The IATA Technology Roadmap Report

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3rd Edition

Foreword

Environmental responsibility is a top priority for airlines, alongside safety and security. In 2007 I outlined a vision for the aviation industry: to achieve carbon neutral growth on the path to a zero emissions future. The challenge was not just to manufacturers, it was directed at all sectors of the industry to play their part in achieving this vision. IATA is playing a leading role in bringing together manufacturers, scientists, government agencies, infrastructure providers as well as airlines to make this happen. The Technology Roadmap project explores some of the potential routes to achieving our vision.

Aviation is responsible for 2% of the world's man-made CO_2 emissions and by 2050 will have grown to 3% according to the Intergovernmental Panel on Climate Change. A growing carbon footprint is unacceptable. IATA has therefore developed a four-pillar strategy, adopted by the industry, governments and regulators, to reduce aviation emissions. The four pillars are technology, operations, infrastructure and positive economic instruments. Of these four, technology has by far the best prospects for reducing emissions.

Aviation has an outstanding track record in technological innovation. We have improved fuel efficiency 70 percent over the past forty years. This roadmap assesses future technologies that will reduce aviation's environmental footprint. In particular it explores the possibilities for improvements in airframes, engines, air traffic management and alternative fuels. It provides an excellent basis to help the industry achieve carbon neutral growth on the path towards a zero emissions future.

The roadmap also symbolises the increasing level of cooperation across the industry on environmental issues. We are all united towards a common goal. Experts from airframe, engine and systems manufacturers, fuel suppliers and research institutes all came together to produce this report. I thank all of them for their hard work.

This document provides the first practical assessment of how the industry can realise its environmental responsibility to reduce and eventually eliminate greenhouse gas emissions. The next challenge is for the industry to work together to turn this document into real measures and projects.

Giovanni Bisignani
Director General and CEO

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Executive Summary

This report is in two parts: this main part and a Technical Annex, which can be found as a pdf file on IATA's public website under www.iata.org/whatwedo/environment.

Scope

The IATA Technology Roadmap provides a summary and assessment of technological opportunities for future aircraft. It looks at technologies that will reduce, neutralise and eventually eliminate the carbon footprint of aviation. Some of these technologies could also be used for retrofits to the existing fleet. The Technology Roadmap aims to identify primarily the potential of new, as yet uncertified technologies. The selected technologies must demonstrate environmental benefits under operational conditions.

The Roadmap provides airlines with updated technological knowledge for future fleet planning. It also provides a basis for discussions with airplane, engine and systems manufacturers, as well as regulators, for defining requirements to meet carbon reduction goals. Additionally, the Roadmap can be used as a tool to forecast the impact of developments in fuel consumption and CO_2 emissions.

The Technology Roadmap comprises airframe and engine technology as well as technological enhancements in air traffic management (ATM) and alternative fuels. It is based on the outcomes of IATA's TERESA project (TEchnology Roadmap for Environmentally Sustainable Aviation), which gathered experts from airframe, engine and systems manufacturers, fuel suppliers and research centres in a joint technology assessment.

Background

Climate change, caused by man-made activities, is a major public policy issue. Many governments are taking action to reduce greenhouse gas emissions. Although no global standards have yet been defined for aviation, IATA is working with the whole aviation industry to achieve carbon neutral growth in the medium term and has outlined a vision to build a zero emissions aircraft within the next 50 years.

Aviation causes 2% of total man-made carbon emissions according to the Intergovernmental Panel on Climate Change (IPCC). This represented some 673 million tonnes of CO_2 in 2007. The industry is growing by around 5% a year in the longer term but efficiencies already in place mean aviation CO_2 emissions are growing by just 2 to 3%. The IPCC forecasts that aviation will represent 3% of total man-made carbon emissions by 2050. A growing carbon footprint is unacceptable for any industry. Therefore, to bring this emissions growth down to zero and eventually to reduce overall emissions, it is critical that manufacturers and airlines work together on technologies to achieve this goal.

Reducing emissions can best be achieved by lowering fuel consumption through efficiencies. The volatile price of fuel is a key driver to reduce fuel burn, reduce emissions and reduce costs. While optimising future efficiencies, safety must always have first priority. So all new technologies must be rigorously evaluated for their safety implications.

Four-pillar Strategy

IATA has adopted a four-pillar strategy to achieve carbon neutral growth as a milestone on the path to an emissions free future:

1. **Technology:** Enhancements to the existing fleet, new aircraft and engines, and research and development of entirely new technologies, designs and fuels. The Technology Roadmap will act as a planning tool to assess the benefits of new technologies in case of future fleet renewals (a small number of new technology items might also be retrofittable).
2. **Operations:** IATA Green Teams advise members on fuel efficiency, covering ground operations, flight planning and operations, fleet renewal programmes and aircraft upgrades with already certified improvements.
3. **Infrastructure:** Infrastructure-related improvements could save up to 12% of CO_2 emissions from aviation, according to the IPCC. The successful implementation of the Single European Sky and the U.S. NextGen Air Transport System is at the core of an efficient and globally harmonised airspace management system.
4. **Economic measures:** Promotion of positive economic instruments to provide real incentives for emissions reductions and to campaign against environmental taxes and charges that do nothing for the environment.

Work Plan

To support the first pillar of the IATA strategy, the TERESA project is being developed in a series of consecutive steps as described below:

1. Comprehensive collection and consolidation of information about current industry initiatives in research and development
2. Overview of a number of key current and upcoming manufacturers' technology programmes
3. Assessment of the cost effectiveness and availability of new technologies for commercial aircraft as well as of their applicability in airline operations
4. Assessment of emissions reduction potential
5. Projection of costs for airlines of procurement and operation of new technology
6. Assessment of technologies available after 2020
7. Development of generic requirements for future aircraft development
8. Projection of potential contributions towards carbon neutral growth and ultimately a zero emissions industry
9. Description of pre-requisites and potential timelines

Steps 1 and 2 were covered in the first half of 2008 and a preliminary report was issued in June 2008. This report includes steps 3 and 4, with an assessment of the relevant technologies, conducted jointly with manufacturers and researchers.

First Results

A broad scope of technologies from all considered areas (airframe, engines, ATM, alternative fuels) was identified and assessed for their environmental benefit and operational applicability. Rough estimates of the total CO_2 emissions reduction potential were made for each of these technologies.

- The most significant aircraft efficiency gains are expected from new engine architectures (open rotor, geared turbofan, counter-rotating fan, etc.) and from natural and hybrid laminar flow, which are all candidates for use in new aircraft types by 2020.
- Numerous smaller improvements, like winglets and reduced-weight components, can be implemented into current series or even retrofitted.
- Alternative fuels (if fully sustainable) could reduce aviation's net carbon contribution by near to 100%. This is because the same amount of carbon dioxide emitted by aircraft would have previously been absorbed during growth of the organic matter serving as feedstock for the fuel.
- Communication, Navigation, and Surveillance (CNS) technologies and systems enable the implementation of globally harmonised ATM concepts that could improve efficiency of operations.

Due to the complex physical interdependencies between the effects of different technologies, it is not possible to simply aggregate the emissions reductions of all the technologies that could be applied simultaneously. A more thorough analysis of these interdependencies is underway, but it is premature to publish figures for global emissions reductions today. However, the results are consistent with a number of studies estimating the overall efficiency improvement in the next decades. The results of these studies range between 20 and 35% emissions reductions for new aircraft in 2020 compared to their predecessors, achieved mainly from the engine type and the use of laminar flow. The TERESA project results give IATA and airlines the confidence that sufficient innovation potential exists to achieve the estimated overall targets.

