Final publishable report

AERONET III

Aircraft Emissions and Reduction Technologies

Coordination Action

Executive summary

AERONET has contributed to an environmentally friendly air transport system by bringing together European expertise in a cooperative, relevant and proactive network covering emissions from commercial aviation and its potential effects on the environment. This report summarises the activities of AERONET III which ran from 1 April 2004 to 31 July 2010 under the EU's Research Framework Programme 6.

Speaking formally, the aims of AERONET III were:

- To support communication in aeronautics community and with atmospheric scientists;
- To facilitate exchange of information and experience;
- To foster and support co-operation and joint actions;
- To identify gaps and needs for research and development;
- To support policy in the regulatory process and R&D programme;
- To increase visibility and general awareness.

These aims were achieved through the formation of a network of expert partners from around the European Union. In total there were 25 Partners from 9 countries. The partners and communities involved covered the whole aeronautics spectrum: aeronautical research centres, universities and research institutes, aero-engine industries, aircraft industries, fuel industries, air traffic management R&D centres, airports, airlines as well as regulatory bodies. Partners ranged in size from major European industrial organisations to SMEs.

AERONET has contributed to cooperation and understanding of aviation and its impact on the environment with a number of varied activities, principally 14 workshops, 10 studies and various related expert meetings. During the course of the project, the public debate on aviation and its local climate impact has gained significant momentum, significantly more than expected and significantly more than was the case in past decades. Partially as a consequence, an important change of emphasis was initiated in AERONET III to give a stronger focus on the multi-discipline and multi-community subject of the Air Transport System and less on the vehicle and its technological developments which were now covered in other EC projects.

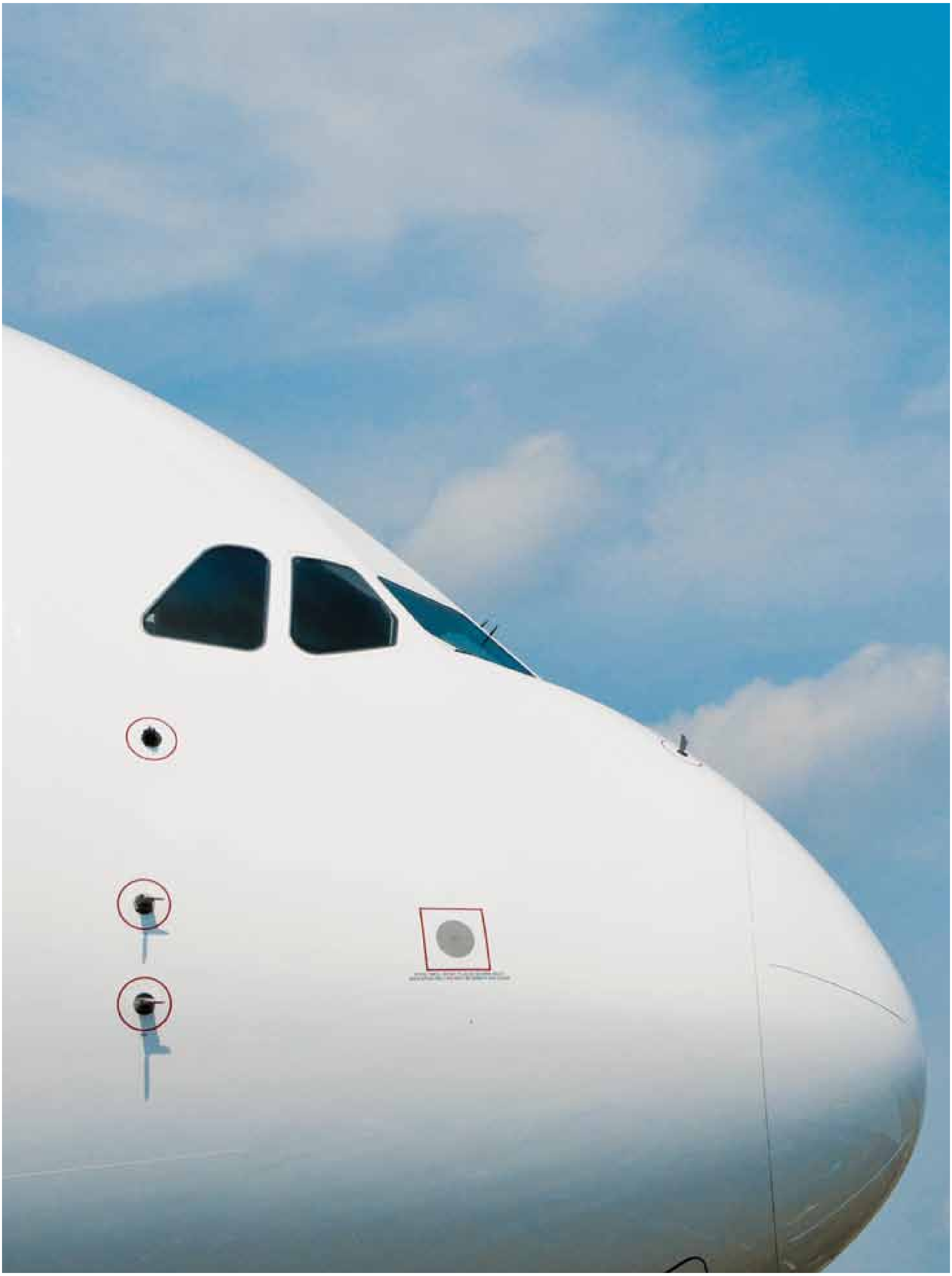
AERONET III gave important impulses to the field of interdependency modelling and tradeoffs. Reducing aviation's impact on the environment is more and more related to finding the right balance between different technical and non-technical developments, specifically social needs and economic costs. Only then can we achieve sustainable development for the air transport system as a whole.

In that context, AERONET III was also actively involved in contributing to the ACARE process by promoting topics such as alternative fuels and atmospheric science. AERONET III actively participated in European and international expert groups (ACARE, ANCAT/MITG, SAE E-31) contributing to the environmental policy and scientific debates.

During the 6 years of the AERONET III project, research gaps have been identified and these are listed throughout this report. Many of these research gaps have of course subsequently been addressed by AERONET members and by others. The remaining research gaps are discussed in the concluding remarks.

Finally AERONET III worked closely together with other related projects and networks (e.g. X-NOISE, ECATS, ELECT) and contributed to a number of project proposals in the field of airport air quality, interdependency modelling and aviation climate impact research.

Looking forward, although the project is ended, the aim is to keep the website and intranet operational after end of the project, for continued dissemination of relevant information – and of course to continue to build on the strong relationships and cooperation built up over the 12 years of the AERONET network.



Contents

Introduction

AERONET has contributed to an environmentally friendly air transport system by bringing together European expertise in a cooperative, relevant and proactive network covering emissions from commercial aviation and its potential effects on the environment. Historically speaking, the EU Project entitled "Aircraft Emissions and Reduction Technologies" (AERONET) was initiated in August 1998, extended in 2001 as AERONET II and again in 2004 as AERONET III. This report summarises the activities of AERONET III which ran from 1 April 2004 to 31 July 2010.

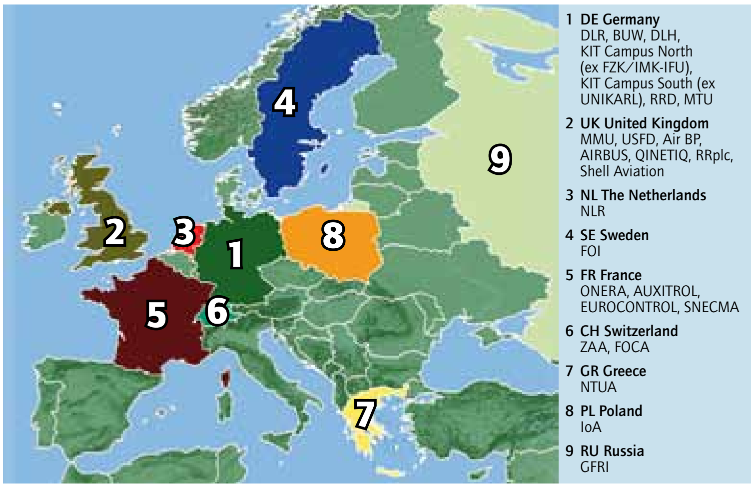


Figure 1: AERONET III Partners

AERONET III was commissioned under the EC FP6 research programme. FP6 aims to contribute to the creation of a European Research Area, namely an internal market for science and technology. It fosters scientific excellence, competitiveness and innovation through the promotion of better co-operation and coordination between relevant actors at all levels. Economic growth increasingly depends on research, and many of the present and foreseeable challenges for industry and society can no longer be solved at national level alone. As part of the "Aeronautics and Space" Thematic priority, AERONET III directly addressed these aims through the means of the "Network of Excellence" instrument funded through EC FP6.

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In a dynamic and rapidly growing air transport sector, minimising the effects of aircraft emissions upon the atmosphere is both increasingly important and increasingly challenging. The largest potential for limiting the growth in commercial aviation emissions over the long term lies in advances in aircraft and engine technology but improvements in air traffic operations can also make a significant contribution.

In addition to issues associated with air quality close to airports, deeper understanding of the atmospheric processes highlights the need for such emissions control with respect to climate change. The establishment of CO_2 reduction goals through the Kyoto protocol, the ACARE goals and, most recently, within the ICAO Members sharpens the need for an inclusive debate between all these communities. Only through such inclusive and international collaboration can international solutions be put in place in this global industry.

With this background, AERONET III was created to continue the role as the European aviation emissions platform where all the stakeholder communities can meet, exchange information, views and experiences gathered in different EC projects and national programmes. This collaboration not only served as information exchange, important in itself, but additionally raised the level of confidence among the communities, identified gaps of knowledge and supported the policy and regulatory process. As a consequence, this strengthened the body of European expertise, thereby providing another means to address the aviation emissions challenge.

This report reviews the three main topic areas covered by the AERONET III network, summarising the results from the various workshops and short studies performed under the banner of AERONET III.

Overview of AERONET III results

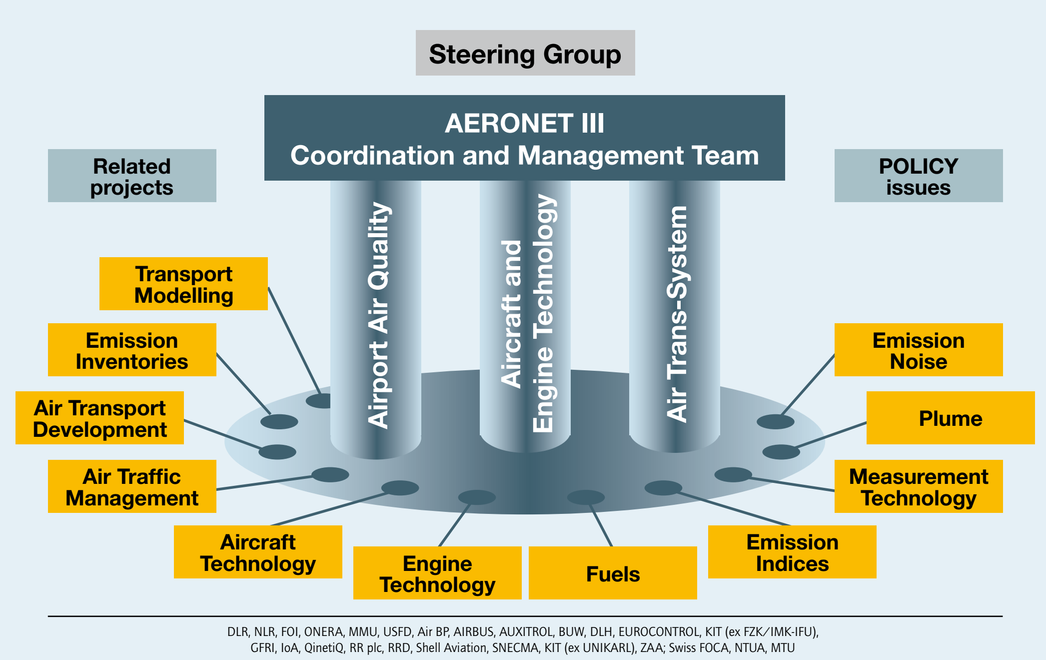
In this main section of this report, we will review the main activities covered by AERONET, arranged by technical topic. In addressing aviation and its environmental impact, AERONET III covered 3 main technical topics:

1. Fuels, aircraft and engine technologies
2. Airport air quality
3. The air transport system and its environmental impact

As illustrated in Figure 2, each of the 3 main technical topics (or "pillars") can be further subdivided into a number of technical specialisms. These are shown in the "bubbles" in the lower half of Figure 2.

