

TECHNOLOGY ROADMAP FOR THE FUTURE AIR TRANSPORT SYSTEM BEING EFFICIENT AND ENVIRONMENTALLY SUSTAINABLE

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ABSTRACT

According to global air traffic forecasts the air transport system will double within the next 15 years. Although today's environmental impact of aviation on climate change is small in comparison to other sectors, the anticipated growth requires substantial enhancements in the emission characteristics of new aircraft and new operational concepts with breakthrough technology improvements. Given the sensitivity of the aviation industry to fuel costs, a highly fuel efficient air transport system is another requirement to achieve economic sustainability. Based on the long-term visions set not only in Europe but also in the US, the presentation will address the key enabling technologies for aircraft design, engines and the operation of aircraft within a future air transportation system achieving these objectives. The conclusion will give an outlook on the global air transport emission balance with respect to level of availability of technology and their possible introduction into service.

1.INTRODUCTION

The air transport system is an essential part of the globalized economy of the 21st century. The development has brought air travel from being a luxury after the World War II to an easy to use and affordable commodity to the turn of the millennium. With the new century new challenges arose for the air transportation system. Aside the tendencies to liberalization and deregulation the focus turned to security aspects following the terrorist attacks of 2001. This topic remains to be addressed, but the security research is on track to develop new strategies to keep aviation a secure transportation system.

However, environmental sustainability remains as a big challenge to be solved. In light of the soaring oil price with a doubling in prices for jet fuel within 18 months (between Jan 2007 and June 2008) and the higher awareness for anthropogenic climate change the air transport system has to adapt to these new condition to sustain its expected growth rates and economic profitability. The introduction of fuel saving technologies into the air transport system is very cost intensive and furthermore political measures like the inclusion of air transport into the emission trading scheme add to the burden for the airline industry.

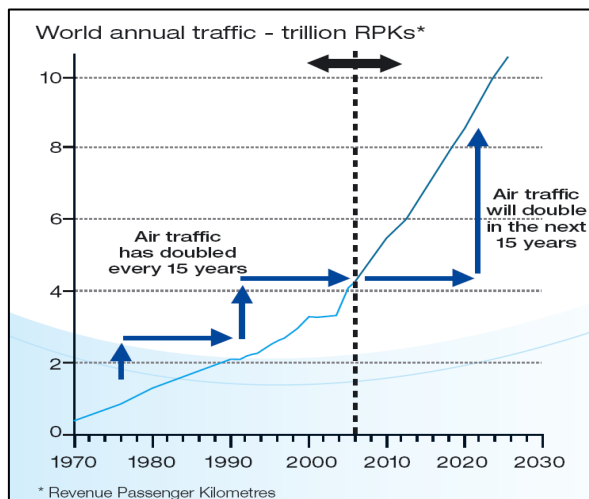
The following paper will present a technology roadmap for the future air transportation system pointing out new concepts being both economically feasible and environmentally sustainable. This includes an assessment of the current growth rate of aviation and the environmental impact, current trends in research and development in Europe, an overview over the main technology fields and the accompanying political measures. An assessment of the global impact will conclude this paper.

2.AVIATION GROWTH AND ENVIRONMENTAL IMPACT

According to the forecasts of the two largest manufactures for commercial aircraft the air transport system will experience growth rates of 4.9 % [Airbus 2007] to 5.0 % [Boeing2008] in the passenger business and even higher rates in the cargo area (both predict 5.8%) for the next 20 years. Associated with this increase is an expected demand for up to 29,000 new airplanes in the same timeframe. As a result the air traffic will double within the next 15 years

(Figure 1). Historical data show that this assumption is realistic. The air transport system proved to be resilient to external crises surviving the oil crises of the 1970s, two gulf wars, economic downfalls, the terrorist attacks of 2001 and large area epidemics like SARS 2002. The air transportation system has more than regained the traffic figures of the pre 9/11 era plus average growth rates. And hopefully this will be true also for the current global crisis of the finance markets.