The main challenge lies in the implementation of these technological innovations. This requires joint action by various stakeholders, in particular:

- ATM: further is required for many of the CNS/ATM deliverables for SESAR/NextGen. Lack of R&D will impact delivery dates. Some elements will require up to 10 years for retrofitting, such as ADS-B IN. Institutional issues, such as the transfer of spacing and separation from air traffic control to flight deck, need to be internationally agreed.
- Sustainable biofuels: certification authorities need to agree on a simplified certification process to accelerate the introduction of new fuels and to lower the risk for suppliers. Suppliers and consumers need to ensure a solid business case for aviation biofuels
- Airlines are urgently awaiting the new short-range aircraft types to achieve substantial fuel savings. A timely entry into service requires a concerted development effort by both airframe and engine manufacturers.
- Continued research funding by public bodies is necessary in all areas of new technology development to achieve a constant innovation speed.

Next Steps

To estimate the total fuel burn reduction of future aircraft, the benefits of new technologies cannot simply be added up. Various technologies will be projected onto a generic aircraft model to account for their interdependencies.

To project the effect of technology on the future worldwide fleet, the findings so far will be incorporated into IATA's Aviation Carbon Model (ACM), which forecasts fuel and carbon emissions and the economic viability of carbon reduction options, as well as into the simplified fuel burn projection model established for IATA's Environmental Committee (ENCOM).

Technical Summary

The purpose of this report is to identify and rank a range of technologies, applicable over different time periods that will reduce greenhouse gas emissions from aviation. These technologies were reviewed for both applicability and their development timeframe. By focusing on technologies that can be used in a range of different applications it is possible to develop a timeline for improvements (see Fig. 1). These technologies fall into three broad types: those that are applicable to engines and airframe; improvements to air traffic management and alternative fuels.

The first application area is for retrofits to aircraft already in service. These technologies offer the most immediate reductions to the environmental impact of the fleet, because they are available for installation immediately or should become available in the near future. Many of them, such as advanced winglets and engine performance improvement programmes are already being incorporated into the fleet.

The second application area is those technologies that are too complicated or expensive for retrofit, but can be incorporated into future production versions of current aircraft. These technologies work both independently and in conjunction with several of the technologies that are generally available for retrofit, thus enabling greater benefits.

The final two areas of applicability are those technologies and concepts that are available for use on new aircraft designs. These technologies have been split into those that could be used on a new design that is intended for entry into service prior to 2020 and those that will become available after 2020 but before 2050. This allows identification of those technologies that might be applicable for a 2020 reference aircraft and those promising technologies that will further help IATA approach its vision to build a zero-emissions plane within 50 years.

Many of the post 2020 technologies are radically new airframe and engine concepts that diverge significantly from the current conventional tube and wing configurations and classical ("Brayton cycle") gas turbine engines. These concepts benefit from the fact that they lie on a different technology development curve, and as such they may therefore provide even greater emissions saving potential in the future.

In addition to identifying a range of potential technology improvements one of the outcomes of this study will be to provide a first-order quantification of the fuel burn and greenhouse gas emissions benefit. An assessment workshop was held, which did not involve detailed modelling of each of the technologies, but rather attempted to allocate general benefits to each. It attempted to discern their impact relative to other technologies and therefore the resulting savings must be viewed as a first-order estimate of what might be possible. However, the range of improvements match those typically found in external literature and other technical studies. These impacts, for each group are presented here.

Many of the technologies listed in the following chapters are mutually exclusive. A good example of this is the inclusion of advanced wingtip devices on aircraft that do not currently have them. Only one type of device, be it a blended winglet or raked wingtip, can be incorporated on an aircraft at a given time. The same holds true for the majority of engine technologies. Furthermore, depending on the constraints imposed by the design and construction of current generation aircraft it is not always possible to realise the full benefit of many of these technologies.

Beyond engine and airframe technology improvements, substantial environmental gains can be achieved from the air traffic management (ATM) system. ATM is being redefined by two major programmes, NextGen in the U.S. and the Single European Sky Air Traffic Management Research (SESAR) in Europe. Both programmes are leading the way for other regions towards the globally harmonised implementation of the future generation ATM system. This is based on ICAO's Global Air Navigation Plan. SESAR and NextGen are shifting the current ground-based CNS/ATM paradigm of air traffic control into an air traffic management system supported by satellite-based navigation, sharing of surveillance data, data link communication, advanced automation support and a net-centric information network of real time air traffic services data.

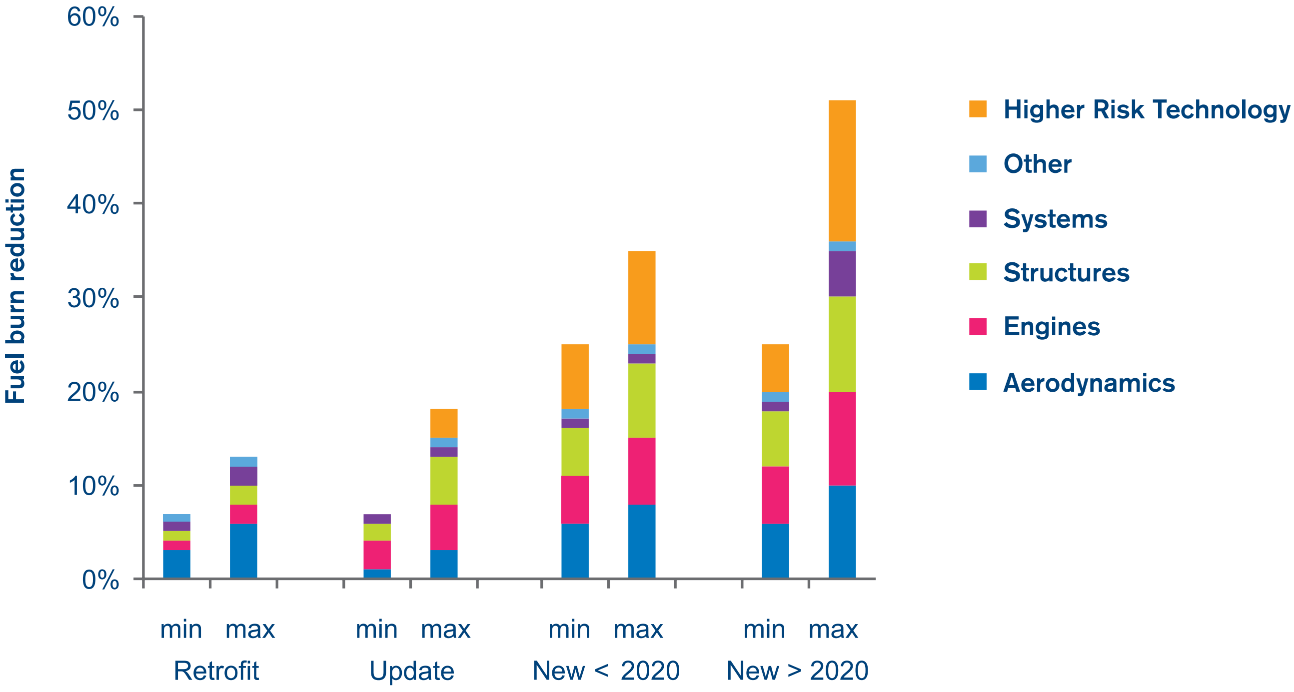
The next generation of ATM must ensure the safety, efficiency, environmental sustainability, and cost-effectiveness of air transport, while accommodating high-density traffic scenarios and all-weather operations without compromising safety.