In the upper part of Figure 2, the organisational structure of AERONET III is illustrated, highlighting the role of the Coordination and Management Team, guided by the Steering Group, to bring together the issues raised by policy makers and the potential solutions developed by related research projects.

The remainder of this section comprises a summary of results of workshops and studies that were performed during the project within the 3 main topic areas.



DLR, NLR, FOI, ONERA, MMU, USFD, Air BP, AIRBUS, AUXITROL, BUW, DLH, EUROCONTROL, KIT (ex FZK/IMK-IFU), GFRI, IoA, QinetiQ, RR plc, RRD, Shell Aviation, SNECMA, KIT (ex UNIKARL), ZAA; Swiss FOCA, NTUA, MTU

Figure 2: AERONET III topics and structure (Organisational Structure)

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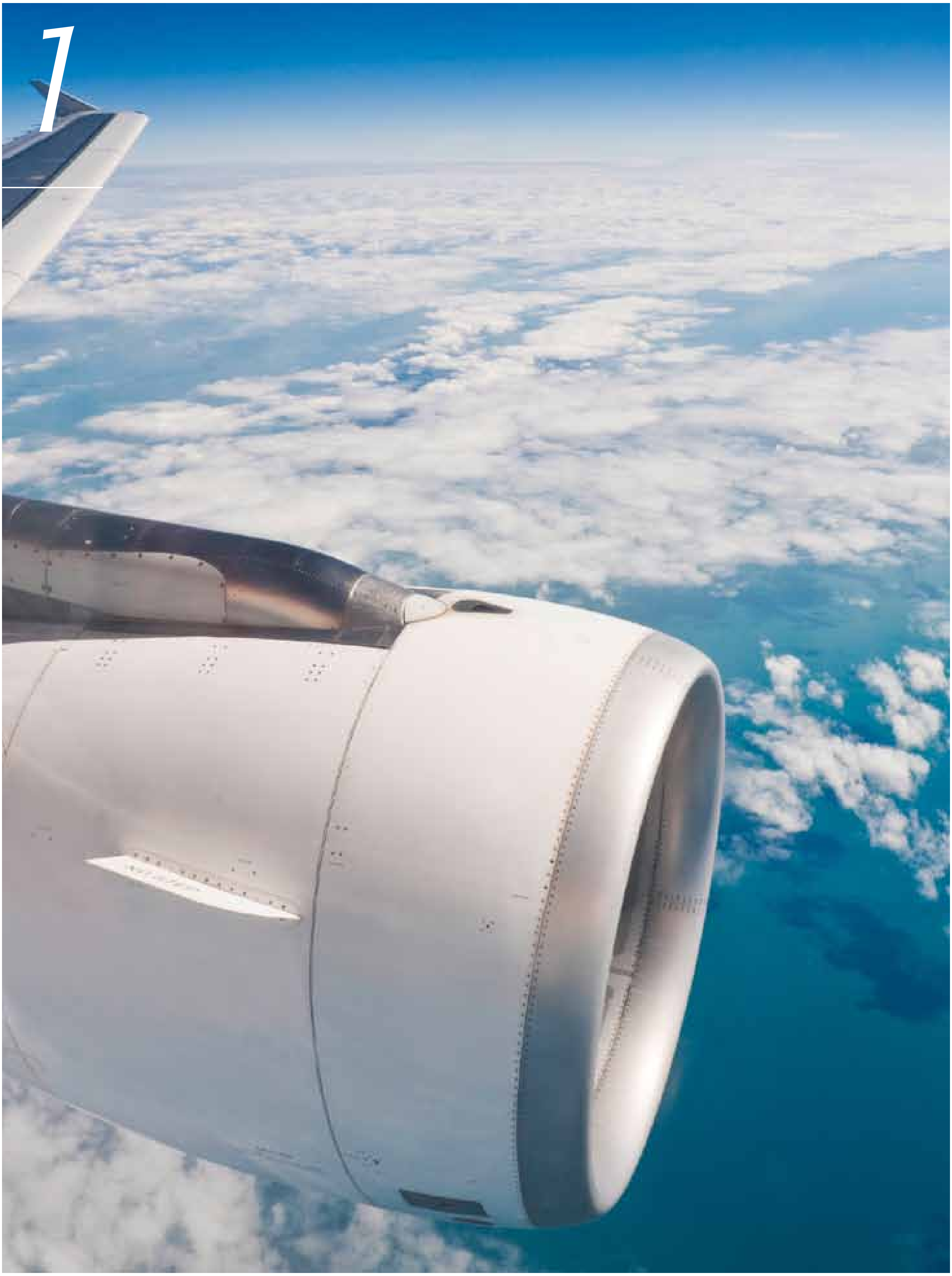

Fuels, Aircraft and Engine Technologies

In this first of the three topic areas, AERONET covered the following subjects through dedicated workshops:

> Improved thermal stability of aviation fuels and the potential improvement in the aircraft emissions
> Alternative fuels for aviation (excluding H_2)
> Hydrogen for aviation
> Auxiliary Power Unit (APU) emissions at the airport
> New propulsion and aircraft concepts for green aviation in the 2020-2050 timeframe

1.1 Improved Thermal Stability of Aviation Fuels

Improving aviation fuel thermal stability is a means to reduce aviation emissions. Work required to facilitate these emission improvements was investigated.

Currently there are many test methods available to assess the fuel thermal stability. These range from simplistic laboratory tests to full scale engine simulators. The aviation kerosene fuel specification which covers almost all fuel used in commercial aviation calls for aviation kerosene to have a thermal oxidation breakpoint higher than 260°C. The current test to measure this thermal stability, called JFTOT™[1], is a go/no go test which verifies that the breakpoint is greater than 260°C but will not give you the actual breakpoint temperature. However, pioneering work by the US South Western Research Institute (SWRI) has produced a methodology for evaluating the fuel breakpoint from the JFTOT samples. Various fuel treatments exist in the way of refinery techniques, fuel additives or synthetic kerosene to improve the thermal breakpoint. Results from the SWRI tests have shown breakpoint values up to 320°C are achieved. However, engine manufacturers have no control over the fuel being supplied to airlines and combustion chambers must be designed with a safety margin on the 260°C breakpoint fuel.

Fuels with improved thermal stability can have an impact on aviation emissions improvements. This is becoming more important as engine pressure ratios increase to improve fuel consumption. The increase in engine pressure ratio results in an increase in engine temperatures enhancing the heat transfer into the fuel. Improving fuel thermal stability would enable significant improvements in whole engine performance and reduction in emissions by improvements in heat management and/or the use of advanced low emission injector systems which are currently excluded.

The actual impact of improved thermal stability is difficult to quantify and needs to be assessed on a specific airframe/engine combination. One study undertaken has suggested that a 20°C improvement in breakpoint may lead to a 0.1% improvement in specific fuel consumption. If realised in service, this would equate to a 0.1% decrease in CO_2 emissions and potentially similar reductions in other emissions species.

One key problem exists in designing an engine for operation on improved thermal stability fuels. Simply stated, the supply of such higher thermal stability fuels needs to be guaranteed. Otherwise expensive and complex intercooling will need to be designed into the engine architecture to cope with lower stability fuel batches. The additional weight (and complexity) of these systems will offset some or all of the emissions gains from the improved thermal stability.

In addition, improved fuels may have ground level emission implications during production due to increased processing requirements. Multiple fuel standards could result, or a base fuel may need to be doped with specific additives to improve the thermal stability. Whichever route is chosen, additional approval processes are required.

AERONET identified the following open questions where specific research is still needed:

> There is too much uncertainty on the actual CO_2 balance in producing a higher thermal stability aviation kerosene. A "well to wing" study addressing the full CO_2 budget should be performed. This should be used to rank the relative alternative means to produce high thermal stability aviation fuels. The study should build on the methodology of the "well to wheel" study conducted for the automotive industry.

> A pilot study should be undertaken to assess the range in thermal stability breakpoints currently being supplied by airlines. It was proposed that this could form part of the existing survey of jet fuel undertaken by QinetiQ on behalf of the UK Ministry of Defence on an annual basis[2].

> New approval processes need to be developed, along with an appropriate test methodology, to ensure that future, non conventionally sourced kerosene's and fuel additives meet the "spirit" of the current specification for aviation jet fuel.

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[1] JFTOT - Jet Fuel Thermal Oxidation Test

[2] At time of writing, this survey has been discontinued

1.2 Alternative Fuels for Aviation

In a world where the price of oil is increasing and the impact of fossil fuels on climate change has become a major global concern, the sustainable growth of civil aviation is challenged by its ability to limit its CO_2 emissions and thereby its effect on climate. Aviation therefore looks to other fuels and fuel sources to limit its climate impact. However, for the technologically highly advanced aviation industry, using biofuels and alternative fuels in aeronautics is a great challenge, since the operational constraints (for example the extreme cold conditions encountered in high altitude flight) are very strict. In addition, the long lifetime of current civil aircraft (over 50 years from design to end-of-service) means that any change of fuel has dramatic impact on the existing fleet and a full changeover to another fuel could, potentially, take over half a century. In addition, aviation kerosene is a highly efficient fuel in respect of its energy density (volume and mass) and its range of other properties. Finding an acceptable, greener alternative fuel specification seems unlikely.

Efforts on "alternative fuels" for aviation should therefore be focussed on viable "kerosene-like" fuel options for aeronautics use, in terms of energy density, technical property limitations, supply issues and best use of resource. Absolutely fundamental are the overall life cycle emissions of the fuel i.e. from production to usage by the aircraft. Current analysis at the time of the workshop (Jan 2007) suggested that next generation "bio-fuel" (biomass to liquid) development presented a clear advantage compared to other options. However, there are many unresolved problems, particularly in the complex area of land usage.

AERONET identified the following open questions where specific research is still needed:

> What would be an ideal fuel in terms of its energy density and other properties;
> What are the potential benefits of XTL (anything to liquid) fuels in terms of their environmental performance? There is a need of a "well to wing" analysis with a quantification of the benefits over the whole life cycle of the fuel;
> How can we break the "chicken and egg" problem of special fuel / special engine combination;
> How to best deal with the specification issue for new fuels (e.g. in cooperation with US and the rest of the global aviation industry);
> What are the relative costs for Biomass To Liquid fuels (including the power plants required) compared to conventional kerosene.

In the context of both fossil and non-fossil feedstock, some of these questions are addressed in current important EU projects (AlfaBird / SWAFEA), aiming:

> To identify and evaluate possible alternative fuels to petroleum kerosene, considering the whole aircraft system;
> To assess the adequacy of a selection of up to five alternative fuels with aircraft requirements, based on series of tests and experiments ;
> To evaluate the environmental and economical performance of selected alternative fuels ;
> To set the path towards industrial use of the "best" alternative fuels.
> To evaluate regulation / certification issues
> To evaluate life cycle and sustainability aspects

1.3 Hydrogen for Aviation

Commercial aircraft designed to be fuelled with liquid hydrogen are technically feasible and could be developed within a period of around 15 years. However, for the time being hydrogen is not a solution for aviation in terms of propulsion. Even without considering the costs of new aircraft, new engine design and their certification, the amount of hydrogen necessary and the cost and technical difficulties to overcome with regard to the production and transportation of liquid hydrogen, would be far too much for the air transportation industry to allow a financially sustainable transition from kerosene to hydrogen. As is the case for alternative hydrocarbon fuels (see Section 1.2), there are also the logistical issues of running two fuel supply infrastructures in parallel. Additionally, before liquid hydrogen should even be contemplated for commercial aviation use, a full life cycle analysis is required to ensure beyond doubt that there is a significant climate change benefit in the use of hydrogen as aviation fuel. Currently, the existence of such benefit is far from clear.

However, the use of Hydrogen for aircraft internal systems is an option, for example in Auxiliary Power Units (APUs) and aircraft water supplies. In this case, it is necessary to focus on fuel cell technologies and their applications, keeping in mind that hydrogen is not the only feasible fuel for fuel cells.

As for main propulsion, any transition from conventionally driven to fuel-cell based aircraft internal secondary supply systems such as APUs needs to be analysed with respect to technical feasibility and the resulting benefits for the environment.

In summary:

> Hydrogen is not a solution for aviation propulsion for the time being and its potential environmental benefit is not clearly demonstrated by Well-to-Wing analyses
> Hydrogen could be used for aircraft internal systems (e.g. fuel cell APUs)

AERONET identified the following open questions where specific research is still needed:

> Fuel cell technologies for aircraft internal systems are an option. However, environmental benefits need to be thoroughly assessed on a whole life cycle basis.