Figure 1: World air traffic growth [Airbus 2007]



With this continued growth rate comes one of aviation's main problems. Although the whole air transport system accounts today only for approximately 2 % of the global man made carbon dioxide emission [IPCC 2000] the growth rate will not be offset by increased fuel efficiency and thus increasing the share of the CO₂ impact with added contributions to global warming. This increased impact is furthermore augmented by the fact that aircraft emissions occur in higher altitudes with more severe implications than ground level emission from other transportation sources. To account for this effect the radiative forcing index (RFI) is used. The IPCC assumes the RFI to be between 2.2 and 3.7 for commercial aviation³.

The RFI and the projected growth rates explain the major effect of the air transport system on global CO₂ emission and therefore the need for improvements in fuel efficiency. This need is furthermore intensified by the high fuel prices directly increasing the airline's operating costs while reducing profitability margins. Because new technologies solving these problems are not readily available further research and development is necessary. Several research programs are currently underway to address these issues.

3 EUROPEAN RESEARCH STRATEGIES FOR THE FUTURE

3.1 ACARE (Advisory Council for Aeronautic Research in Europe)

In 2001 the European aviation community recognized the requirement of new technologies for aviation in the 21st century using a structured approach. Therefore the Advisory Council for Aeronautic Research in Europe (ACARE) was established, a high level group of about 40 representatives from EU member states, the EU Commission, airlines, the manufacturing

industry and academia. In its Strategic Research Agenda 1 (2002) five focus areas were identified:

- Quality and Affordability
- Environment
- Safety
- Air Transport System Efficiency
- Security

Additionally, specific goals were defined to be achieved by the year 2020. In the context of this paper only the goals for the areas Environment and Air Transport System Efficiency are mentioned:

ACARE Environmental Goals are

- To reduce fuel consumption and CO₂ emissions by 50%
- To reduce perceived external noise by 50%
- To reduce NO_x by 80%
- To make substantial progress in reducing the environmental impact of the manufacture, maintenance and disposal of aircraft and related products

ACARE Air Transport System Efficiency Goals are

- Accommodation of three times more aircraft movements compared with 2000
- Enabling 99% of flights to arrive and depart within 15 minutes of their advertised scheduled departure time, in all weather conditions

These ACARE goals were furthermore reviewed in the Strategic Research Agenda 2 in 2004, where the main focus areas were confirmed to be still of high importance. The strategic approach was slightly changed to a more holistic approach ensuring the involvement of all stakeholders e.g. airports which were not adequately covered earlier. The second agenda introduced a long term view going beyond 2020 adding promising technology concepts not to be available for the market by 2020. These strategic considerations led to the launch of the Clean Sky Joint Technology Initiative research program by the European Commission which will be explained in the following chapter.

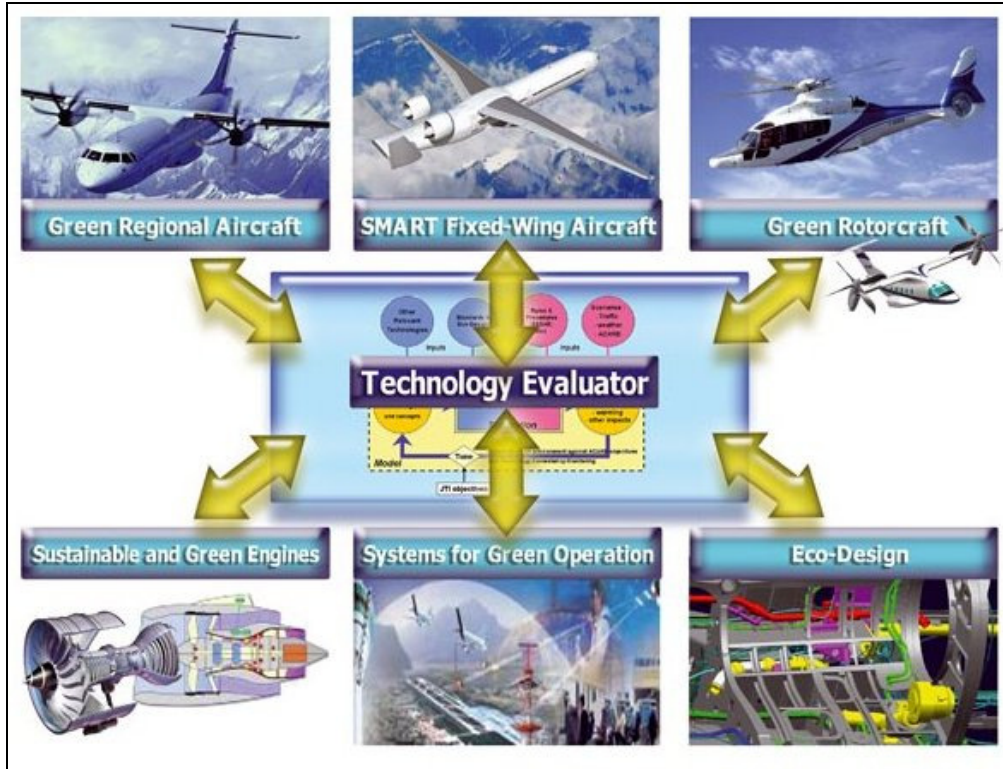
3.2 Clean Sky Joint Technology Initiative