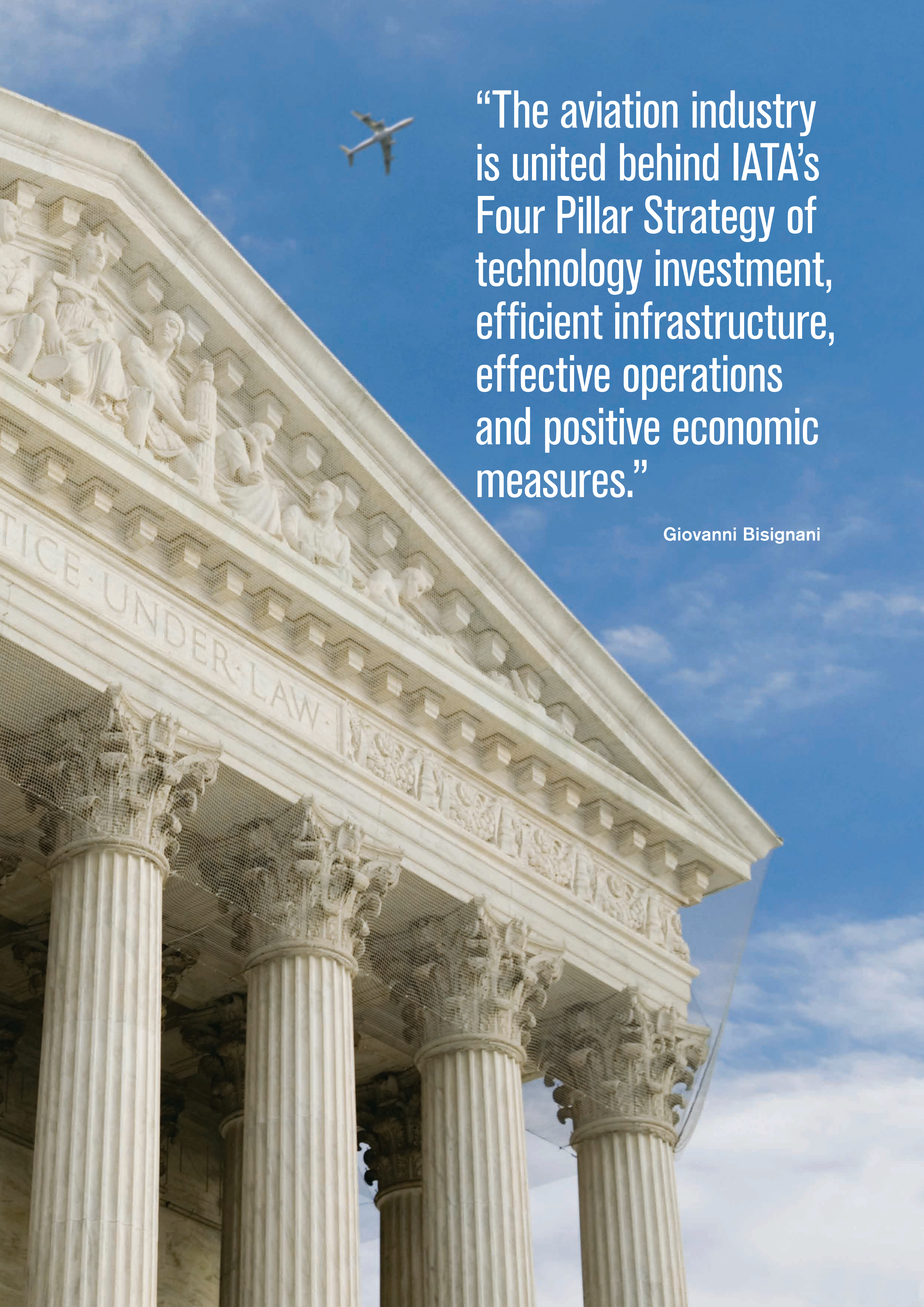
The final area of significant potential for reduction in greenhouse gas impact is alternative fuels. While the engine, airframe, and ATM technologies focus on reducing the overall fuel burn of the fleet, alternative fuels focus on reducing the net carbon impact of the fuel itself, independent of the total amount of fuel burn. This is especially true of so-called drop-in fuels, those that can be used for current aircraft engines without modifications, and be blended with current jet fuel. Assuming a total replacement of fossil-based fuels by renewable-based (sustainable biofuels), the net carbon impact could theoretically be reduced by 100%. However, other lifecycle emissions (e.g. production and land use) must be considered. Moreover, at least in the first time after introduction, blends with conventional jet fuels are most likely, which only allow a proportionate share of carbon reduction.

A secondary effect of many of the currently envisaged alternative fuels includes the potential reduction of pollutant emissions that affect local air quality, some of them also having climate change potential. These extra benefits further serve to increase the value of the fuel. Moving beyond drop-in fuels has the potential to change the design paradigm for new aircraft. This could enable even greater efficiencies and reduced fuel burn and not just reduce the carbon impact.

The climate change potential of all of the technologies in this report provide a path toward the mitigation of aviation's growing climate change impact. However, this is not an area of static development. New technologies and concepts are being demonstrated all the time. Some of these may prove more attainable and beneficial than those currently listed, especially in later years. There is therefore an even greater potential to reduce both the climate change impact of aviation and its overall energy intensity.

Fig. 1: Range of fuel burn reduction potential for aircraft retrofits, production updates and new aircraft types before and after 2020.





"The aviation industry is united behind IATA's Four Pillar Strategy of technology investment, efficient infrastructure, effective operations and positive economic measures."

Giovanni Bisignani

1. Introduction

1.1 Background and Motivation

Global climate change is attributed to the emission of anthropogenic greenhouse gases, especially carbon dioxide, into the atmosphere by all devices that burn hydrocarbon-based fuel. To mitigate the adverse impacts of increasing amounts of greenhouse gases on the global environment, all industries must take action to reduce, and ultimately eliminate, these emissions.

Aviation's contribution to global CO_2 emissions is 2% (Fig. 1-1) and its contribution to total greenhouse gas emissions is approximately 3%, since other exhaust gases and contrails emitted during flight also contribute to the greenhouse effect. The aviation industry contributes approximately 8% to the world gross domestic product[a], and aviation growth is projected to be 5 to 6% per year. By 2050, the IPCC forecasts aviation's share of global carbon emissions will grow to 3% and its contribution to total greenhouse gas emissions will be 5%. Although this figure is relatively low, a growing carbon footprint is unacceptable for any industry. The industry takes its environmental responsibilities seriously and that is why it is seeking for ways to reduce emissions through the technological possibilities covered in this report among other measures. Aviation has a strong track record of addressing environmental concerns. Over the past 40 years soot has been eliminated, noise levels have been reduced 75%, and fuel efficiency has improved 70% (Fig. 1-2). Therefore, it is the responsibility of the aviation industry to implement effective and visible measures that encourage its members to become good stewards of the Earth. In short, the aviation industry must set an example for conservation and the reduction of greenhouse gas emissions.

In addition to the issues caused by climate change, there is now an increasing demand and competition for the world's natural resources. While it is still debatable whether proven worldwide oil reserves are in decline, the price of oil reached a peak of $147 per barrel in mid 2008. Although oil prices have fallen, fuel costs remain a major burden for airlines. The industry's dependence on oil as the exclusive source of fuel leaves airlines vulnerable to oil price rises.