1.4 Auxiliary Power Unit (APU) Emissions at Airports

APUs are small gas turbines installed in commercial aircraft to provide power and conditional air when the main engines are not running. Perhaps surprisingly, APU emissions can represent a significant part of the total emissions at an airport. Emission inventory and airport air quality assessment specifically related to APU emissions are being carried out. One issue here is the level of validity of datasets. Current assessments are mainly based on generic and not real world data. The question is also to what extent real-world data would improve the validity of these inventories.

AERONET identified the following open questions where specific research is still needed:

> Measurement methodology standards for APU emissions need to be improved;

> A reference certification cycle for APU operation (in the spirit of the aircraft main engine LTO reference certification cycle) does not yet exist.

The development of emissions guidance and standards for APUs would be useful to the APU industry to evaluate and improve its products and contribute positively to the airports air quality. In the meantime, airports have recognised the extent of the potential emissions from APUs and are taking measures to control their use, in particular by installing ground power and conditioned air at the aircraft stand (gate).

1.5 New Propulsion and Aircraft Concepts for Green Aviation in the 2020-2050 Timeframe

A number of large European programs (DREAM, Clean Sky SAGE and SFWA) are addressing the challenges of environmentally friendly aircraft and engine technologies in order to meet the ACARE goals for 2020.

Already in the 1980s, significant pressure to achieve substantial reductions in specific fuel consumption was driven by the escalating cost of fuel. At the time, aero-engine manufacturers looked at the development of advanced open rotor propellers. This research effort has been continued with the aim to develop and validate technologies for significantly reducing the engine specific fuel consumption and thereby reducing the CO_2 while at the same time achieving acceptable noise levels. These large programs are significant and costly undertakings developing new engine technologies and configurations like geared open rotor, direct drive open rotor, large 3 shaft turbofans, geared turbofans, and turboshaft configurations.

Alongside the engine developments, very significant efforts are also focused on smart wing technologies like natural and hybrid laminar flow as these offer a high potential for friction drag reduction through the wing. A very important aspect here is also the innovative integration of the powerplant into the aircraft. With respect to a huge number of previous activities the major challenge is to apply laminar flow technology for large transport aircraft under industrial conditions and in an operational environment. This has not been achieved to date.

Other emerging experimental applications are fuel cells for electric propulsion of small aircraft such as motorised gliders. At present scaling of fuel cells to the power requirements of large aircraft does not appear to be feasible for the foreseeable future. As stated earlier, in all these situations, benefits should first be assessed by Well-to-Wing analysis, considering the various means by which hydrogen may be produced.

Additional to these activities, efforts need to be undertaken to investigate more long term research options beyond 2020. As current technologies have inherent limitations with respect to their potential for improvement, some “out of the box” thinking is needed for the long term future.

Research aims should be to bring forward technologies to a technology readiness level which industry can then commercialise at reasonable cost and risk. Complimentary to this is the development of a progressive but stable regulatory regime which encourages, rewards and perhaps even mandates these break-though technologies in order to provide the essential environmental performance improvement necessary for continued sustainable growth of commercial aviation to meet society’s needs. In the absence of such research and technology demonstration and a progressive regulatory regime, industry will not have the funds or the incentive to enter high risk research programmes on their own. Consequently, there is a danger that aviation could fall into a low risk low technology industry, similar to automobile manufacture in the middle of the 20th century. The EC Clean Sky initiative is a good first step along this progressive research road.

2

Airport Air Quality and its Environmental Impacts

In this second of the three topic areas, AERONET III covered the following technical topics, using workshops or studies:

> Determining airport air quality
> Health impacts of volatile organic compounds

2.1 Determining Airport Air Quality

Air quality issues at airports are relevant to the EU Environmental Council directives aim at developing overall strategies for air quality control and mitigation.

Figure 3: Congestion at the airport impacts local air quality

Air quality standards are set for a range of air pollutants through successive Daughter Directives (CD-1996, 1st DCD-1999, 2nd DCD-2000, 3rd DCD-2002, 4th DCD currently) with application for airport air pollution from 2010 on. The EC directives contain appropriate methodologies to assess any air quality non-attainment (or exceedance) and the strategies needed for implementation of target values. Main drivers here are public health and ecosystem protection.

Primary exhaust emissions at airports and secondary pollutants belong to the family of regulated gas plus particulate pollutants classified as hazardous air pollutants. These have harmful effects on human health and can also be precursors of the important secondary pollutants such as ozone. Pollutants to be considered at the airport are NO_2, Particulate Matter (especially the very small sizes), ozone and also Volatile Organic Compounds (see below).

Mitigation measures applied to emissions have to consider the relationship between emission levels, the characteristics of different sources at airports and the pollutant concentration being regulated. The relationship is very complex and non-linear.

Emission databases at airports for future regulatory purposes (or for mitigation action) need to be completed and improved by using the best real world information at airports.

Concerning numerical tools and dispersion modelling for airport application and assessment, at least 2 approaches have to be considered: first at the micro scale including the aircraft plume, micro turbulent scales (such as the impact of buildings on dispersion or accumulation); and second at the local-regional scales where pollutants are oxidized and mixed with emissions from other sources into the ambient atmosphere, including the atmospheric boundary layer depth (conventionally up to 900m altitude) and airport vicinities. There is another dimension, that of regional scale dispersion but this is highly dependent upon geographic and climatic conditions as well as upon the total regional emissions from other man-made and natural sources.

Continuous monitoring and specific sophisticated measurement campaigns are still highly valuable both for air pollution regulation and for model validation, for example, showing that meteorological conditions play an important role in airport air quality. During winter high pollution concentrations can be caused by low wind speeds, low mixing layer heights and consequently minimal dilution of aircraft emissions.

Figure 4: Aircraft plume exhaust measurement at the airport for air quality purposes

AERONET identified the following open questions where specific research is still needed:

- Clear and well defined drivers for airport air pollution: EU directives, ICAO recommendations, national regulations[3];
- Trade-offs between air quality and noise at the local level, and between local air quality and climate change on global level;
- Complete and realistic information on airport operations, engine power settings, auxiliary power unit specification, time-in mode[4] emissions data from ground access vehicles and ground support equipment, local power plants, all necessary to complete and make the airport emission calculation as precise as possible;
- A higher-level-of-confidence emission model for operational engines, required for detail calculation of emission species at landing and takeoff conditions and along taxiways;
- A full and detailed emission database (time-dependent, spatial variations) appropriate for air pollution studies and modelling at local and regional scales;
- A category of numerical dispersion models appropriate to regulatory application, taking into account the most pertinent atmospheric processes representing the current state of scientific knowledge relevant to different air pollution scales and adapted to airport and vicinities;
- Consistent measurement strategies and adequate instrumentation for monitoring emissions concentrations around airports to anticipate the potential application of EC directives and to support numerical dispersion model validation.

2.2 Health Impacts of Volatile Organic Compounds (VOCs)

A dedicated AERONET study on volatile organic compounds was carried out. These pollutants are specifically relevant with respect to health impact – specifically there are considerable uncertainties over the actual emissions from airport operations, the actual exposure levels and the potential health effects from such exposure. The summary of the results of the study is given below:

Volatile and semi-volatile organic compounds are known to have a non-negligible impact on human health, mainly due to their carcinogenic effects, to their reactivity to ozone formation (precursors) and to their contribution to suspended particulate matter (PM) formation.

Publications regarding health risks associated with aircraft activities include two aspects: environmental impact assessment at airports, which concern exposure of airport workers and urban residents to exhaust pollutants of engines operating at the ground, and assessment of jet fuel vapours to population exposure. Workers at airports and people living in neighbouring areas are potentially exposed to chronic (longer term) health effects, while airport visitors might be exposed to acute (shorter term) health effects.

Aero-engine exhausts contain non-methane hydrocarbons (NMHC). Hydrocarbons are organic compounds composed entirely of carbon and hydrogen atoms (and sometimes oxygen). There are three main classes of hydrocarbons: saturated, unsaturated and aromatic. Most hydrocarbons in jet fuel belong to the saturated and aromatic families.

In the past, research has focussed on urban and rural areas, with a special emphasis on aromatic compound characteristics, due to their known and suspected carcinogenic nature and their reactivity in photochemical reactions. Nevertheless, airports include different VOC source emissions from: aero-engines, ground access vehicles, ground support equipment, fuel storage and refuelling evaporations. Within the airport environment, very little is known about emissions of speciated hydrocarbons. Only a limited number of VOCs have been monitored at airports.

Volatile organic compounds, oxygenated or not, are mainly produced by combustion processes at high temperature within the aero-engine combustion chamber. They are accompanied by the production of soot particles and most likely by some polycyclic aromatic hydrocarbons (PAH, semi-volatile).

The airport atmosphere may contain hundreds of VOCs that might have an identified impact on public health as carcinogen products. In terms of epidemiology, a classification of some VOCs with regards to their toxicity exists. As an example, Category A contains VOCs with well-known human cancer risks (e.g. benzene), category B, the VOCs with probable human risk and category C for possible human risks based on animal testing. Formaldehyde (also a VOC) falls into the B-category. Exposure to this species is considered as a risk of lung and nasopharyngeal cancer.

Over the surface of fine particles (soot) produced by aero-engines, some semi-volatile VOCs are possibly adsorbed; they can include the family of pollutants classified as PAH (Polycyclic Aromatic Hydrocarbons) with strong cancer risks and skin irritations. VOCs can also act as ozone precursors – that is they promote ozone formation. Ozone itself can then promote further health impacts.

Airport air quality is subject to emissions of multiple VOCs from aero-engines and from other surrounding biogenic sources. VOCs from aircraft are not well identified, nor are they precisely quantified in terms of emission characterisation. They are also not continuously observed in term of population exposure.

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[3] Progress on this conclusion from the 2005 workshop has been significant with the implementation of the various directives mentioned on page 16 as well as the publication of ICAO Doc9889.

[4] Time-in-mode is the time spent at each engine power setting. Each different power setting will have different emissions rates.

Some VOCs are categorised as odorant, in particular acetaldehyde and formaldehyde. Light VOCs are more odorant and irritating than heavy VOC. Along with noise, odour is probably the main cause of neighbourhood complaints at airports.

Only a few airports have conducted field measurements of VOCs over a long period. As, globally speaking, flying has become the fastest growing means of transportation, there is an increasing need to conduct evaluations concerning the impact of aircraft emissions at ground level.

Various studies have been carried out which show that important proportions of high alkanes and aromatic compounds are contained in aircraft fuel. Exposure to jet fuel may be found to cause eye and skin irritations, respiratory complications and have a neuro-toxic risk on human health.

A comparison between airport air quality and the air quality in mega cities shows that VOC concentration at airport areas were found to be similar to, or even higher than, urban area values.

The VOC concentration varies with the seasons. VOC concentrations are higher during the cold season due to longer lifetime and lower active chemical degradation. Regarding VOC measurement techniques, there are three kinds of measurement: passive sampling, active sampling and automatic sampling.

As a result of the short study, AERONET identified the following open questions where specific research is still needed:

In order to improve the quality of knowledge of VOC emissions at airports, to better quantify their contribution to air quality pollution in the vicinity of airports (in terms of toxicity and health impact), and their interaction with NO and NO_2 and their role as ozone precursors;

- Conduct test-bed systematic measurements of speciated VOC engine emissions using existing applicable measurement techniques;
- Assess emission indices for speciated VOCs from test bed experiments and add speciated VOCs to the ICAO emissions databank;
- Generate more precise emission inventories of speciated VOCs directly related to actual operational procedures at airports;
- Significantly increase the number of systematic speciated VOC measurements at airports for better quantification of their impact on air quality with respect to EC directives as well as evaluating the VOC/NO_2-interaction[5], for ozone formation, for hazardous pollutants (carcinogens) and for Particulate Matter (mostly nanoparticles considerably smaller than $PM_{2.5}$);
- Assess by combined model-measurement experiments the contribution of unburned heavy hydrocarbons on Particulate Matter formation and composition at airports.