Following the ACARE recommendations the Clean Sky Joint Technology Initiative was launched in 2007 by the European Commission in cooperation with the industry, research institutes and other partners within the EU. With a budget of 1.6 billion Euros it is one the largest research programs in the EU, lasting from 2007 to 2013. The main goal is to reach the ACARE goal faster in a concentrated effort compared to the usual industry development cycles of 10 years.

Clean Sky's main goal is to develop six so called Integrated Technology Demonstrators (ITD) in a multidisciplinary approach for each of those demonstrators. The six ITD covering a broad range of the air transportation systems are Smart Fixed Wing Aircraft, Green Regional Aircraft, Green Rotorcraft, Sustainable And Green Engines, Systems For Green Operations and Eco Design. All of them are linked by a common simulation platform called Technology

Evaluator to assess the environmental improvement of the technology developed in the different ITDs using a process based model of the air transport system (Figure 2).

Figure 2: Structure of Clean Sky Project [Clean Sky JTI 2008]



A large number of goals within the six demonstrators are addressed within the detailed research program. The most interesting ones related to this paper will be mentioned below.

In the fixed wing aircraft project the goal is to reduce aircraft noise by 5 to 10 dB and emission from fuel combustion by 10 % to 20 % for medium and long-haul aircraft. This is to be achieved by reducing the wing's aerodynamic drag using active and passive flow and load control. The other main area of research will be new aircraft configurations due to new engine concepts. For regional aircraft the main objective is the adaption of market ready technologies like the use of carbon fibre materials to fit the requirements of regional aircraft.

The aircraft engines account for most of the noise and fuel consumption characteristics of airplanes and for the air transportation system. Therefore the development of greener engines is crucial for reaching the ACARE goals and an important part of the Clean Sky initiative. Within the program up to five full sized engines will be produced evaluating new technologies and concepts. Some of those concepts will be explained here.

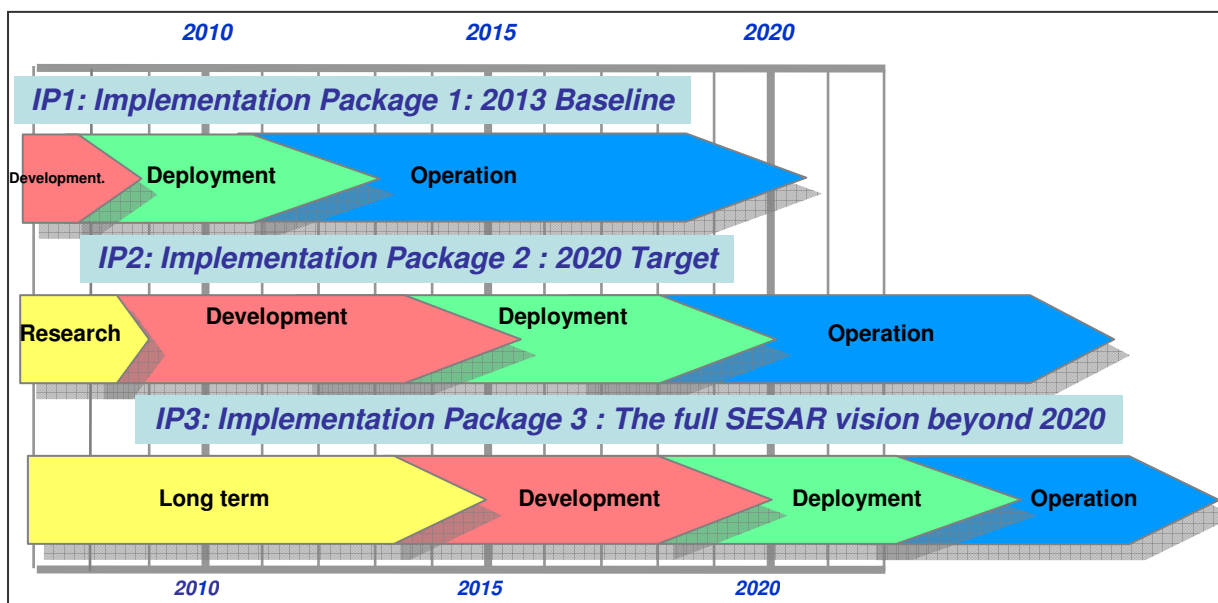
The Systems For Green Operations demonstrator project is part of the holistic approach within the Clean Sky program. The research covers all flight phases including ground operations with the main objective to reduce noise and emissions. Four concepts will be looked at in detail, new aircraft energy concepts, more environmentally friendly trajectories,