Fig. 1-1: Contributions of various industry sectors to man-made CO_2 emissions

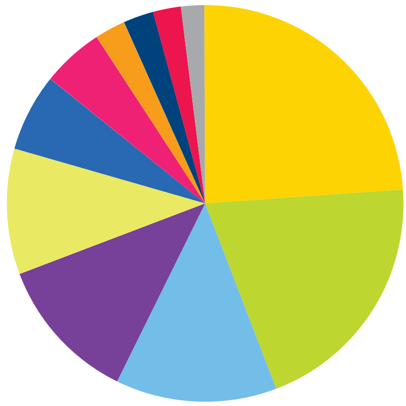
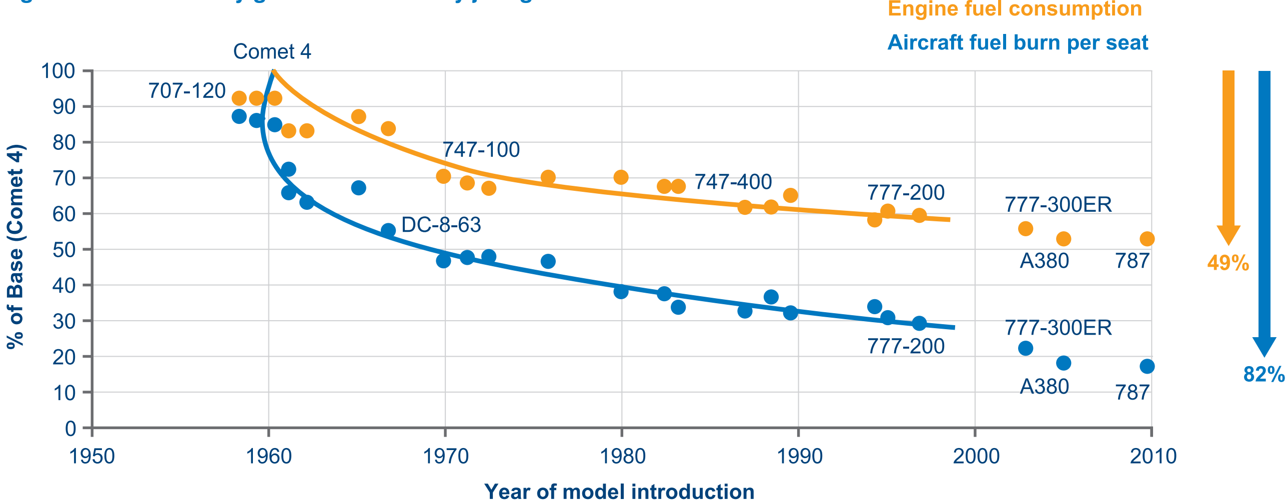


Fig. 1-2 Fuel efficiency gain since the early jet age



[a] *This includes not only the goods and services that are directly provided by the industry (airlines, OEMs, suppliers, support facilities, etc.), but also the secondary economic growth made possible by tourism, freight carriage, business facilitation, etc.*

To help the industry focus and to initiate an action plan, IATA developed the Four Pillar Strategy. It identifies a set of specific actions that should be undertaken by the aviation industry to reduce fuel burn and thus greenhouse gas emissions, keep the airlines economically viable, and ultimately define an industry that has a net zero carbon contribution to the global atmosphere (Figs. 1-3 and 1-4). The four pillars are:

Pillar 1: Technology

- Short Term: Incorporation of Service Bulletins that reduce fuel burn and aircraft weight
- Medium Term: Airline fleet renewal with new aircraft and new engine technologies
- Longer Term: Entire new aircraft design
- IATA's target is for 10% of the fuel used by aircraft to be an alternative fuel by 2017
- These alternative fuels must be compatible with existing engines and airplane systems. They must be able to be blended with existing petroleum-based fuels and the supply must be sustainable and reliable.

Pillar 2: Operations

- In coordination with air traffic management improvements, operational efficiency improvements can make a big difference in fuel savings.
- More efficient flight planning can reduce fuel reserve requirements.
- Aggressive weight reduction programmes save fuel.
- Further improvements will be realised with upgrades to the avionics system on board airplanes coupled with an improved air traffic control system.

Pillar 3: Infrastructure

- The technical elements of air traffic services, such as communication, navigation, surveillance, separation minima and air traffic flow management that have a direct impact onto the availability of optimum flight profiles in the terms of speed, route of flight, climb/descent profile and altitude.
- Airport infrastructure development and the elements involved with movement of passengers, aircraft movement and servicing landed aircraft can also play a role in saving emissions.
- Many of the infrastructure challenges are not technical, and IATA works with governments and authorities to help achieve optimum solutions.

Pillar 4: Economic Measures

- Positive economic instruments to provide incentives to improve efficiency and reduce emissions
- Emissions trading and carbon offsets can play a role but this needs global coordination and agreement. Credible global standards are essential.

Fig. 1-3: Projection of aviation fuel burn and CO_2 emissions per revenue ton kilometre, relative to 2005 value

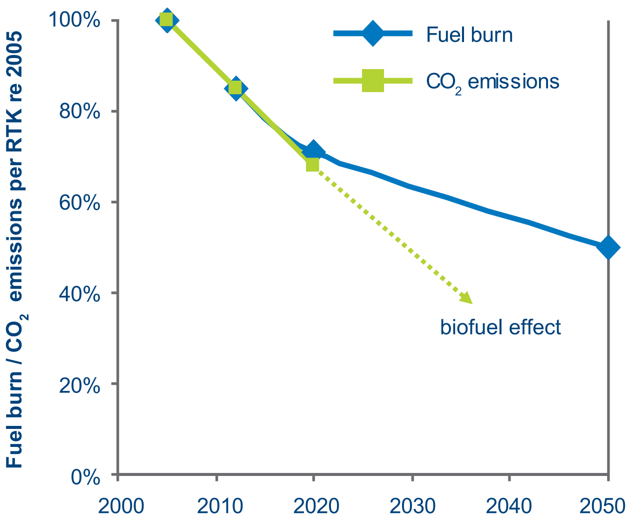
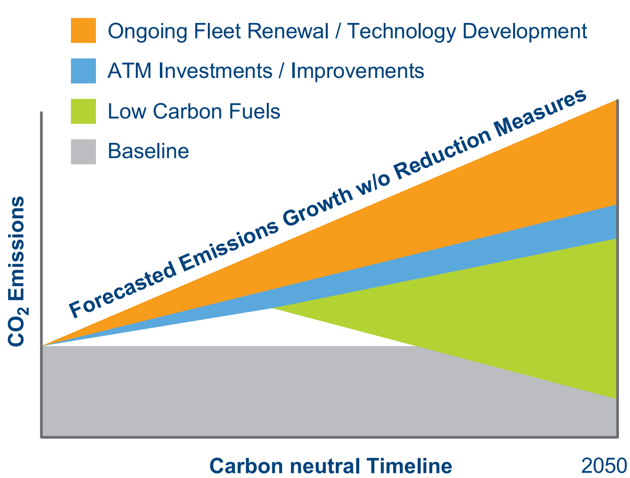


Fig. 1.4: Schematic evolution of aviation CO_2 emissions. under the effect of reduction measures



Being the representative of the world's airlines, IATA can bring airlines, original equipment manufacturers (OEMs), suppliers, and regulatory bodies together. To provide the airlines with a comprehensive perspective regarding the most challenging issues, IATA initiated the Technology Roadmap for Environmentally Sustainable Aviation (TERESA) project by leveraging the Four Pillar Strategy. This project was initiated in June 2007 when Mr. Giovanni Bisignani, Director General and CEO of IATA challenged manufacturers to build a zero-emissions plane within 50 years.

The major findings, outcomes, and recommendations of the TERESA project are presented in this document.

1.2 Objectives

The objective of this project is to identify and assess current and future possible technologies that will increase aircraft efficiencies, thus lowering fuel use and reduce the carbon emissions that adversely impact the global environment. The airframe and engine manufacturers, systems suppliers and research facilities continue to study and develop environmentally friendly technologies. The purpose of this report is to document the estimates of technology readiness and of emissions reduction potential from the present time through to twenty years time and beyond. To ensure that this report presents a realistic assessment of the identified technologies and operational proposals, IATA has facilitated a dialogue between manufacturers, operators and credible research centres worldwide.