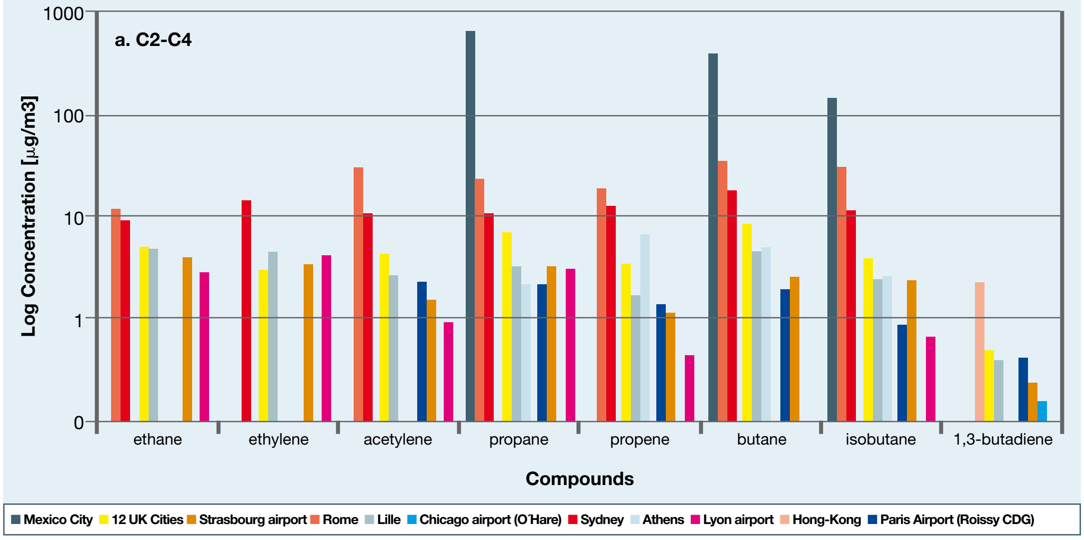

Figure 5: Comparison between airport and mega cities VOC concentration

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[5] *The effect of VOCs on the formation of NO_x*

3

Aviation System Approach and its Related Environmental Impact

In this third of the three topics addressed by AERONET III, AERONET took a wider view of the aviation system as a whole. Under this heading the following topics were addressed through dedicated workshops and studies:

- Alternative futures for the Air Transport System
- Research "means and needs" to deliver the ACARE 2020 environmental goals
- Green flight
- Interdependency modelling
- Trade offs

Partly as a result of other major projects such as Clean Sky picking up a large part of the technology networking requirements, the later years of the AERONET III programme were focussed on this third topic aimed at the aviation system as a whole. Hence it is given more prominence in this report.

3.1 Alternative Futures for Air Transportation from a System Perspective

Alternative futures for air transportation from a system perspective were investigated from the perspective of the development of the aviation system as a whole including technological, economical, environmental and operational issues as well as identifying 'bottlenecks' in, and constraints on, the system.

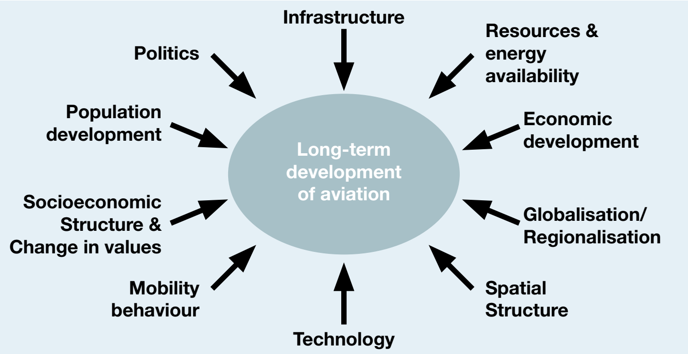

Figure 6: Influence factors for the long term development of aviation

(source: CONSAVE 2050)

Future aviation environmental impact needs to be analysed with a view of the likely scenarios for the future of the air transportation system (airports, aircraft, airlines, ATM, technologies) and the impact of constraints (safety measures, political restrictions, economy, demand, supply and, of course, environment). Potential 'trade-offs' need to be considered where different environmental issues may cause conflicts in terms of technological development and economic impacts.

Topics addressed were those deemed to be the important drivers for the future of aviation, namely key trends in aviation technology and demand, potential solutions to reduce emissions and aviation long term scenarios and visions.

The following conclusions were reached:
Although nothing is certain, there is potential that the air transportation of the future might be radically different from what we know:

- Simple cheap aircraft with low acquisition, use and maintenance costs could be developed. The concept is that modern aircraft are cleaner aircraft. By increasing the pace at which modern aircraft are developed and introduced, the average world fleet age, currently over 20 years, could decrease, thereby decreasing the global impact of the aircraft on the environment;
- During the past 15 years, the typical airline business model has changed drastically (from monopolistic national airlines to low cost companies, for instance). It is obvious that new trends in travelling will appear and that actual business models will have to adapt. One typical example for this actual trend is to entice passengers to shop onboard the aircraft rather than to pay an all-inclusive fare;
- The nature of freight transportation may need to be rethought as well. Specialized aircraft (and not refurnished existing airplanes) may need to be designed especially for freight, using specifically relevant technologies. In addition there may be a chance to introduce an alternative fuel (eg liquid hydrogen) to special freight airports and hence to the air freight sector, but only if it is proven to be an environment-friendly, cost effective alternative fuel. This development would enable the air transport system as a whole to get experience with a new fuel infrastructure and dedicated aircraft;
- Actual airports are very conservative in their design and the airport of the future will probably need to be redefined. Considering the potential new business model, the environmental regulations and the wishes of the consumers, airports will have to be redesigned to meet these new and conflicting demands. The shape and structure of such an airport is not yet clear;
- Systems based on travel between large hubs or based on travel from point–to-point should be investigated with a particular focus on the effects for the environment and requirements for new aircraft;
- Regulatory effects, especially on emissions and economics, should be assessed first by a defined modelling process. There is clearly a need for developing a European set of tools and methods to compare the different impacts of regulatory measures;

- Social sciences and external drivers of aviation need to be addressed more systematically. The analysis of the behaviour of customers, of trends and demand in the future require thorough analysis and need to be included in the studies dealing with future air transportation;
- Looking at wider, holistic airport constraints: beside the capacity limits caused by the number of runways or operational procedures, there are other constraints which become more and more relevant, such as environmental caps or expansion limits because of civil protest. While actual studies in this research area are dealing with single airports or global demand, an overview of all airport constraints and their future effects on capacity, emissions etc. is not available;
- Finally, it is well known that a better understanding of the quantitative effects of air transportation on the atmosphere (especially on the creation of cirrus) is necessary in order to judge the priority and effort required to limit global aviation emissions.

3.2 Research "Means and Needs" to Deliver the ACARE 2020 Environmental Goals

The objective of this workshop was to review the Strategic Research Agenda II (SRA) in order to identify specific research needs with respect to aviation local, regional and global environmental and climate impact. This work was also contributing to a subsequent ACARE SRA addendum document, where AERONET experts were actively involved.

FP7 is a significant research opportunity that can influence ACARE goal delivery. Given the time required for product development and market introduction, research would have to lead viable technologies and other capabilities by 2018 (at Technology Readiness Level 8 (TRL8)) to result in products entering service in 2020. Accordingly, it was suggested that the priority for FP7 in the environmental area should be towards those technologies that stand the best chance of contributing to realisation of the ACARE goals. The ACARE goals were considered to be extremely challenging and needed a gear change on research work in order to come within reach.

A combination of research into evolutionary improvements and 'blue skies' or 'frontier' research was identified as a need. This research mix would aim to unlock step-change technologies that can close the gap between traffic growth and fleet technology improvement. Additional resource is needed to stimulate and test higher-risk novel and advanced technology ideas to the point that promising options can be taken forward through 'technology readiness' evaluation.

Scenarios are a key to understanding the most productive research directions. Mechanisms and arrangements should be sought to enable scenarios to be constructed, updated and maintained to provide a 'living' forward look that will help guide research and wider policy strategies.

Greater maturity in models and simulation tools would help to explore technologies and operating practice in a cheaper and more flexible manner. Developing tools to examine and iterate design options, their practical application and system functionality is a crucial means of accelerating the delivery of aeronautical developments for environmental gain.

A holistic systems approach, beyond research, will be needed to deliver the ACARE environmental goals and thereafter keep the sector on a sustainable track. It is important to put research in the context of stimulating action and reaction by the aviation sector. New system approaches need to be envisaged and tested to help the sector to break out of some inherently unsustainable practices and structures.

Cross-disciplinary collaborative research with the scientific community is needed in order to explore the interaction between vehicle design, its in-service operation and its subsequent environmental impact. Evolving evidence of aviation's atmospheric impact suggests the need for closer working to understand the trade-offs.

AERONET identified open questions where specific research is still needed:

The ACARE SRA II is a fairly comprehensive assessment of the issues that contribute to the greening of aviation, to help it grow to meet predicted demand on a sustainable basis. Nevertheless, a number of topics were identified and felt to need more emphasis on account of their potential for delivering achievable benefits. Specifically, these were:

- Understanding the extent and climate impact of aviation-induced contrails and cirrus cover
- Development and life cycle impact assessment of novel and alternative aviation fuels and fuel sources
- Environmental impact and mitigation of the airport noise and air quality
- Aviation scenario monitoring and development
- A European Interdependency Modelling capability for the air transport system

3.3 Green Flight

A General Overview of "Green Flight"

Green flight covers the whole air transport system (ATS) and aims to reduce the ATS environmental impact. AERONET III investigated the following topics from the viewpoint of the potential of "Green Flight" to improve aviation's environmental performance:

- ATM / airport / airlines
- Aviation environmental policy
- Industry
- Atmospheric science

ATM / airport / airlines

ATM goals for environment are related to better efficiency, specifically to horizontal efficiency (shortest routes and optimum speeds), vertical efficiency (optimum altitudes and climb rates) and minimisation of air & ground delays and holds. Horizontal efficiency also means increased capacity and reduced delays. One example gaining much attention at present is the implementation of advanced continuous descent approaches (CDA) in a high traffic situation with its potential to substantially reduce descent phase emissions.

AERONET III identified the following research issues related to ATM, airports and airlines:

- Tools and methodologies to reduce direct and en route inefficiencies
- Identifying ways to decouple transport performance and environmental impact (ie find ways to make productivity substantially independent of aviation's environmental impacts)
- Operational means to reduce the impact of airports on local air quality
- Opportunities to implement better airport collaborative environmental management
- Identification of environmental constraints and associated delays
- Impact assessment of interdependencies
- Development of clear ATM strategic objectives
- Methodologies for safe and efficient ACDAs in high density traffic situations

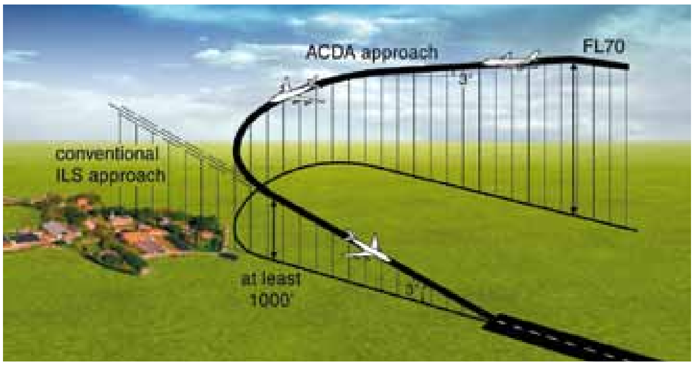

Figure 7: Advanced Continuous Descent Approach

Aviation Environmental Policy

Aviation is a truly global industry, both from a manufacturing and operational point of view. There are several globally accepted emissions regulations enacted through ICAO CAEP[6]. However, from the aviation environmental policy point of view, there is little global agreement over economic instruments as means to reduce aviation emissions. Such options, both on a global and a regional scale (as per EU ETS), need to be assessed in detail and common methodologies need to be found. Also a European modelling tool set on interdependencies needs to be developed as support for policy makers.

AERONET III identified the following policy related research issues:

- Inclusion of aviation in the European Emission Trading Scheme[7]
- Common methodology for Emission charges at airports[8]
- Development of basic, responsive and aircraft type aviation policy modelling systems together with impacts assessment and monetisation add-ons for use as required
- Proposals for short, medium and longer term projects for future European policy modelling work

Industry

In the context of the ACARE environmental goals, novel and innovative engine architectures are being investigated (e.g. open rotors, intercooled turbofan etc.). Significant effort has been spent in large European or national research programs (e.g. UK Environmentally Friendly Engine program). The European Joint Technology Initiative "Clean Sky" is a very large European program setup to meet the ACARE environmental goals, through 6 dedicated technology platforms covering mainly the vehicle aspects of air transport, namely:

- Fixed wing aircraft
- Regional aircraft
- Rotorcraft (helicopters)
- Engines
- Systems for green operations
- Eco-design

Currently perceived research goals for the short and medium term have been embraced by the "Clean Sky" programme. An example of a research topic in the "Engines" platform, an intercooled gas turbine configuration, is shown in Figure 8.