improved ground operations and as a new operation management approach the Green Mission. This research project is closely related to the SESAR program.

3.3 SESAR Single European Sky ATM Research

The current European airspace is highly fragmented with different procedures and technical systems in use caused by different national air navigation service providers. The fragmentation leads to unwanted delays and inefficient routings for the airlines increasing cost and pollution. To increase the capacity and efficiency of the airspace system the Single European Sky initiative was initiated. The fundamental European legal basis was established 2004. The necessary research and development activities are structured in the SESAR program. The SESAR program is divided into three phases. The definition phase was completed in 2008 with the development phase lasting from 2008 to 2013, after with the deployment phase will follow from 2014 onwards. The overall budget allocated to SESAR is more than 2 billion Euros (Figure 3).

Figure 3: Structure of SESAR [Pusch 2008]



The main objectives of the SESAR program are the defragmentation of the European airspace and introduction of innovative technologies. As performance targets were defined an increase in capacity by factor 3, the improving of safety, the reduction of air traffic management cost and the reduction of emissions by 10 %. These goals are fitting in the overall ACARE strategy and connect with the Systems For Green Operations demonstrator of the Clean Sky initiative. Especially the trajectory management, network operation plan and full integration of airport operations concept of SESAR will be linked with the operations demonstrator.

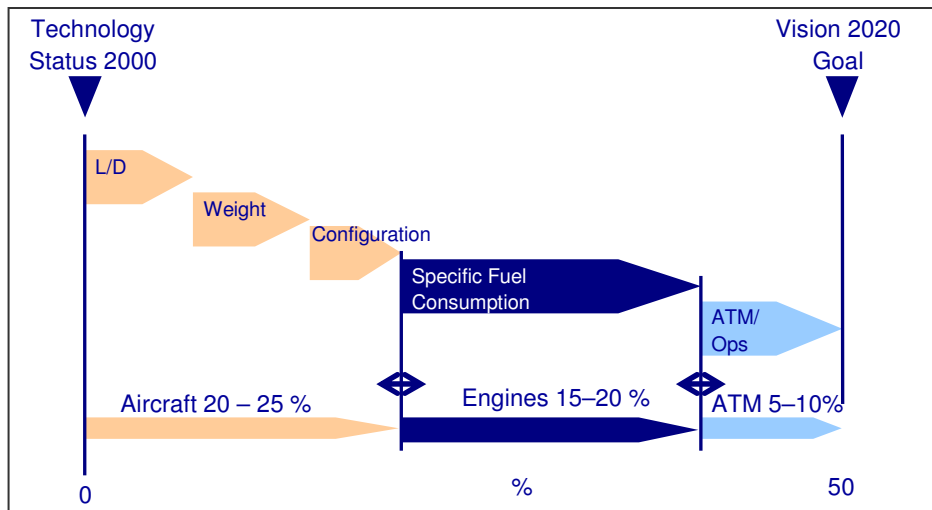
3.4 7th Framework Program of the European Commission

Accompanying this strategy and key research programmes, there are a number of other R&D programmes supported by the European Commissions within its 7th Framework Program 2007 until 2013 in the area of Aeronautics and Air Transportation addressing the technology fields important for eco-efficient air transport.