It is understood that there will be challenges in incorporating new technologies in a timely and coordinated manner. Changes to the airframe, systems and engines that will increase efficiencies must be coordinated with upgrades to the air traffic control system so the advantages can be realised. A net fuel burn reduction is possible only if aircraft efficiency gains are not cancelled by increased fuel burn due to airspace and airport congestion. Biofuels offer great promise to reduce dependence on oil and the feedstock can consume carbon dioxide from the atmosphere. However, these biofuels must have the same or greater specific energy of conventional fuels and it must not take a greater amount of conventional energy to produce these alternative fuels than they save.

By documenting these technologies and by assuming an industry coordinating role, IATA plans to play a central role in bringing the industry together to achieve a zero net carbon footprint.

1.3 Scope

The scope of this project is to:

- Identify technologies that will reduce the environmental footprint of air transport
- Collect information from OEMs, engine manufacturers, suppliers, academic and government research facilities about these technologies
- Assess and evaluate the benefits, costs and drawbacks of each technology.

Technologies in the following four areas are considered:

- Airframe
- Engines
- Air Traffic Management
- Alternative Fuels

They will be assessed for those technologies that can be incorporated now (existing service bulletins), between the current time and 2020 (next generation of airplanes that will be produced) and beyond 2020 (concepts for the future).

The assessment in this report comprises the benefit of all technologies for fuel burn and CO_2 emission reduction as well as their implications for other environmental aspects (noise, local air quality), on aircraft operation, integration into the airspace and cost aspects (investments and operational costs).

In order to avoid any competitive issues, information collection and assessment refers to single technologies and their potential environmental benefits, and not to specific new aircraft programmes.

In this phase of the TERESA project, the assessment of climate impact was restricted just to CO_2 emissions and not other greenhouse gas emissions. Nitrous oxides (NO_X) emitted by aircraft engines contribute to the greenhouse effect and also to local air quality degradation; they were accounted for in TERESA through the latter effect. The impact of contrails and cirrus clouds generated by aircraft is still poorly known; it was therefore considered premature to take it into account for future aircraft design.

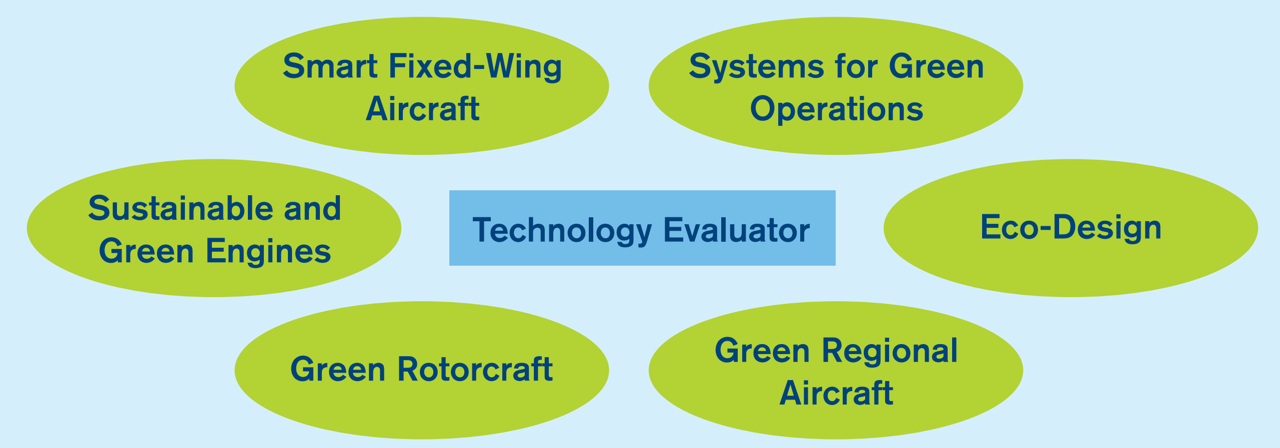


Figure 1-5: Structure of the €1.6 bn EU R&T programme "JTI Clean Sky"[5]

1.4 Related Activities

Reducing greenhouse gas emissions is one of aviation's biggest challenges today along with safety and security. It is the main driver for numerous programmes in aviation research and development (R&D) as well as for various initiatives by regulatory authorities and policymakers. The aviation industry is confronted with increasing expectations and pressure from politicians as well as from the general public to reduce its emissions, despite increasing demand for air travel. Roadmaps are now required to describe credible ways to reach this goal.

On the research side, visions and aspirational goals have been defined as guidelines for fostering and steering R&D activities and allocating public funding most effectively.

The best-known initiative in this area is the "European Aeronautics Vision for 2020" published in 2001 by the "Group of Personalities" from aeronautical research and industry[2]. This advisory body to the European Commission was tasked to give a long-term view of research priorities and needs in all areas of permanent challenge to air transport, namely: Customer orientation, Time efficiency, Cost efficiency, Environment and Security. On its initiative the Advisory Council on Aeronautics Research in Europe (ACARE) was created and established a Strategic Research Agenda (SRA)[3] to realise this vision.

ACARE goals in terms of environment for new aircraft in 2020, relative to 2000, are[4] (Fig. 1-6):

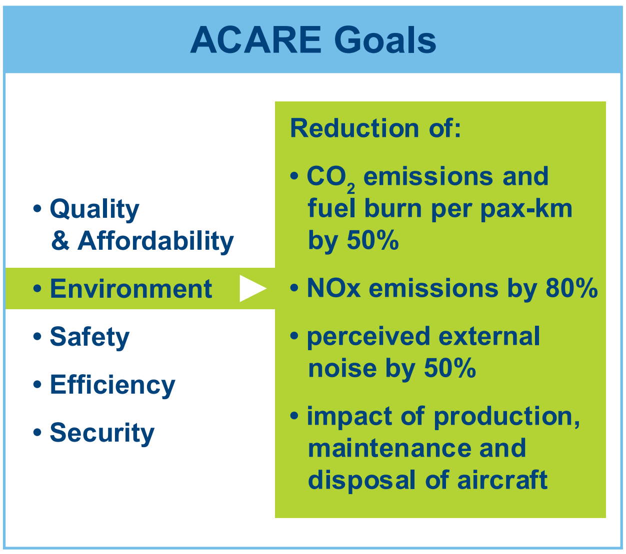
- Reduction of CO_2 emissions and fuel consumption per passenger kilometre by 50%
- Reduction of NO_x emissions by 80%
- Reduction of perceived external noise by 50%
- Reduction of impact of production, maintenance, and disposal of aircraft

The fuel and CO_2 reduction goal of 50% is split as follows:

- 15 to 20% through engine improvements
- 20 to 25% through airframe improvements
- 6 to 10% through ATM improvements

The EU's research and technology (R&T) funding policy is focused on achieving these goals. The Joint Technology Initiative (JTI) "Clean Sky"[5] is a €1.6 billion R&T programme covering the environmental aspects of aviation (see Figure 1-5). Most of the technologies addressed in "Clean Sky" are mentioned in the Roadmap.

