup>2</sup>).

After being the technical leader of Ariane 6 launcher bolted junctions in France and a research associate on Z-pinned composite structures at the Bristol Composite Institute in the UK, I am back at the Institut Clément Ader. Thanks to the €1 million prize awarded by the Lopez-Loreta foundation, I am now leading a 5-year project "VIRTUOSE" that aims at scaling up the capabilities of our "Discrete Ply Model" on medium-sized specimens (400x400 mm<sup>2</sup>). The objective is now to be able to simulate a wide range of structural configurations (notch, impact, bolted junctions...) submitted to multi-axial loadings. This numerical tool will then be transferred to the main aeronautical actors at the end of the project to help them design structural parts more efficiently.

**Third prize:  
'PRELIMINARY AND ADVANCED  
STRUCTURAL DESIGN OF A THREE-  
MODAL CAMBER MORPHING WING  
FLAP FOR LARGE CIVIL AIRCRAFT  
APPLICATIONS'**

*Dr. Francesco Rea – Università degli Studi di Napoli Federico II*



The dissertation developed during my PhD degree in Industrial Engineering deals with the design of adaptive structures for large

civil aircraft. Working in this area since my MSc degree in Aerospace Engineering, my main effort was to prove the feasibility of a novel, energy-efficient and multi-functional high-lift device using common aerospace materials and commercial-off-the-shelf components for a full-electric actuation system. The research started with the analysis of critical load conditions, actuation performance required, and industrial needs for enabling proper characteristics of the three-modal morphing Fowler flap (3MMF). Lightweight and compact actuating leverages driven by electromechanical motors were designed to comply with demanding requirements for real aircraft implementation: minimum actuating torque, minimum number of motors, reduced weight, and available design space. Following the final concept assessment, the novel device was able to provide: 1.1% fuel reduction, 12% high-lift performance improvement, and 2% aerodynamic efficiency gain in off-design flight conditions.

In addition to fuel saving, the adaptive twist capability of the flap trailing edge

could also enable maneuver load alleviation leading to significant wing root bending moment reductions.

This technology was developed for the next generation regional aircraft within the REG-IADP (Air Green 2 consortium) within Clean Sky 2, led by Leonardo Aircraft Division.

During my research, I had the opportunity to work with various European research centers (CIRA, ONERA) and leading companies (Leonardo Aircraft Division, Siemens PLM Software). In addition, I was visiting researcher at DLR, Institute of Composite Materials and Adaptive Systems (Braunschweig) from September 2017 to February 2018. Results of my research have been widely disseminated internationally in journals and conferences.

After working for 3 years on my PhD, I've chosen to focus my career on the aeronautical industry. I am now working for Leonardo Helicopters as Research and Innovation engineer where I am working on the Next Generation Civil Tiltrotor.

# CLEAN SKY AT AERODAYS AND LE BOURGET

## Aviation industry declares commitment to future Clean Aviation partnership

On 19 June twenty-three Aeronautics Industry leaders, Research Organisations and University Associations across Europe signed a Joint Declaration of European Aviation Research Stakeholders Related to Clean Aviation in Horizon Europe, to express their strong commitment to a future European partnership that can lead the way towards a deep decarbonisation of aviation by 2050. The partnership should build on the progress made under the Clean Sky programmes, and develop further-reaching innovations and concrete roadmaps for their implementation in a new breed of aircraft from 2030 and beyond.

Signatory parties included Airbus CEO Guillaume Faury, Safran CEO Philippe Petitcolin, Rolls-Royce CEO Warren East and Leonardo CEO Alessandro Profumo. The Joint Declaration was handed over to Jean-Eric Paquet, Director-General for Research and Innovation, European Commission.

Read the full story on our website: [www.cleansky.eu](http://www.cleansky.eu)



## Clean Sky at Le Bourget, France

Clean Sky had an exciting week at Le Bourget from 17-23 June! Highlights included the signature of a Joint Declaration on a future Clean Aviation partnership, a conference giving an insight into Clean Sky's work with synergies with Regions and Member States, and a Memorandum of Understanding signed with the French region of Nouvelle Aquitaine.

In addition, project officers from Clean Sky welcomed hundreds of visitors throughout the week to the exhibition stand, where several pieces of innovative technology from the programme were on display. European Commissioners Violeta Bulc and Pierre Moscovici, Director-General Henrik Hololei, and many students including the EUROAVIA Stuttgart association visited the stand to learn more about Clean Sky's achievements towards greener aviation. Catch up with all the news and pictures on our website!