4 TECHNOLOGY FIELDS

Three main technology areas were identified as most promising to achieve the desired efficiency improvements: airframe and aircraft systems, engines and operations. Figure 4 shows the anticipated contributions to fuel efficiency in the individual areas. These topics already identified in the research programs above will be discussed more detailed in the following referring to distinctive examples since a comprehensive list is outside the scope of this paper.

Figure 4: Contribution Towards ACARE Fuel Efficiency Target



4.1 Airframe and Aircraft Systems

The mass reduction of airplanes has been a basic technique to reduce the fuel burn and to increase efficiency. New aircraft have to be lighter for further reduction of fuel consumption but have also to be stronger due to higher safety requirements. A major technology is the use of composite structures replacing the traditional aluminum. New aircraft like the Boeing 787 and the Airbus 350 use composite materials for up to 60 % of the primary aircraft structure thus improving fuel efficiency. It is expected that the increased use of composites will reduce the CO₂ emissions by 4 %.

Large improvements will also be needed in the area of aerodynamics to reach the goals defined above. The focus is on improved characteristics of the wing. Reducing aerodynamic drag with laminar flow through active and passive flow control is a promising approach. Additional drag reduction will also be achieved with new technologies for the fuselage. Maintaining a laminar flow over large portions of the wing and the fuselage could reduce CO₂ emissions up to 15 %.

One of the major system changes will be the “more electric aircraft” where different energy systems are integrated in innovative electric system architectures. The standard energy architecture of a commercial aircraft is practically unchanged since the arrival of modern turbojet planes in the 1960s with mechanical, electric, hydraulic and pneumatic systems which are all powered by the engines. The goal is to reduce the number of systems to reduce complexity, to reduce maintenance cost and to reduce aircraft mass. In the end these measures will lead to a reduction in emissions as well as a reduction in operating costs. First concepts are already introduced into the Airbus 380 where backup hydraulic actuators for flight

controls are powered by decentralized hydraulic pumps rather than from the centralized systems. In the Boeing 787 the bleed air system is replaced by an electric system powering both the anti-ice system and the environmental control system (i.e. air conditioning). Furthermore, more electric systems allow for new power management approaches for the whole aircraft reducing fuel burn by efficiently producing and distributing energy according to operational needs. Another approach in this area is the replacement of the APU with fuel cells. It is expected that this alone could reduce the CO₂ emissions by 3%.