Fig. 1-6: ACARE high-level and environmental goals



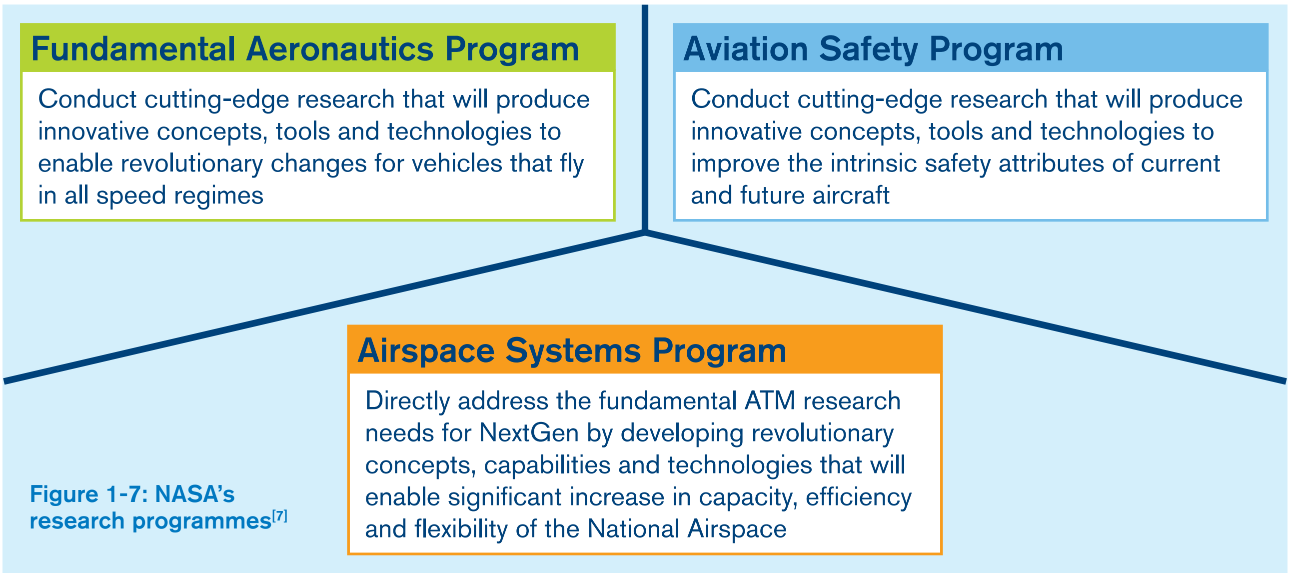


Figure 1-7: NASA's research programmes[7]

In the US, the National Science and Technology Council (NSTC) established similar goals for the near term, mid term, and far term periods[6]:

- Near term (<5 years) R&D goals and objectives
  - 33% reduction in fuel burn compared to reference aircraft (B737-800 with CFM56/7B engines)
  - 32 dB cumulative below Stage 4 noise limit
  - 70% below CAEP 2 limit for LTO NO_x emissions
- Mid term (5-10 years) R&D goals and objectives
  - Minimum of 40% reduction in fuel burn compared to reference aircraft
  - 42 dB cumulative below Stage 4 noise limit
  - 80% below CAEP 2 for LTO NO_x emissions
  - 3-5% energy intensity improvement for existing 2006 baseline operational procedures
- Far term (>10 years) R&D goals and objectives
  - Up to 70% reduction in fuel burn compared to reference aircraft (25-year stretch goal)
  - 62 dB cumulative below Stage 4 noise limit (25-year stretch goal)
  - Better than 80% below CAEP 2 limit for LTO NO_x emissions
  - 6-10% energy intensity improvement for existing 2006 baseline operational procedures

NASA's current investment is trying to address these challenges through three main research programmes, as illustrated in Figure 1-7.

On the **regulatory** side, ICAO decided in 2001 that it was not appropriate at that time to introduce a CO_2 emissions standard, similar to noise and local emissions standards. Since CO_2 emissions are directly proportional to fuel consumption, the market pressure through fuel price was considered to be a sufficient driver to emissions reduction[8].

International aviation is not included in the greenhouse gas reduction targets under the Kyoto Protocol, applicable to Annex-I countries. Due to the nature of border-crossing flights, there is no internationally accepted way to attribute emissions from international aviation to the budgets of specific countries, as is implemented for stationary sources or domestic air traffic. Nevertheless, the Kyoto Protocol asked Annex-I (developed) countries to address greenhouse gas emissions from international aviation by working through ICAO.

In 2007, the 36th ICAO Assembly created the Group on International Aviation and Climate Change (GIACC). Its mandate is to develop and recommend to ICAO an aggressive programme of action on international aviation and climate change, in preparation for the United Nations Framework Convention on Climate Change (UNFCCC) Copenhagen meeting in December 2009. One major task of GIACC is to make reliable quantitative estimates and projections of future aviation emissions trends and abatement potential. For this purpose ICAO's Committee on Aviation Environmental Protection (CAEP) is working on comprehensive models describing future aircraft fleet composition, operating patterns and emissions production[9]. Such models depend on the availability of data describing current fleets and operations as well as on the foreseeable technological, operational and infrastructural improvements. CAEP has asked the aviation industry for relevant input to this modelling work to assist the GIACC work.

For an **industry** response to this request it is necessary to harmonise the goals and projections in terms of CO_2 emissions reduction between the different stakeholders of the aviation industry (airlines, airports, air navigation service providers, aircraft manufacturers). The Air Transport Action Group (ATAG)[b] has recently taken this action. It is gathering and comparing goals and predictions from the worldwide associations representing the stakeholder groups (IATA, ACI, CANSO, ICCAIA) to agree on a harmonised projection.

Most of these projections use simplified models assuming a constant or at least smoothly varying annual improvement rate, which take into account only very approximately actual implementation of specific technological, operational or infrastructural improvements.

The **TERESA project** aims at filling this gap by identifying the single technology items that need to be implemented to achieve an overall fuel burn reduction.

Highest priority is given to those technologies that not only yield a strong fuel burn reduction, but also are beneficial in terms of operational and environmental requirements (non-fuel costs, ATM compatibility, noise, local air quality).

Thus this report presents environmentally friendly technologies that will be available in the next decade, should help airlines in their planning for the necessary fleet renewals and retrofits to reduce fuel burn and CO_2 emissions.

[b] *ATAG, a Geneva-based association, is an independent coalition of organisations and companies throughout all stakeholders groups of the air transport industry that have united to drive aviation infrastructure improvements in an environmentally-responsible manner*

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"The environmental challenges of aviation can only be met if all stakeholders in aviation cooperate."

2. Project Organisation

2.1 Partners and Roles

The environmental challenges of aviation can only be met if all stakeholders in aviation cooperate. The main potential for emissions-reducing technologies can be found in the following areas:

- Airframe: Aerodynamics, weight and materials, on-board systems, new design concepts
- Engines: New engine architectures, improved combustion efficiency, materials and components
- ATM: Improved system efficiency and airspace capacity supported by available and new on-board system technology
- Alternative fuels: Reduced carbon footprint using sustainable biojet fuels

To cover all these areas, IATA involved the main OEMs in each of these fields, as well as leading research institutions in aerospace technology that focus on technology evaluation.

Table 2-1: TERESA project partners

Airframe Manufacturers	Airbus, Boeing, Bombardier, Embraer
Engine Manufacturers	General Electric, Pratt & Whitney, Rolls Royce, Safran
System Suppliers	Hamilton, Honeywell, Rockwell-Collins, Thales
Fuel Industry	BP, Chevron, Shell, Total, UOP
Research	Georgia Institute of Technology, German Aerospace Centre (DLR), Bauhaus Luftfahrt, NASA

A task force was created within the Safety, Operations and Infrastructure organisation of IATA with IATA personnel and consultants assigned from both Geneva and Montréal IATA offices as participants.

All project partners were involved in the project through:

- Regular telephone conference calls
  - “Joint”: involving all partners together
  - “Technical”: focused on specific technical areas
- Participation in the Technology Assessment Workshop
- Giving expertise and feedback into the project group

With this multi-stakeholder cooperation a widely agreed data collection for the current and future developments and evaluation of the technology potential could be achieved.