[www.cleansky.eu](http://www.cleansky.eu)





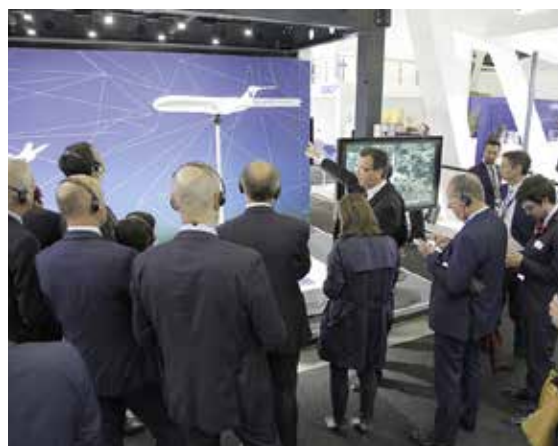
## Clean Sky at Aerodays, Romania

From 27-29 May Clean Sky was in Bucharest for AEROdays, with a joint exhibition stand with the European Commission and a busy conference programme. Axel Krein presented achievements of the Clean Sky 2 programme so far in a keynote speech on Tuesday 28 May, focusing on how Clean Sky technologies are working to reduce the environmental and climate impact of aviation. Throughout the three-day event, many Clean Sky projects were also presented by technical experts in breakout sessions.

A particular highlight was the ceremony for the Clean Sky Academy's Best PhD Award, which recognises outstanding research work by young scientists in applied sciences and engineering for aeronautics. This year's winner is Dr. Roberto Merino-Martinez, for his thesis 'Microphone arrays for imaging of aerospace noise sources'. Second and third prizes went to Dr. Joel Serra and Dr. Francesco Rea respectively. Read more about their theses on pages 12-13.

The exhibition stand showcased several of Clean Sky 2's innovative technologies to reduce CO<sub>2</sub> and noise from aircraft, and was visited by many conference participants throughout the event.

Check out our website for news and pictures from the event. [www.cleansky.eu](http://www.cleansky.eu)





# MARK YOUR CALENDARS

## Aerospace Europe Conference (AEC2020) Bordeaux – 25-28 February 2020

Clean Sky is pleased to take part in the very first edition of the Aerospace Europe Conference (AEC2020), organised by 3AF and CEAS with the support of Clean Sky, SESAR and ESA.

The event will take place on 25-28 February 2020, and will provide an exceptional opportunity to exchange knowledge and results of current studies and to discuss directions for future research in the fields of aeronautics and space. The programme will give a unique overview of global research efforts aimed at reducing the environmental impact of aviation and space activities. Clean Sky will be present with an exhibition stand and speakers in the conference programme.

Read more: <https://www.cleansky.eu/event/aerospace-europe-conference-eac2020>

## Clean Sky annual event – Brussels 21-22 April 2020

Save the date for Clean Sky's annual event, which will take place on 21-22 April 2020 in Brussels! The two days will bring together European policy-makers, aviation industry leaders, SMEs, research centres and universities to discuss what the future of innovative green aviation will look like.

[www.cleansky.eu/events](http://www.cleansky.eu/events)



## Transport Research Arena (TRA2020) Helsinki – 27-30 April 2020



TRA, the Transport Research Arena, is the largest European research and technology conference on transport and mobility. TRA2020 is themed "Rethinking transport - towards clean and inclusive mobility" and brings together experts from around the world to discuss the newest innovations and future of mobility and transport.

[www.traconference.eu](http://www.traconference.eu)



## ILA Berlin and Aerodays 2020 Berlin – 13-17 May 2020

Meet Clean Sky and the European Commission at ILA Berlin, joined with Aerodays 2020, from 13-17 May 2020! We will be showcasing some of our innovative projects to reduce CO<sub>2</sub> and other emissions from aircraft, and participating in an exciting event programme! [www.cleansky.eu/event/ila-berlin](http://www.cleansky.eu/event/ila-berlin)

## Farnborough International Airshow United Kingdom – 20-24 July 2020



Save the date for Farnborough International Airshow, taking place next year from 20-24 July 2020! Visit Clean Sky in the Research and Development Zone to learn more about our projects for sustainable aviation! [www.farnboroughairshow.com](http://www.farnboroughairshow.com)

Executive Director: Axel Krein  
Editor: Maria-Fernanda Fau, Head of Communications

The Clean Sky 2 Joint Undertaking receives funding under the Horizon 2020 Programme for research and Innovation. Views expressed in this publication do not represent any official position but only those of its author.

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White Atrium, 4<sup>th</sup> floor, Av. de la Toison d'Or, 56-60  
1060 Brussels