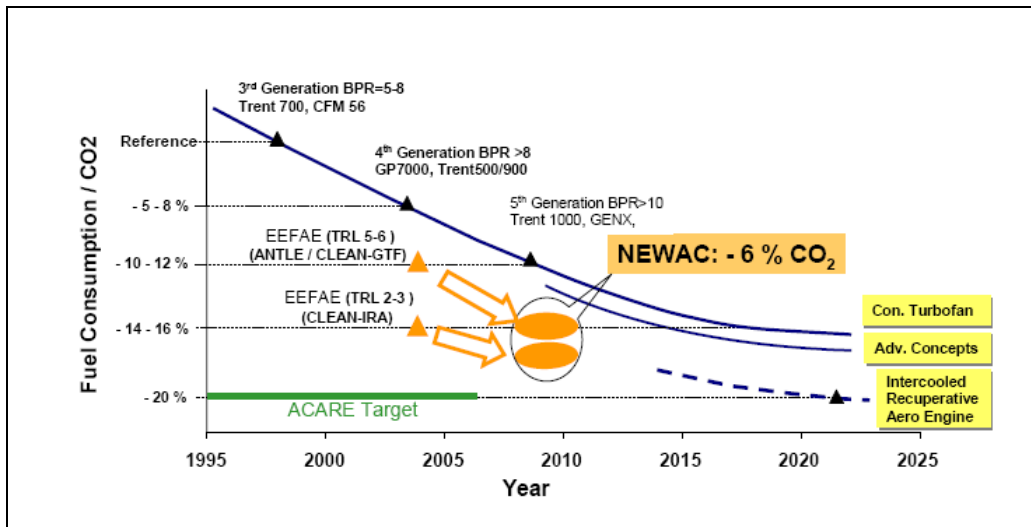
4.2 Engines

Engines are a major contributor to noise and CO₂ emission as well as being the only source of NO_x emission of an aircraft. The ACARE goals of reducing CO₂, noise and NO_x emissions are difficult to achieve by themselves alone, but the combination of these three goals in one single approach is especially challenging for the engine design. Conventional concepts indicate that a reduction of CO₂ will increase NO_x emissions and e.g. a noise reduction leads to an increase in CO₂ emissions. A prominent example of this engineering dilemma is the open rotor or unducted fan concept. First flight tests were conducted during the late 1980s showing a possible reduction in fuel burn, but the noise level increased significantly. This concept is nowadays revisited in combination with other innovative technologies.

The geared turbofan will be the first new technology concept to be introduced into the market. The gear drive allows the low pressure turbine (LPT) and the fan to rotate at different speeds allowing the LP turbine to rotate three times as fast as today. At these speeds both the fan and the LPT run at optimum speeds resulting in increased efficiency. The first engines currently in development based on this concept are Pratt & Whitney's Pure Power engines for the new regional aircraft families of the Mitsubishi Regional Jet and the Bombardier CSeries. A reduction of 12 % in fuel burn, a noise reduction of 15dB and up to 55 % in NO_x (compared to CEAP 6 standards) is expected by the manufacturer. The engine is currently in flight test and the expected entry into service will be in 2013.

However, achieving the ACARE goals requires even more advanced concepts. One approach is the intercooled recuperative engine core combining two measures to improve the thermodynamic characteristics. One measure is the cooling of the airflow between the low and high pressure compressors. The benefits of intercooling are a lower flame temperature and thus a higher specific power for the engine core. Lower temperatures in the combustion chamber result in significant lower NO_x emissions. Higher specific power allows for the reduction of engine core air flow and total core mass thus increasing the bypass ratio resulting in reduced specific fuel consumption. The other measure is the recuperation of the exhaust gas thermal energy into the airflow before the combustion. This results in an additional improvement in efficiency. This concept is part of the NEWAC (New Aero Engines Core Concepts) research project within the European 6th framework programme. However, these are conceptual studies and an engine ready to enter service is not expected before the year 2025 or later. Figure 5 shows the technology potentials of various concepts with regard to CO₂ emissions over time.

Figure 5: NEWAC target for CO2 reduction [Wilfert 2007]



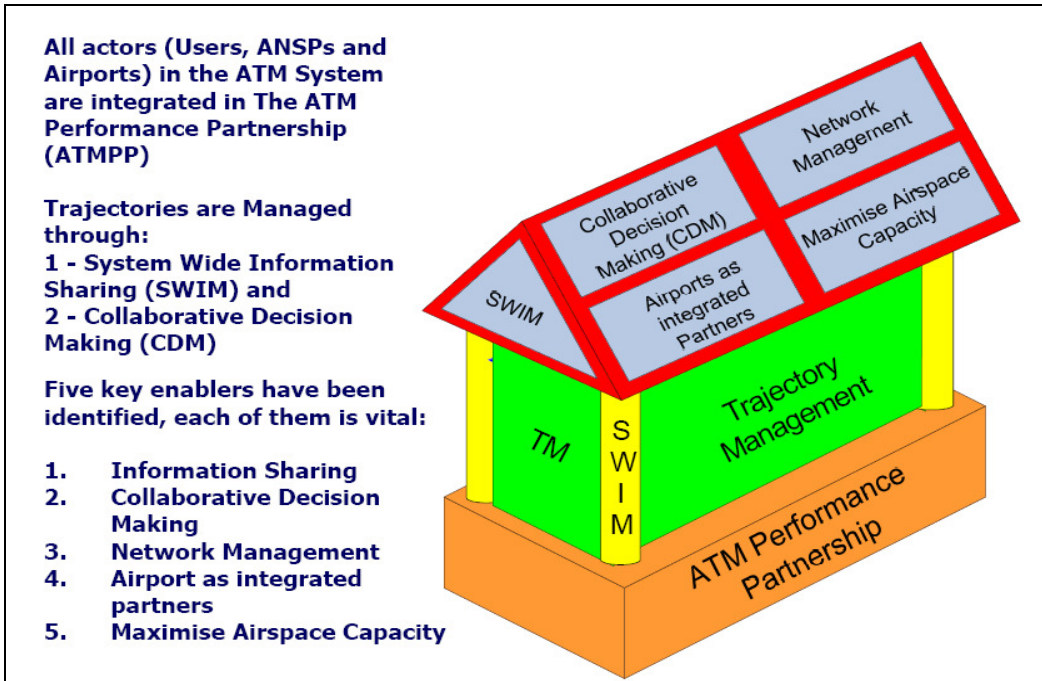
Additional concepts currently investigated in several research programmes are a new open rotor, counter rotating fan and counter rotating core engines. Furthermore, active flow control within the engines and adaptive elements to account for different operational situations are under scrutiny for their possible contribution to the ACARE goals.