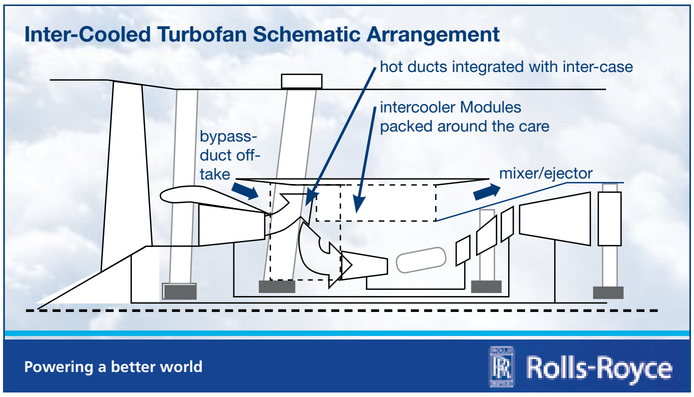

Figure 8: Intercooled turbofan

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[6] International Civil Aviation Organisation Committee for Aviation Environmental Protection, a UN special agency

[7] This recommendation has of course now been carried out

[8] Now covered by ECAC Recommendation 27/4 with a planned update in 2011

Atmospheric science

Climate science is a complex topic in itself. The addition of detailed, regionally and vertically differentiated aviation emissions adds to this complexity. Nevertheless, significant advances have been made in the understanding of aviation's impact of the global atmosphere (Figure 9). However, there are still many uncertainties. In particular, the exact impact of cirrus clouds on radiative forcing needs to be better understood. All these uncertainties are large enough to make efficient and cost effective aviation environmental policy making an extremely difficult and controversial subject. As climate impact understanding improves, mitigation options to reduce aviation climate impact and avoid ice super saturated regions need to be investigated in more detail. The idea behind mitigation options is to minimise the aviation climate impact by optimizing flight routes and flight altitudes.

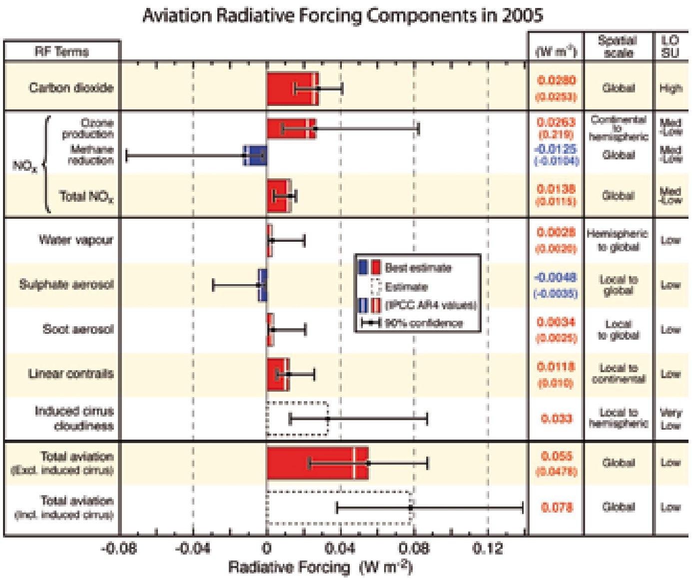

Figure 9: Aviation radiative forcing and estimated effect of cirrus clouds (Radiative forcing components from global aviation as evaluated from preindustrial times until 2005. Bars represent updated best estimates or an estimate in the case of aviation-induced cloudiness (AIC) as listed in Table 2. IPCC AR4 values are indicated by the white lines in the bars as reported by Forster et al. (2007a). The induced cloudiness (AIC) estimate includes linear contrails. Numerical values are given on the right for both IPCC AR4 (in parentheses) and updated values. Error bars represent the 90% likelihood range for each estimate. The median value of total radiative forcing from aviation is shown with and without AIC. The median values and uncertainties for the total NOx RF and the two total aviation RFs are calculated using a Monte Carlo simulation. The Total NOx RF is the combination of the CH4 and O3 RF terms, which are also shown here. The AR4 value noted for the Total NOx term is the sum of the AR4 CH4 and O3 best estimates. Note that the confidence interval for 'Total NOx' is due to the assumption that the RFs from O3 and CH4 are 100% correlated; however, in reality, the correlation is likely to be less than 100% but to an unknown degree. The geographic spatial scale of the radiative forcing from each component and the level of scientific understanding (LOSU) are also shown on the right.) Source: Aviation and global climate change in the 21st century, David S. Lee et al, Atmospheric Environment, Volume 43, Issues 22-23, July 2009, Pages 3520-3537

AERONET III has identified the following research issues related to atmospheric science:

> Route optimisation for minimal fuel consumption (including optimised speed);
> Fly higher, fly lower, fly (early) during day, fly around ice super saturated regions;
> Reduce soot emissions at the engine level;
> Provide information for better weather / contrail / cirrus / ice super saturated regions (ISS) prediction;
> Evaluate climate impact of mitigation options;
> Evaluate and reduce uncertainties in climate science understanding;
> Better determine the impact of contrails-cirrus on additional radiative forcing;
> How many of the observed cirrus clouds are produced by aviation;
> Does an additional constraint like "avoiding ice super-saturated (ISS) regions" lead to a breakdown of the ATM system or to other environmental interdependencies e.g. what additional CO_2 emissions are produced while detouring ice supersaturated regions;
> What are the additional costs due to detouring around ice super-saturated regions.

Green Flight Roadmap

Green Flight is intended to cover primarily the en-route cruise flight in the upper troposphere and lower stratosphere, including green enhancements in air traffic control and management addressing CO_2 and/or non-CO_2 effects. In reconsidering this operational part of the air transport system, the objective was to give an overview on relevant current projects and thereby further develop the green flight research roadmap for the coming years.

Aviation has an impact on climate which originates from aircraft engine exhaust emissions into the atmosphere. The most relevant emission species are carbon dioxide (CO_2), nitrogen oxides (NO_x), particles (soot, sulphate) and water vapour (H_2O). Despite the significant progress that has been made in reducing the specific emissions of aircraft, in particular CO_2, the absolute emissions have increased rapidly during the recent decades and are projected to steadily increase with future air traffic growth. Mitigation of the climate impact of aviation is therefore important through both technical and operational means. Application world-wide as soon as feasible and reasonable will have to take into account safety, available technology, scientific uncertainties, interdependencies and possible tradeoffs.

Research Roadmap for Green Flight:

The current Green Flight Research Roadmap summarises and fosters research on green flight options. The roadmap has fed into the definition processes of the SESAR Work Programme, the remainder of the EU FP7 Work Programme and any other research agenda at international level (e.g., ICAO/CAEP), at European level (ECAC/ANCAT), at national level (EU State Members) and at institutional level (EASA, ECATS). The following – not comprehensive but limited – list of relevant Green Flight topics is considered in the framework of the AERONET Green Flight Research Roadmap:

Topic 1: Single European Sky ATM Research (SESAR), specifically more environmentally efficient ATM systems ;
Topic 2: Reduced cruise speed operations for fuel and CO_2 emissions efficiency;
Topic 3: Green flight for improved fuel efficiency, reduced emissions and reduced climate impact;
Topic 4: Smart flight routing for reduced aircraft induced cloudiness;
Topic 5: ATM fast-time simulation for green flight assessment;
Topic 6: One-stop versus Non-stop long-haul flight operations;
Topic 7: Air-to-air refuelling on long distance flights of civil aircraft;
Topic 8: Formation flight of civil aircraft[9];
Topic 9: Jet or Prop for short- to medium-haul flights.


Figure 10: Artist impression of a green flight concept "air-to-air refuelling of civil aircraft"(copyright NLR)

From an environmental point of view, these topics are important because they involve improvements in fuel, emissions and/or contrail-cirrus efficiency. Efficiency improvements, for instance, in fuel/CO_2 emissions might range from just a couple of percentage points (e.g., topic #2), up to 10 percent (#1, #6, #8) and even, theoretically, up to 30 percent (#7, #9) in potential savings of fuel/CO_2 emissions per flight. Whether such improvements can be achieved in service is of course yet to be proven.

Despite their apparent promise, these green flight options are not "quick wins". Serious interdependencies and trade-off issues surround and therefore constrain the actual implementation of specific fuel-efficient green flight options. Frequently, these tradeoffs are caused by airspace capacity and other ATM constraints, resulting in a negative effect on time-related operating costs, passenger comfort and perception. Some, not all of these, result in emissions inefficiency. One sacrosanct constraint, if it can indeed be regarded as a constraint, is aviation safety – which is paramount in civil aviation. A different type of constraint exists in the presence of research gaps, such as the medium to low level of scientific understanding of the non-CO_2 effects of aviation on climate. Another example would be the current lack of higher resolution and otherwise improved models to forecast meteorological and "chemical" weather. Similarly prediction of aviation-induced contrail-cirrus formation is currently not as accurate as needed to allow implementation of green flight topics #3 and #4.

Taken together, lack of research and development into these trade-off issues and gaps is one of the reasons for delay in implementation of green flight options.

In order to get a better view of the potential of one or more green flight concepts in the actual air transport system including the defined trade-off issues, it is necessary to perform thorough assessments. Such strongly recommended assessments are explicitly addressed in green flight topic #5 on ATM fast-time simulation of green flight options in the actual air traffic and air traffic management (ATM) environment. In order to carry out a more advanced cost-benefit assessment, abatement and climate damage costs need to be known. A suitable metric which indicates climate damage costs would allow cost-benefit analysis to be performed simultaneously during the optimisation procedure. Such a metric is, however, still under complex and unresolved discussion within the policy maker and scientific communities.

Despite all the above-mentioned issues, the majority of topics in the roadmap are part of an ongoing research program/project (e.g., topic #1[10] and #3[11]) or even already in partial operation (#2, #9). At the time of the workshop, other topics were submitted as a proposal (#7) or currently in a "stand-by" / "on-hold" position at a basic research level (#5, #6, #8). In terms of timescale for implementation, most Green Flight topics, have an estimated earliest time of entry into service between 2020 and 2025.

The overall conclusion and recommendation from this Green Flight Research Roadmap is that a lot of opportunities remain for additional operational measures to be investigated and to be applied. Although a few green flight concepts are already in operation by airline operators and subject to ad-hoc improvement, many other green flight options are still at a low level of research. It is up to the aviation industry, policy makers and research funding organisations to pick up these potential "cherries from the cake". That said many are not easy pickings, requiring fundamental changes to the air traffic and the aviation system.

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[9] *Improved efficiency through formation flight, similar to migrating birds*

[10] *SESAR*

[11] *REACT4C*

In conclusion therefore, many of the topics in the Green Flight Roadmap remain open and, AERONET III has identified the following research opportunities and gaps beyond the work in SESAR:

> Reduced cruise speed operations for fuel and CO_2 emissions efficiency;
> Green flight for improved fuel efficiency, reduced emissions and reduced climate impact;
> Smart flight routing for reduced aircraft induced cloudiness;
> ATM fast-time simulation for green flight assessment;
> One-stop versus Non-stop long-haul flight operations;
> Air-to-air refuelling on long distance flights of civil aircraft;
> Formation flight of civil aircraft;
> Jet or Prop for short- to medium-haul flights.

3.4 Interdependency Modelling

Aviation has made substantial reductions in noise, emissions and costs since the introduction of the jet airliner. As some level of technological maturity is reached, these former win-win situations regarding noise, emission and cost reductions are not always satisfied, resulting in further aviation system development now requiring potential trade off between these factors. The recent growth of interest in interdependency modelling springs from a realisation that not only do we need to understand the interrelationships between all the different technical environmental and economic factors that affect aviation, but also that we now have the technical know-how and computing power to integrate all the major influencing variables in aviation into a single model or modelling system.

AERONET did some extensive research in the domain of interdependencies modelling and trade off aspects through the EFEMTA study (Enhancing compatibility of European Financial and Environmental Modelling tools for aviation).

The aim was:

> To define a European view of the analytical requirements for CAEP policy considerations (Figure 11) for CAEP/8 and thereafter and the likely requirements for Europe-based econo-environmental modelling of aviation in the medium term;
> To provide an inventory of potentially useful existing and emerging models, together with a gap analysis identifying missing capability.

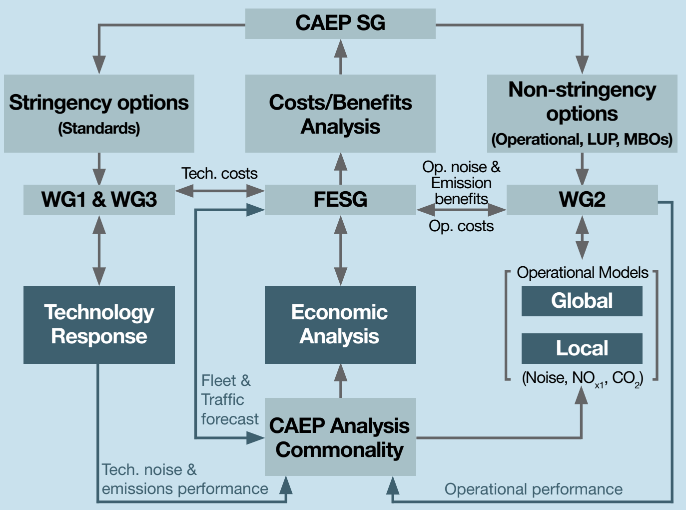

Figure 11: CAEP interdependencies framework

As a result, five modelling systems were defined which should provide the required European modelling capability on aviation & environment assessments:

> Basic modelling system (without feedback loops[12])
> Responsive modelling system (with feedback loops[13])
> Aircraft type modelling system (aircraft technology modelling)
> Impacts add-on (e.g. climate impact tool)
> Monetisation add-on (e.g. Cost-benefit analysis tools)

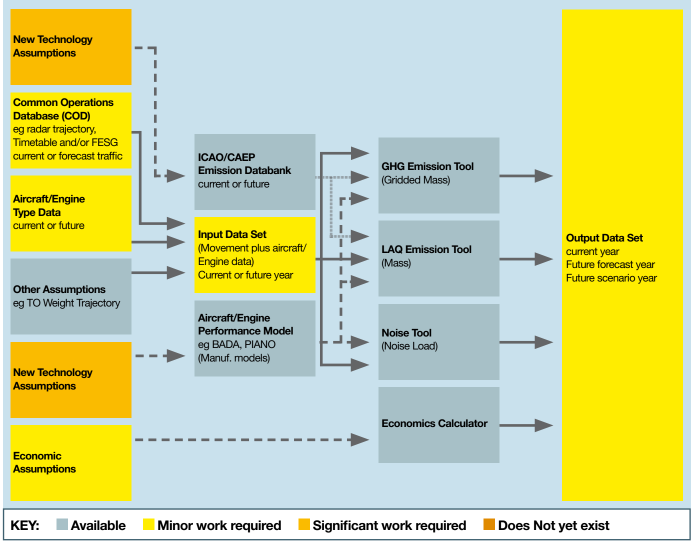

Figure 12: Basic modelling system

In the EFEMTA study, recommendations were made for the short to long term as to how to build a European interdependency modelling capability in form of a models toolset.

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[12] *ie taking input flight movement data and simply calculating noise, emissions and costs*

[13] *ie using the cost data from an initial "basic" modelling calculation to assess the response of the customer and industry and thereby to change the input flight movement data in an iterative looped modelling process*

This led first to an activity funded by EASA (the EEMA study, Basic Economic and Environmental Modelling system for Aviation) to develop a European basic modelling system in prototype form to address policies directly related to regulation. This basic system comprises European and ICAO data sources and models and the links between them, based on a Data Warehouse concept.

Additionally this led to the submission of a European project proposal (TEAM, Toolset for Environmental Aviation Modelling, now called TEAM_Play) to define, as concluded in the EFEMTA and EEMA study, a European view of the analytical requirements for CAEP policy considerations for CAEP/8 and to set out the likely requirements for Europe-based econo-environmental modelling of aviation in the medium term. The aim is to develop a European toolset combining various existing modelling modules. In addition, the MONITOR project is underway to provide scenario input to any aviation policy modelling system.

Meantime, at the CAEP level, the MODTF (CAEP Modelling and Databases Task Force, now renamed MDG (Modelling and Databases Group)) expert group was created to examine the CAEP/8 short term modelling requirements.

From the AERONET III and EASA studies, additional topics for further investigation were identified to be:
> Interdependency modelling IPR issues
> Interdependency modelling definition of policy use cases
> Interdependency modelling definition of a common metric

These topics were handled separately in the following three AERONET III studies.

Study 1 Interdependency modelling: IPR issues

Several independent models have been developed in Europe, each of them targeting certain issues with regard to aviation emissions, noise and their local and global impacts. However, these modelling activities have not yet yielded in an integrated model taking into account interdependencies between different regulatory measures. To achieve this objective, existing European models need to be brought together into a flexible toolset allowing for the assessment of forthcoming policy measures from a wider, integrated perspective.

The scope and objectives of this short study were:
> Identification of relevant issues regarding organisational options and of best practices on how to effectively establish durable cooperation between European actors;
> Europe-wide discussion on different organisational structures, business models and relevant issues concerning intellectual property rights (IPR).

The study was performed by NLR, DLR and QinetiQ and, in addition, involved representatives from the European aviation noise community (X-NOISE: Snecma), the European aviation environmental impact community (QUANTIFY: DLR) and relevant European institutions (EASA and EUROCONTROL).

The short study results are based upon the outcome of desk research, information exchange, task force conference call discussions, bilateral interviews, participation in workshops addressing interdependency modelling, and finally from review comments on the final draft report.

To identify relevant organisational issues and best practices and thereby to establish durable European cooperation, current and past examples in Europe and North America have been collected and analysed. These include the suggestions made in the 2007 EEMA[14] Study proposing alternative options for organisational structures to manage the cooperation needed for successful modelling at a European scale. These options included "business-as-usual" project level, a small agency on standardisation, an independent European modelling management and coordination group, or – as the ultimate format – a durable and comprehensive network of expert modellers and stakeholders. Existing research and organisation structures were analysed. These included in the US, the organisation setup to manage the development of the US Aviation Environmental Tools Suite (US FAA funded). Within Europe: similar initiatives by EASA and EUROCONTROL, and the range of instruments available within European programmes like the EU Framework Programmes (FP6 and FP7), ERANET and other long-existing programmes like COST, EUREKA and GARTEUR were examined.

The analysis highlighted different approaches and the multiple opportunities to management of aviation environmental modelling and research. The current European approach is dominated by the highly competitive EU framework and national research programmes. Reductions in the funding and coordination roles of organisations have resulted in a somewhat disjointed approach to research in terms of ongoing compatibility and continuity. Continued national programmes unintentionally promote duplication, while EU Framework Programme research is highly oversubscribed resulting in strategically important projects being dropped. Moreover, the finite nature of projects also promotes a less than strategic approach to a European modelling capability.

Although there are significant organisational and cultural differences, there are lessons to be learned from the US PARTNER organisation, in particular that in this policy (not commercial) driven area, the funds are under control of the policymakers allowing them to develop capability and knowledge exactly when and where it is needed to support policy needs – whilst also retaining the element of competition between the organisations involved. With the rapidly evolving roles of

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[14] *EEMA: EASA-funded study on a Basic Economic and Environmental Modelling System for Aviation*

EASA and EUROCONTROL, there appears to be a significant opportunity to improve coordination and project funding within Europe, guided by experiences on both sides of the Atlantic. Nonetheless, these are really subjects for further elaboration and discussion because at December 2009 AERONET workshop on Interdependency Modelling a strong central (institutional) management and coordination role was rejected unanimously, amongst others, for reasons of preservation of diversity, creativity and freedom of research and interdependency modelling.

On the issue of legal provisions on use, access, intellectual property rights (IPR) and ownership (of data and tools, such as individual models and complete systems) - current views are that there is really a need for clarity and for practical solutions. Where appropriate, alternative provisions which better fit the application and operation of the European interdependency modelling capability need to be identified, discussed, updated and/or newly defined and recommended.

The EEMA Data Warehouse concept – ultimately a web-based platform for provision of common data – demonstrated feasibility and value of collecting and controlling the model input data. Acting as a warehouse for model outputs, it provides an additional benefit in terms of quality control. Nevertheless, constraining IPR issues remain. The EU FP7 TEAM_Play project, which should elaborate the Data Warehouse concept, suggests differential levels of data access to tackle these IPR issues. In case of proprietary/competitive data, there will be provisions and restrictions via different data access portals. A layered approach with open and limited access will therefore be applied. In addition, the non-authorized user will be offered alternative datasets instead, which will include publicly available data or otherwise default, dummy or best-estimated data (the latter computed with use of available tools).

Joint ownership of European interdependency modelling systems and/or making the data and software "open source" or "freeware" have also been considered. However, this appears to be one step too far in today's not-yet-fully-coordinated environment, but is an important issue to consider in the near future anticipating a rapidly changing world with growing use of the internet and increased availability and freedom for use of data.

In summary, a common balance between openness and intellectual property protection is needed. In the current short study, good progress is made towards the goals to identify relevant issues regarding organisational options and best practices on how to effectively establish durable cooperation between European actors. Moreover, different organisational structures, business models and relevant issues concerning intellectual property rights (IPR) have been discussed Europe-wide via dedicated workshops and via review of the current short study results. It is hoped that the TEAM_Play project can take these issues forward to solution.

Study 2 Interdependency Modelling: Policy "Use Cases"

In the frame of a European aviation interdependency modelling toolset, a number of policy use cases have been defined. The main objective in this context was to identify use cases with high political relevance which addressed important topics that were already on the agenda of policymakers or at least were expected to be so in the future.

In times of growing air transport, a dominating topic is the rising environmental impact caused by aviation through noise, local air quality (LAQ) and greenhouse gas emissions (GHG). Regulation is currently extensively discussed at the European level. That is why the majority of the chosen use cases deal with regulative measures that introduce current or future options for limiting the environmental impact of aviation. In addition, the number of chosen use cases was enlarged to include topics relating to the economic impact of air transport in order to complete the picture and to allow consideration of the value of extending European modelling activities in this field. The "use cases" proposed in the study were:

Use case	Title	Economy	Society	Noise	LAQ	Climate	Technology
1	Monetisation of the impact of noise on residential neighbours of airport X	X		X			
2	Potential trade-offs linked to a technical change by subvention of the introduction of direct injection combustor design	X				X	X
3	Efficiency effects of the Single European Sky	X				X	X
4	ATM improvement by introduction of eco-routing with the focusa on the European air space					X	
5	Assessment of the effect of potential incentives for the use of alternative fuel sources, specifically biofuels	X				X	
6	Reaction of airlines on the introduction of the European ETS (Airline Response Modelling)	X				X	
7	Modelling of the (climate) effects of regulatory plane phase-outs					X	
8	NO_x related landing charges (NO_x regulation)	X				X	
9	Direct and indirect effects of the aviation sector around airport X	X	X	X	X		
10	Evolution of aircraft noise annoyance by year 20XX			X			
11	Particulate matter regulation		X		X		
12	Effects of a liberalisation of grandfather rights in the case of slot allocation with regard to frequencies and fleet size at different airports	X					
13	Subsidies for regional airports	X	X				

Looking at the capability and gap analysis which was discussed alongside the use cases, it is clear that the main problem preventing the elaboration of such use cases is that no common EU toolbox exists that bundles the European modelling competencies together. Existing models mainly focus only on one aspect e.g. the development of CO_2 emissions. Interdependencies between different environmental effects or an economic assessment of a special policy measure are often excluded. This can lead to ineffective decisions if not all potential tradeoffs are evaluated.

It is concluded that if the full impact of aviation on the environment is to be assessed, it is necessary to focus on complex use cases in aviation research and to carefully select the methodology in order to deal with potential gaps in data or capabilities. In addition, the build up of an EU modelling toolbox is highly desirable in order to bundle existing competencies and thereby to prepare relevant information to aid policy decisions in a cost effective but comprehensive manner.

Study 3 Interdependency Modelling: Metrics

The broad range of research and model development carried out in the field of aviation and its socioeconomic and environmental impact has provided many components that can be used to make assessments of policy or mitigation measures in aviation. What has become apparent is that there is no one set of assessment criteria that could be explicitly defined and that would adequately fulfil the assessment needs of all aviation scenarios.

As a consequence, a methodology has been proposed that would allow a statistically robust model to be developed using criteria that are chosen by the model user. This methodology allows the consideration of both qualitative and quantitative data and permits the statistical representation of the relative importance of each component. The resulting figures then allow the identification of an optimum solution from a list of alternatives.

The model also allows trade off assessments to be performed based on the relative importance of assessment criteria. However, it was noted that the trade-off should not be performed based on solely numerical factors and that a set of rules should be adhered to so as to ensure that trade-offs are valid under the definition of overall improved sustainability.

A case study on “Reduction of Sulphur in Aviation Fuel” has been performed using the developed methodology above. This case study addresses a global aviation problem with a global solution – namely reduction or removal of sulphur from aviation fuel by global agreement to change the fuel specification. Costs and benefits are therefore global, requiring judgements on that scale. In order for this work to progress beyond the conceptual model and case study described in the main study, it would be beneficial to apply the methodology to a number of case studies with the aim of identifying further where the strengths and weaknesses of the model lie.