4.3 Operation

The optimization of airline operations offers another large potential for efficiency improvements. In this wide area all operational aspect of the air transportation system are under scrutiny. These include ground operations of vehicles and aircraft at airports and the flight trajectories of the aircraft through the airspace including regulatory and legal frameworks. The goal is to realize time and fuel efficient routes for the aircraft in the airspace by reducing detours and holding procedures. The waiting times with engines running in airport queues are a further aspect for improvement of efficiency. One goal is the use of 4D route planning coordinating flight trajectories with time coordinates leading to a free flight concept with little intervention by air navigation service providers. This optimization of flight routes can save up to 9% of fuel.

The technology and regulatory improvements within the European SESAR project could reduce the emissions by 12% within the European airspace. This includes the formation of an ATM Performance Partnership, the application of System Wide Information Management (SWIM) and Collaborative Decision Making (CDM). The principles of the Concept of Operations within SESAR are shown in Figure 6.

Figure 6: SESAR - Principles of the Concept of Operations [DFS Deutsche Flugsicherungs GmbH]



Further into the future are concepts of formation flight and air fueling both applied for long haul air traffic. Formation flight is a bionic principle observed on migratory birds. These birds fly long distances in V shaped formations saving considerable amounts of energy. An application to long haul air traffic could reduce the CO₂ emissions by 10% although flying aircraft close to each other will raise safety concerns to be equally addressed. Furthermore aerial fueling concepts are in discussion. The fueling of long haul airplanes will reduce the total mass of fuel that is transported making airplanes lighter in various stages of a commercial flight. This will improve operational flexibility since smaller airports could be integrated in flight schedules and will reduce fuel consumption (up to 25%), which is directly related to the aircraft mass. Equally, noise footprints will be significantly smaller with lighter airplanes. A first step to introduction of this refueling concept could be stopover fueling on airports. Studies currently look into programmes to include such stopover landings in long range flights. This is in contrast to the ultra long range airplanes currently offered by the airplane manufacturers (B777-200 LR, A 340-500).

5 POLITICAL MEASURES

Besides the technical improvements for delivering the desired improved efficiency, political measures could foster further improvements by offering incentives to introduce new more efficient technology or punishment for the usage of more polluting aircraft. Here only already existing or anticipated measures will be mentioned.

5.1 Emission Based Landing Fees

Landing fees are the main aviation related revenue source for airport operators. These are usually based on aircraft mass with heavier aircraft causing higher fees. As a first measure to control the environmental impact around airports a noise surcharge was established. Aircraft

were categorized into different noise classes and charged an additional fee according to their assigned category.

Similar to the noise surcharge concept an emission surcharge concept was introduced at 15 European Airports. Two different concepts to determine the noise surcharge are in use. The landing fee premium concept is used at Berne, Geneva and Zürich airports as well as at the Euroairport in France. In this concept aircraft are classified by the emission of the installed engines. Each class of aircraft is then assigned a factor ranging from 0.9 to 1.5 which will be multiplied with the landing charge.

The emission value concept is based on the ECAC recommendation 27-4. The emission value represents a nitrogen dioxide equivalent produced during the standardized ICAO landing and take off cycle (LTO). The emission value is then multiplied by an emission charge.