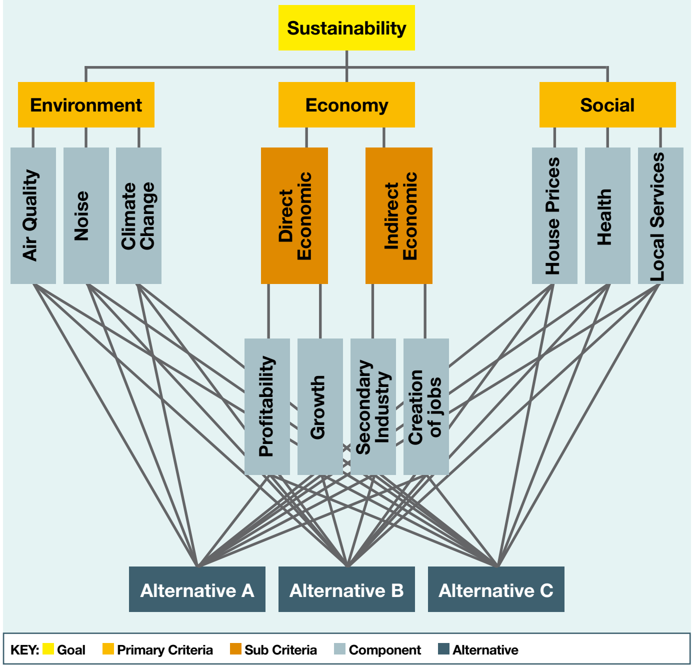

Figure 13: A possible two level hierarchy for assessment using a three pillar criteria

From this case study, it was concluded that:

- The pairs comparison method which is proposed provides a valuable method to assess policy options, particularly where quantified information is not fully available and qualitative judgments need to be made. It circumvents many of the pitfalls associated with purely quantitative methodologies such as monetisation;
- To obtain a robust result, particular care needs to be taken in the choice of criteria and their weighting within the context of the problem being addressed. Sensitivity cases are normally essential to promote an understanding of the key assumptions;
- Analysis of the individual numerical values provides insight into the relative importance of each criterion and the key influences on the final rankings;
- Visualisation through ranking of individual criteria and of overall results provides easier insight into the relative influences of each criterion;
- Visualisation though radar plots provides more immediate highlight of the relative merits of each interdependent criterion;
- The “use cases” carried out demonstrate that the key criteria affecting a policy option can be captured, compared and visualised in such a way to reveal key interdependencies in a potentially realistic manner;
- Even with these visualisations, uncertainties may be such that the way forward is not obvious. However, this methodology will have highlighted, not hidden, the interdependencies, thereby allowing best use of technical, economic and political judgement, alongside a transparent process, to reach an optimum policy decision.

3.5 Trade-Offs

AERONET further addressed this issue of interdependency and trade-offs through a large symposium organised together with X-Noise and CEAS. The results of this symposium are summarized below.

Efforts to minimise the environmental impact from aviation are associated with complex inter-relationships between various disciplines. Thus, when selecting mitigation strategies, trade-off aspects between air quality, climate change and noise impacts have to be considered, while ensuring that safety and capacity are maintained or enhanced.

The environmental impacts of air transportation, as well as its benefits, rely on a complex interaction of interdependent technological and operational systems. These systems are operating within policy constraints and evolving with market conditions.

Today, the green technology design and R&D activities are almost exclusively focusing on only noise, only air quality, or only climate change. Very few research activities underline the real world interdependencies between these environmental aspects as they are happening in the aviation sector. Also, economic costs related to policies and to project implementation are often not considered. As a result, the engineering and organisational realities of the air transportation system are not fully reflected and policymakers' decisions in one domain may then produce unintended negative consequences in another.

A correct assessment of the interdependency issues is therefore crucial for all aviation stakeholders. It is necessary to integrate consideration of all environmental and socio-economic impacts simultaneously, and establish new understanding of the interdependencies amongst these effects.

In assessing trade-offs, the ACARE strategic research agenda has of course to be considered. Literature review shows that, by 2020, there is considerable doubt that the contribution of aviation to climate change and the impacts of aviation particulate matter and hazardous air pollutants, as well as noise contours around airports will be reduced as planned.

However, further work has to be done in order for the EU to become a global leader in researching, developing, and implementing technological, operational and policy initiatives that jointly address mobility and environmental needs. A need for analytical tools that can effectively assess interdependencies amongst emissions, and between noise and emissions, is expressed by several aviation stakeholders and specialists.

Technologies
Technologies need to be developed and properly demonstrated, requiring extensive efforts, resources and funding. Technical tradeoffs need to be considered when designing the environmental performance of a product (NOx, fuel burn and noise). However, aircraft technology must not be considered in isolation but complemented by operational aspects and supported by policy. Novel approaches need to be explored beyond evolutionary progress. Environmental optimisation cannot be separated from the broader product optimisation, even if the environmental dimension were to become a prime design and technology driver. Rising fuel costs will drive fundamental changes across the industry in terms of the airline business model. Additionally, future "green" energy availability is crucial and there are technical and certification framework challenges which need to be addressed, depending on the energy sources which are to be used.

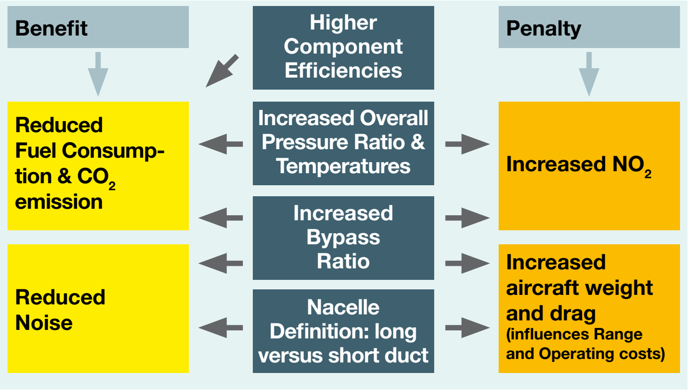

Figure 14: Example of technical trade-offs when designing an engine (source RR plc)

Policy
Policy issues address the balance between sustained growth and sustainable impact, in terms of health, ecosystem and climate impact. The US view is defined especially in "NextGen", a program to reach sustainable aviation transportation and implying that environmental goals and targets will be common to all stakeholders in the aviation system. The need for a comprehensive approach with indicators and economic measures is also expressed by ANCAT and by airport stakeholders.

Operations and Capacity
One of the first major activities improving aviation environmental impact by operational improvement are trials and research in the area of continuous decent procedures (CDA), conducted in Europe and Asia as well as in the US. CDA can reduce fuel consumption and emissions as well as changing the noise impact of the descent and approach phase of flight. The experience from the CDA implementation shows the need for improved CDA design techniques taking into account several technical criteria as well as the non-technical constraints such as geography and policies. This needs to be done in a systematic way. Other activities include the scheduling and coordination of en-route traffic, as researched in simulations and trials. From a study of metrics and costs, it could be concluded that whilst there are some metrics and costs available to use in assessment studies, in some areas there

are none and in some areas they are contradictory. A unification and verification study is therefore needed.

In addition to noise, airport air quality (AAQ) is still a constraining factor for some airports. Requirements for increased capacity are often constrained by safety and environmental limitations. Research programmes are ongoing to develop methods for enhancing capacity and safety concurrently. On the subject of CDA implementation and its impact on capacity, there are examples showing that CDA implementation does not necessarily have an adverse effect on capacity. In fact, capacity can be increased when CDA is properly implemented by using vectoring and the optimum point to start the continuous descent. However, the many constraints due to human factors, acceptance from pilots and controllers, limitation by national sectors and general airspace availability, all make it clear that further learning and research is necessary.

Tools

Modelling activities in North America are being carried out to develop a comprehensive tool suite incorporating environmental challenges, environmental interrelationships, legacy/regulatory policy obligations, market scenarios, technology and operational issues. In Europe there are several different tools with no obvious or established interface, although several initiatives exist or are being worked on to cope with this situation. The need for interdependency modelling tools is recognised throughout the community and while there is a great European capacity which is less organised but open and transparent, the US toolset is well organised and potentially significantly more effective.

Noise and Emissions Trade-offs Through Operational Practices

As already described above, Continuous Descent Approach (CDA) has the potential to reduce both noise and emissions during takeoff and landing at airports. Therefore AERONET, together with X-noise (X-Noise-AERONET trade off working group), carried out a specific study on this topic in 2 phases which are summarized below:

Phase 1

The topic of noise and emissions tradeoffs was explored in the context of operational practices. Current knowledge and uncertainties have been assessed, and future trends of possible impact reduction through improved operational measures were investigated. To do this, the study brought together the aviation experts of the two European networks and additionally involved the entire aviation sector (CAA, ANSP, Airline, Airport) through a CDA implementation trial.

The study had two objectives:

1. To assess the current knowledge
2. To conduct a trial to investigate data accessibility and new procedure implementation and acceptance.

Identifying the available tools to assess the impact changes was a demanding task. The present study addressed a limited number of questions, focusing on operational practices related to noise reductions. Noise Abatement Procedures (CDA, NADP, modified approach angles, etc) were used to assess operational trade-offs, illustrating their contribution to noise reduction in the airport vicinity and also their impact on emissions/fuel burn. It is self evident that noise analysis should also include an analysis of emissions impacts and fuel burn, as these variables may be affected by procedure changes both in the air and on the ground.

Currently researchers are working on automation tools and minimum aircraft equipage to reduce the pilot and controller workload associated with the procedures, maintaining safety aspects as a priority. However, pilot and air traffic controller acceptance is essential in implementing new procedures.

A trial was conducted to define different operational scenarios, assess noise and emission benefits from FDR[15] data, develop a proper methodology and assess the level of acceptance through implementation. The CDA trial was undertaken at Bucharest Henri Coanda Airport, involving TAROM[16] aircraft.

Data analysis on acceptance shows a general interest in implementing the CDA procedure, with, in this particular case, more interest in reduction of emissions and fuel burn than in shrinking the noise contour. The outcome of the study shows that continual development and optimisation of operational procedures are essential for minimizing the environmental impact of aviation. It is a fundamental advantage of operational procedures that they can often be implemented with the existing fleet and have the potential to make an immediate improvement in the environmental impact of aviation.

Phase 2

Phase 2 of the operational trade-offs task was carried out by MMU, FOI and NLR as an extended part of Phase 1. Its aim was to analyse noise and emissions trade-offs through operations and assess the relevant impact on the airport environmental capacity. This may be achieved by working closely with an airline company which is the provider of FDR data. The effort associated with this task was an opportunity for the AERONET experts to work with the aviation stakeholders, exchange knowledge and experience based on a selected case-study. Following on the gaps and conclusions formulated at the Kiev Symposium (Oct 2008), this task needed to identify the link between new operational practices and noise & emissions trade-offs.

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[15] *FDR – Flight data recorder – a source of detailed data on actual flight parameters*

[16] *TAROM – Rumanian Airline*

The outcome of the work is contained in a study structured in five main parts. The outcome of this study is summarised below:

I. Review of the main operational practices and their influence on noise and emissions trade-offs

Literature review identifies CDAs as the most appropriate new operational practice linked to the objectives of this task. The type of CDA and the status of its implementation are presented, as well as the opinion of the Eurocontrol experts on the importance of CDA in reducing aviation noise and emissions. The impact of real world air traffic control is also mentioned, and the important role of aircraft flight management systems (FMS) in optimising the new operating technique is underlined. According to the ICAO Continuous Descent Operations (CDO) Manual (Doc 9931), CDA is considered to be a new flying technique, not a new operational procedure.

II. Trial selection and stakeholders' involvement

In order to assess the environmental trade-offs involved in implementation of CDA, a trial was organised and flight data recorder analysed. The selected trial included the Rumanian airline TAROM operating an Airbus A318 and therby providing FDR data. The Rumanian air traffic management service provider ANSP-ROMATSA provided input from the controllers, Bucharest Henri Coanda Airport was involved in assessing the impact of operational trade-offs on the airport environmental capacity and the Romanian CAA presented concerns on the possible impact on the operational capacity due to the CDA implementation at Bucharest Airport.

III. Data collection and analysis

The FDR data collected from 6 CDA were sent to FOI and NLR for analysis, but due to its raw format, difficulties were encountered in analysing those data. Therefore, a mixed methodology in analysing FDR data was used, with a focus on fuel burn. Data corresponding to fuel burn per leg were compared to flight plan (i.e. planned fuel burn) and an interview post flight with the pilot involved identified the number of thrust restoration and level-offs used as well as any early configuration extension or level flight involved in starting the CDA procedure. The last of these will have an impact on noise in the area situated under the flight track. The results were also discussed with European experts involved in implementing new operational practices.

IV. Aviation noise and emissions trade-offs: Impact on airport environmental capacity

The implementation of CDA as a single event will not have a perceived impact on airport environmental capacity. Thus, when TAROM is implementing a CDA/CDO while all other airlines are operating standard procedures, the reduction in noise and emissions is negligible. However, there are periods during a day when only TAROM is landing at Bucharest Airport (e.g. 1800-2100hrs) and if all its aircraft are landing in CDAs, a reduction in noise is perceived at Mogosoaia and Buftea (two villages situated around 20 and 15 km far from the runway). Level flight segments are acceptable if not associated with thrust restorations. A CDA in itself normally has insignificant impact on final approach and therefore on air quality (below 3000ft). No data available below 1000ft.

The data analysis shows that from a minimum noise point of view, the arriving aircraft should be kept as high as possible for as long as possible. However, a stable approach must not be compromised.

V. Conclusions and recommendations

Trade-offs through operational measures is an important means to assess the environmental impact at airports, and thus to identify which operational practices should be implemented at a noise sensitive airport, or at an emissions sensitive one. However, the pilot involvement in flying optimum CDA trajectory can have a significant impact on the results. A CDA is only efficient if early configuration extensions and thrust restorations are avoided.

The study concludes with the need for more research in the area of operational trade-offs while better expertise in extracting FDR data is necessary to assess the magnitude of the reduction in noise and/or emissions. A joint industry action plan is required to allow more efficient use of airspace e.g. route placement, fuel efficiency and noise abatement.

Source: Dan Trusca, Head of Airbus Fleet, TAROM; landing at Munich Airport, May, 2009

3.6 Wild Card Events – Volcanic Ash

In April and May 2010, the last few weeks of the AERONET III project, European aviation was caught somewhat unprepared for the extent of disruption caused by the volcanic ash from the Icelandic volcano Eyjafjallajökull. Whilst necessary safety procedures were already in place, the relatively thin ash cloud spread over a large area of busy airspace required quick action to identify means to continue safe flying in the presence of volcanic ash at various heights and various concentrations. A number of individual AERONET partners were involved in the quick response activities at the time of the initial airspace closures. Recognising this, AERONET III organised an additional session on the topic in the AERONET workshop at the end of April 2010. In addition, a dedicated workshop was held exactly two months later to pull together the latest information and to assemble a view on medium and longer term work required to minimise the impact of future incidents.

AERONET III studied the questions of the physical phenomena and their impacts on the air transport safety, as well as how the whole air traffic system had coped with this event. This covered an overview on the state of knowledge related to the impact of volcanic ashes on airframes and engines, information on spreading and concentration of the ash in the atmosphere as well as the necessary measurement systems. The workshop also presented the perspective of the air traffic management authorities and the airlines.

As a result of the event, recommendations were provided on future research activities needed to respond appropriately to the critical issues for aviation on how to handle such uncontrollable global and regional events. The emphasis of these recommendations was on improving the detection, measurement and modelling of volcanic ash presence to enhance the operational decision-making processes. These recommendations included:

Technical

> Using measured data to improve prediction methods and speed up the process;
> Assembling models to quantify ash loading together with information on the probability of exceeding thresholds;
> Equipping high flying and long range research aircraft with Lidar, in situ instruments for large particles and SO_2 for source determination and validation, including preparation of instrumentation for measurements in dangerous air masses;
> Making high-quality secondary information available to decision makers;
> Analyse ash mass uptake by aircraft engines with/without damages in European airspace.

Organisational

> Responsive validation of the risk assessment models supporting the decision making;
> Develop a R&D roadmap to coordinate research and measurement activities and to develop a coherent approach to the validation of the relevant input data, models, etc., targeted for the specific purpose of risk management in air transport, as developed and applied at European level and in ICAO;
> Involve manufacturers (airframe and engine manufacturers and equipment manufacturers for sensing issues) and operators (pilots) of aircraft, operations and safety related aspects, including non-EU countries;
> Establish an interdisciplinary and cross-sectoral network.

4

AERONET III Final Workshop / Concluding remarks

A final AERONET III workshop was held in April 2010 to bring together the results of the work in the three work packages:

> Aircraft and Engine Technology Aspects of Emissions Reduction
> Airport Air Quality, and the
> Air Transportation Environmental System

A summary of the outcome is included in the following "Concluding Remarks" section.

Concluding Remarks

AERONET has contributed to cooperation and understanding of aviation and its impact on the environment with a number of varied activities, principally 14 workshops, 10 studies and various related expert meetings. This information exchange has taken place within and outside the consortium on the leading technical and scientific developments in the field of aviation and its environmental impact.

During the course of the project, the public debate on aviation and its local climate impact has gained significant momentum, significantly more than expected and significantly more than was the case in past decades. Partially as a consequence, AERONET III witnessed a number of very important European programmes and activities being initiated in this field. Whilst in its 1st and 2nd phase, AERONET was more an initiator, bringing together different communities, AERONET III had a different emphasis, namely using the relationships developed in AERONET I and II to develop understanding of the emerging issues and cooperation on means to address those issues.

An important change of emphasis was the stronger focus on the multi-discipline and multi-community subject of the Air Transport System and less on the vehicle and its technological developments. Such technical developments were being covered in a range of other European dedicated research projects.

AERONET III gave important impulses to the field of interdependency modelling and tradeoffs. Reducing aviation's impact on the environment is more and more related to finding the right balance between different technical and non-technical developments, specifically social needs and economic costs. Only then can we achieve sustainable development for the air transport system as a whole.

In that context, AERONET III was also actively involved in contributing to the ACARE process by promoting topics such as alternative fuels and atmospheric science. AERONET III actively participated in European and international expert groups (ACARE, ANCAT/MITG, SAE 31) contributing to the environmental policy and scientific debates.

Within the three major topic areas, there are many areas for research identified throughout this report. Of course, given the 6 year timescale of the coordination activity, many of these research gaps have already been filled – through the EU research programme, through national programmes or through changes in the priorities of the aviation industry. Important among these are the Clean Sky Joint Technology Initiative, the SWAFEA alternative fuels project, the MONITOR scenario project and the TEAM_Play interdependency modelling project.

Assuming these projects go ahead, remaining research and knowledge gaps for future attention include:

Technology

> Understanding the costs and benefits of higher thermal stability fuels for aviation;
> Learning from the work in the US, go beyond the remit of SWAFEA to determine the impact for Europe of emerging alternative feedstock sources for aviation kerosene;
> Continue the pressure on APU manufacturers to provide data on APU emissions at airports;
> For aviation technology beyond Clean Sky, research aims should be to bring forward technologies to a technology readiness level which industry can then commercialise at reasonable cost and risk. Complementary to this is the need for development of a progressive but stable regulatory regime which encourages, rewards and perhaps even mandates these breakthrough technologies in order to provide the essential environmental performance improvement necessary for continued sustainable growth of commercial aviation to meet society's needs.

Airport Air Quality

> Complete and realistic information on airport operations and emissions;

- A category of numerical dispersion models appropriate to regulatory application for different air pollution scales and adapted to airport and vicinities, including measurement strategies and adequate instrumentation for monitoring emissions concentrations around airports to support numerical dispersion model validation;
- Specifically for VOCs and PM, conduct test-bed systematic measurements of speciated VOC engine emissions using existing applicable measurement techniques to allow better quantification for airport inventories.

Aviation System Aspects

related to goals beyond 2020:

- Continue high priority research on understanding the extent and climate impact of aviation-induced contrails and cirrus cover;
- Aviation scenario development through to 2050;
- Development of a European Interdependency Modelling capability for the air transport system, specifically including an understanding of technology tradeoffs;
- Effectiveness analysis of one-stop versus Non-stop long-haul flight operations, air-to-air refuelling on long distance flights, reduced cruise speed operations formation flight and jet or prop for short- to medium-haul flights.

related to ATM, airports and airlines:

- Tools and methodologies to reduce direct and en route inefficiencies;
- Identifying ways to decouple transport performance and environmental impact;
- Operational means to reduce the impact of airports on the local air quality, including airport collaborative environmental management;
- Development of clear ATM strategic objectives;
- ATM fast-time simulation for green flight assessment.

related to policy:

- Proposals for short, medium and longer term projects for future European policy modelling work.

related to atmospheric science:

- Provide atmospheric data and costs effectiveness analysis of avoiding contrail / cirrus / ice super saturated regions;
- Evaluate climate impact of mitigation options;
- Evaluate and reduce uncertainties in climate science understanding;
- Better determine the impact of contrails-cirrus on additional radiative forcing;
- Determine how many of the observed cirrus clouds are produced by aviation.

related to wild card events:

- Establish an interdisciplinary and cross-sectoral network to develop system wide risk mitigation strategies for wild card events.

In addition to identification of these research gaps, AERONET III has worked closely together with other related projects and networks (e.g. X-NOISE, ECATS, ELECT) and contributed to a number of project proposals in the field of airport air quality, interdependency modelling and aviation climate impact research.

Looking forward, although the AERONET III network is ended, the aim is to keep the website and intranet operational after end of the project, for continued dissemination of relevant information – and of course to continue to build on the strong relationships and cooperation built up over the 12 years of the AERONET network.

Further Information

Further information on AERONET III activities is available on the AERONET website at www.aero-net.info or from Ms Irena Champion, email: Irena.Champion@dlr.de.

The following Table 1 lists the workshops held by AERONET III:

No.	Name of Workshop, Venue, Date
1	Workshop on Airport Air Quality IV (Schiphol), 5 - 6 April 2005
2	Workshop on Air Transportation System; Alternative Futures for Air Transportation from a System Perspective (Stockholm), 31 May - 1 June 2005
3	Workshop on Fuel Thermal Stability (Sheffield), 28 - 29 September 2005;
4	Workshop on European long-term emission reduction goals and how to support the SRA II". (Brussels), 24 - 25 January 2006
5	Workshop on Green Flight (Stockholm), 20 - 21 November 2006
6	Workshop on Alternative Fuels for Aviation (Sheffield), 24 January 2007
7	Workshop on Hydrogen for Aviation (Sheffield), 25 January 2007
8	Workshop on APU Emissions (Erding/ Munich), 5 April 2007
9	Workshop on Interdependency Modelling (Amsterdam), 17 - 18 January 2008
10	Symposium on Aviation Environmental Tradeoffs and Interdependency (Kiev/Ukraine), 6 - 8 October 2008
11	Workshop on New Propulsion and Aircraft Concepts for Green Aviation (Manchester), 1 July 2009
12	Workshop on Interdependency Modelling (Brussels), 17 - 18 December 2009
13	Workshop on Green Aviation – Trends and Future Challenges (Brussels) 28 - 29 April 2010
14	Workshop on Volcanic Ash Impact to Aviation "The Eyjafjallajökull Incident, The European air traffic system reaction to a sudden and uncontrollable event" (Brussels), 30 June - 1 July 2010

Table 1: AERONET III Workshops

Table 2 lists the short studies commissioned by AERONET III:

No.	Name of the Short Study, Year
1	Air Transport Impact on the Local, Regional and Global Atmosphere – "Top-10 Paper", [2004]
2	Volatile Organic Compounds and Impact on Airport Air Quality – "VOC-Study"; [2006]
3	Report from Preparatory Study on Noise and Emissions Trade-offs through Operational Practices, [2008]
4	Aviation new energy carriers, [2009]
5	Enhancing Compatibility of European Financial and Environmental Modelling Tools for Aviation – "EFEMTA", [2009]
6	Interdependency Modelling: Policy "Use Cases", [2010]
7	Interdependency Modelling: Metrics, [2010]
8	Green flight Roadmap, [2010]
9	Short Statistical Study of the Impact on Local Air Quality of the Shutdown of European Airspace in April 2010; [2010]
10	Short Study on Noise and Emissions Trade-offs through operational practices; Task 2.5 [July 2010]

Table 2: AERONET III Short Studies

AERONET III Technical Data

Contract Number	G4RT – CT – 2003 502882
Acronym	AERONET III
Title	Aircraft Emissions and Reduction Technologies
Project Type	Coordination Action
Project start	01 April 2004
Project end	31 July 2010
Project duration	01 April 2004 - 31 March 2008
1st Extension	2 years (1 April 2008 - 31 March 2010)
2nd Extension	2 months (31 March 2010 - 31 May 2010)
3rd Extension	2 months (31 May 2010 - 31 July 2010)
Total duration	6 years and 4 months
EC Scientific Officer	Dr. Dietrich Knoerzer, European Commission, DG Research-H.3 Aeronautics, (CDMA 04/161), Brussels
Project Coordinator	DLR - Alf Junior (Secretary: Irena Champion)
Project Partners	(1) DLR (2) NLR (3) FOI (4) ONERA (5) MMU (6) USFD (7) Air BP (8) AIRBUS (9) AUXITROL (10) BUW (11) DLH (12) EUROCONTROL (13*) FZK-IMK/IFU (14) GFRI (15) IoA (16) QinetiQ (17) RR plc (18) RRD (19) Shell Aviation (20) SNECMA (21*) UNIKARL (22) Zürich Airport (23) MTU (24) NTUA (25) Swiss FOCA (26*) KIT

** = Partners 13 and 21 merged to Partner 26 KIT (1 Sept 2009)*

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