The fees strongly depend on aircraft and engine type. Sample calculation for an Airbus 320 with CFM-56 engines and a Boeing 777-300 with GE 90 engines show a range from a reduction of 58 USD (A320 at Euroairport) to a surcharge of 507 USD (B 777 at Stockholm). These fees are levied per take-off and/or landing depending on the airport.

5.2 Inclusion of Aviation in the Emission Trading Scheme (ETS)

Emission trading is one instrument of reducing the carbon dioxide emission for climate control. This mechanism was introduced with the Kyoto Protocol. The idea is to allocate emission rights for CO₂ emitting industries based on a predetermined or desired level for a period of time. These emission rights or certificates could be traded freely thus encouraging less polluting technologies because of possible profits from selling unused emission rights to others. Two different principles are used in the allocation of emission certificates, free distribution or by auction.

The first international trading mechanism is the EU emission trading scheme with its first phase lasting from 2005 to 2007. Only energy producing and large CO₂ producing industries (steel, cement) took part in the ETS. In 2008 the EU decided to include aviation into the European emission trading scheme (ETS) beginning 2011 for intra-European flight and from 2013 for all flight departing or arriving in the European Union. If the certificates will be auctioned or distributed freely as well as the total number of emission rights are still undecided. Another factor will be the question if aviation certificates could be traded with certificates from other industries or if aviation will have a special trading scheme where the emission reductions have to be achieved within the air transport industry.

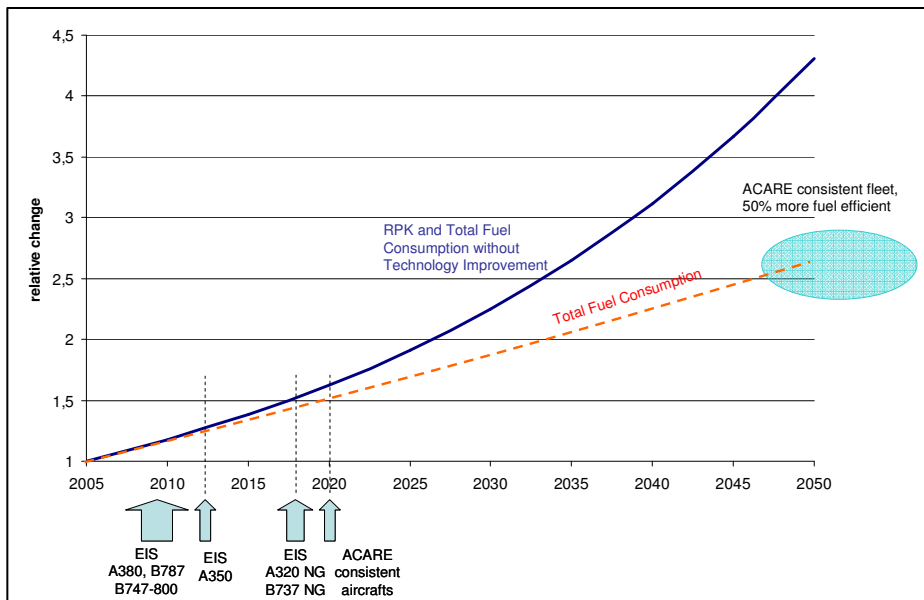
The cost associated with the inclusion of aviation into this system is expected to be 5.3 billion EUR annually according to the Association of European Airlines (AEA). Studies show that ticket prices will increase moderately between 30 US cents and 4.35 US dollars depending on flight length.

6 GLOBAL IMPACT

Making the air transport system more sustainable as well as more efficient is a major task in the coming years. The steady growth of the air transport system will lead to higher emissions and a greater environmental impact despite the currently low percentage of aviation related CO₂ emissions. Without major technology improvements the fuel consumption and thus the

carbon footprint will grow significantly (Figure 7), even considering the implementation of e.g. ACARE technology which might be fully deployed in service only by around 2045

Figure 7: Average Fuel Consumption of the World Passenger Fleet [Hüttig,Gmelin 2008]



However, the biggest challenge, to decouple the aviation growth and thus the total fuel consumption respectively the CO₂ emissions and reduce the emissions in total or bring them down under a given capping is still not foreseeable within the next 20 to 30 years. Therefore, new and dramatic long-term objectives are already under discussion like CO₂ neutral-growth (IATA) or even zero-emission airplane (Airbus).

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