To work in a climate of expertise exchange rather than of competition, the participating OEM companies were asked to focus on new technologies and not on new products, and to involve the respective technology expertise. Mainly during the Workshop, they gave their assessment of the relevant technologies regarding maturity and timeframe for availability, fuel savings, environmental impact, necessary investment, impact on operations and other aspects influencing their feasibility.

The Georgia Institute of Technology was IATA’s main partner in the project. It collated information about all relevant technologies. It also ran the Technology Assessment Workshop in its premises in Atlanta, using a methodology well proven with other customers, such as the National Institute of Aerospace (NIA) , which is described in Section 2-3.

2.2 Project Structure and Timeline

To establish the Technology Roadmap supporting the first pillar of the IATA strategy, the TERESA project is being developed in a number of consecutive steps as described below.

Steps 1 and 2, which mainly comprise a description of all relevant technologies, were covered in the first phase of the project and documented in the preliminary version of the IATA Technology Roadmap dated June 2008. An updated version will be available soon.

The current project phase (June to November 2008) focuses on the assessment of the emissions reduction potential. It mainly covers Steps 3 and 4 and gives some first ideas about Steps 5 and 6.

A full long-term projection of technology evolution and its impact on emissions reduction as well as a more thorough projection of costs is planned for 2009. A set of generic requirements for future aircraft development is planned as a main outcome. The cooperation with OEMs is expected to continue on the same basis as before, and a strong involvement of airline experts is envisaged.

2.3 Methodology

The methodology used in the TERESA project provided a means by which the technology strategic plans may be justified by addressing the following questions:

- What are the strategic goals?
- How much performance capability is needed to meet the goals?
- When will the technology enter into service?
- How risky is the endeavour?

The same method developed at Aerospace Systems Design Laboratory (ASDL) at the Georgia Institute of Technology in Atlanta, Georgia, USA has been extensively utilised in a Congressional study for an integrated five year research and technology plan for US aeronautics[1].

Table 2-2: Timeline of major TERESA tasks

1st half 2008	1. Comprehensive collection and consolidation of information about current industry initiatives in research and development 2. Overview of a number of key current and upcoming manufacturers' technology programmes
2nd half 2008	3. Assessment of the cost effectiveness and availability of new technologies for commercial aircraft as well as of their applicability in airline operations 4. Assessment of emissions reduction potential
2009	5. Projection of costs for airlines of procurement and operation of new technology 6. Assessment of technologies available after 2020 7. Development of generic requirements for future aircraft development 8. Projection of potential contributions towards carbon neutral growth and ultimately a zero emissions industry 9. Description of pre-requisites and potential timelines

The TERESA methodology was initiated by the collection of a large amount of data and information about specific technologies from scientific literature and partners actively involved in the airline, airframe, engine, air traffic management (ATM) and fuel industries. During this phase of the program more than 75 technologies were identified and discussed through telephone conferences. The second phase of the methodology involved a technology assessment workshop that took place on 30 September and 1 October 2008. The event was hosted by the ASDL. The workshop regrouped more than 30 experts from all technical backgrounds to evaluate the impact of the technologies with respect to the IATA goals and aircraft attributes listed in Table 2-3. This table also includes a set of implementation criteria that is used to filter the global improvement potential of a set of technologies based on retrofitability, costs, technology maturity and time horizon.

Once the experts populated the relationships between technologies, aircraft attributes and goals, the results were compiled into a technology prioritisation and ranking tool. The results presented in the next chapter were gathered using the TERESA prioritisation and ranking tool. This interactive tool can be combined later with an interdependencies matrix to estimate the level of compatibility between the technologies.

The TERESA methodology provided a structured, traceable, and transparent process for planning and technology prioritisation. The key element of the methodology was the inclusion of experts throughout the process. The end product allows for specific scenario analysis that can be used as the foundation for creating detailed strategic roadmaps and quantitative technology assessments and tracking.

Table 2-3: Goals, implementation criteria and aircraft attributes considered at workshop

Goals	Aircraft Attributes		Implementation Criteria
▪ Improve fuel efficiency	▪ Reduce airframe weight	▪ Increase aerodynamic efficiency	▪ Retrofittability
▪ Reduce greenhouse gases	▪ Reduce engine weight	▪ Increase fuel energy density	▪ Retrofit costs
▪ Improve local air quality	▪ Reduce specific fuel consumption	▪ Increase non-propulsive energy efficiency	▪ R&D investment required
▪ Reduce community noise	▪ Reduce airframe noise	▪ Increase air traffic management system efficiency	▪ Annual operating costs
▪ Increase capacity/ reduce delays	▪ Reduce engine noise	▪ Increase asset utilisation	▪ On-aircraft investment costs
▪ Increase operational efficiency	▪ Reduce non-CO_2 emissions	▪ Maintain infrastructure compatibility	▪ Time for implementation
	▪ Reduce maintenance costs		▪ Technology Readiness Level
	▪ Reduce personnel costs		
	▪ Reduce delays		

Chapter References

1. National Institute of Aerospace, “Responding to the Call: Aviation Plan for American Leadership”. http://www.nianet.org/pubs/AviationPlan.php, 2005. [Online; accessed 17-September-2008].

Technology offers the best potential to reduce emissions."

Giovanni Bisignani

3. Evaluation and Results

3.1 Timeline of Solutions

The development of an evaluation capability, as described in the methodology section, has enabled the selection of a range of technologies and concepts that will assist the commercial aviation system in meeting the IATA environmental goals. These technologies fit into three broad categories. The first group is those, which can be retrofitted to existing, in-service aircraft, or will be available for inclusion on new production aircraft of the same model. The second group is the technologies that require the development of new aircraft designs and models but are anticipated to be available for inclusion on new aircraft that would enter service between 2008 and 2020. Finally, to provide further insight into the possible future trends there is a group of promising technologies that will come of age after 2020.

The various technologies are described in detail in the Technical Annex. The development and availability timeline for these technologies, and a range of air traffic management concepts and improvements, are shown in Figure 3-1.

These technologies are displayed with a range of possible availability timelines based upon the current technology readiness and the development timeline.

The following sections describe the outcome of the selection process that was facilitated by the workshop that was held at the Georgia Institute of Technology.

The impact values presented in the tables that follow are based on the results from the workshop. Each technology was rated by its technology readiness level (TRL) as defined by NASA. As mentioned in the methodology section, the participants of the workshop populated two matrices: Goals to Attributes, and Attributes to Technologies. Consequently this mapping allows the ranking of technologies as a function of the goals' importance. The participants then established a consensus on the following importance of the respective goals:

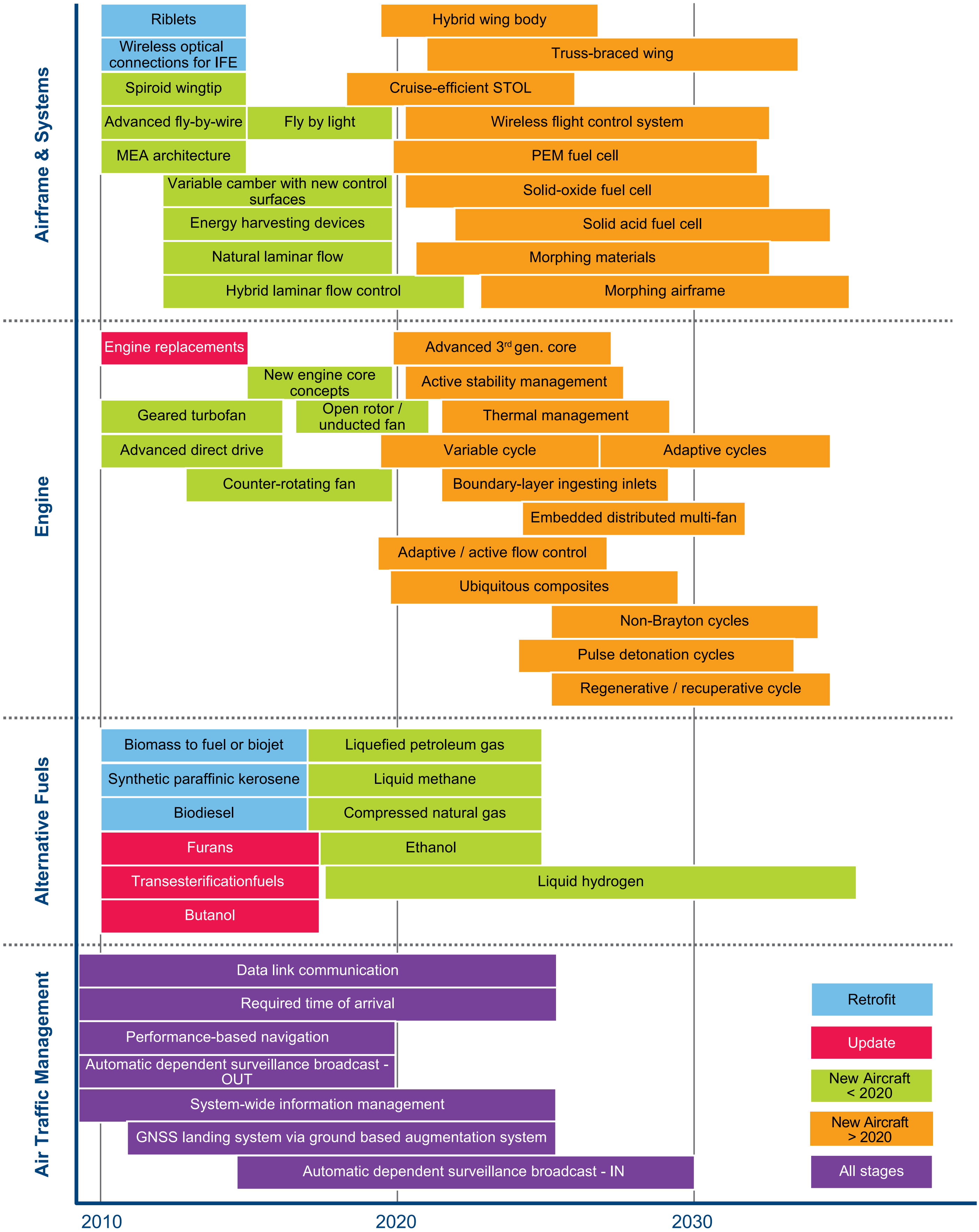
Table 3-2: Goal importance agreed at workshop

Goal	Importance (%)
Improve fuel efficiency	20
Reduce CO_2	30
Improve local air quality	10
Reduce community noise	10
Increase capacity/reduce delays	15
Increase operational efficiency	15
Total	**100**

Table 3-1: Currently available technologies

Airframe		Engine	ATM
▪ Active load alleviation ▪ Aircraft graphic films ▪ Advanced alloys ▪ Blended winglet ▪ CentrAl ▪ Composite primary structures ▪ Composite secondary structures ▪ Drag reduction coatings ▪ Fluoropolymers ▪ Friction stir welding ▪ Glare ▪ High strength glass microspheres	▪ High power Lights-Emitting Diode (LED) for cabin lighting ▪ Landing gear drive ▪ Laser beam welding ▪ Lithium batteries for secondary power ▪ More efficient gas turbine Auxiliary Power Unit (APU) ▪ Raked wingtip ▪ Variable camber with existing control surfaces ▪ Wingtip fence ▪ Zonal dryer	▪ Advanced combustor ▪ Engine retrofits: > advanced heat-resistant materials > better blade design > more efficient energy management ▪ Variable geometry chevron ▪ Variable fan nozzle	▪ Data Link Communications (VHF-ACARS and VDL Mode 2, SATCOM and HF) ▪ Performance Based Navigation (PBN) ▪ Automatic Dependent Surveillance Broadcast (ADS-B) OUT ▪ Automatic Dependent Surveillance Contract (ADS-C) ▪ Multilateration ▪ Auto-loading FMS with data link instructions ▪ FMS Required Time of Arrival (RTA)

Figure 3-1: Possible timeframes for availability of technologies



3.1.1 Baseline Aircraft

In order to compare the impact of the different technologies a baseline aircraft was defined. For the tables in the following section, the baseline aircraft is assumed to be a 120-passenger aircraft with an approximate takeoff gross weight of 60,000 kg (132,000 lb) and a fuel capacity of 24,000 litres (6,550 US gallons). Consequently a 1% reduction of fuel burn or, equivalently, of CO_2 emissions is presumed to be equivalent to a fuel saving of 250 litres (65.5 US gallons) or 200 kg (440 lb) of fuel.

3.1.2 Retrofit Plus Serial Modifications

Technologies that can be retrofitted to current, in-service aircraft have the potential to rapidly provide fleet wide improvement, however modest. The outcome of this study has identified a range of technologies that are currently available or are anticipated to become available for retrofit to the current fleet. The technologies available for retrofit to current in-service aircraft are given, in the rank order of meeting the goals as agreed in the assessment workshop, in Table 3-3.

It is important to note that the technology CO_2 impacts are not independent. This study did not include an assessment of a combined set of technologies, since combining technologies implies a higher level of complexity and non-linear interactions. This makes it difficult to predict the cumulative impact.

Some key retrofitable technologies can be identified as high impact from Table 3-3. In the airframe category, the wingtip technologies provide a relatively large CO_2 impact reduction varying from 3 to 5% with an estimated one-digit million US$ R&D investment. The engine retrofits technology is expected to reduce CO_2 between 1 to 2%. The engine benefits come at an estimated R&D investment ranging in the order of hundreds of millions US$. The fuel technologies have great potential, however they are not currently available and will most likely enter service between 2010 and 2020. The ATM technologies listed here do not require large aircraft modification. These technologies come at a low retrofit cost, and their impacts can be applied to a wide spectrum of aircrafts. By combining some of the retrofitable technologies together, it is conceivable to achieve a 10% improvement in CO_2 emissions.

Table 3-3: Technologies available for retrofit

Technologies		Fuel burn reduction	TRL	Availability Timeframe	Estimated Retrofit Costs (US$ million)
Airframe Technologies					
	Composite secondary structures	~1%	9	Current	0.1 to 1
	Wingtip fence	1 to 3%	9	Current	1 to 10
	Raked wingtip	3 to 6%	9	Current	1 to 10
	Blended winglet	3 to 6%	9	Current	1 to 10
	More efficient gas turbine APU	1 to 3%	7	Current	1 to 10
	Lithium batteries for secondary power	< 1%	5	Current	< 0.01
	Variable camber with existing control surfaces	1 to 2%	8	Current	1 to 10
	High strength glass microspheres	~1%	6	Current	1 to 10
	Aircraft graphic films	~1%	9	Current	0.01 to 0.1
	Zonal dryer	~1%	9	Current	0.01 to 0.1
	Riblets	1 to 2%	7	2010+	1 to 10
	Drag reduction coatings	< 1%	9	Current	< 0.01
	Landing gear drive	< 1%	7	Current	0.1 to 1
	Wireless optical connections for in flight entertainment	< 1%	5	2010+	0.1 to 1
	High power LEDs for cabin lighting	< 1%	9	Current	0.01 to 0.1
	Fluoropolymers	< 1%	6	Current	1 to 10
Engine Technologies					
	Engine retrofits [c]	1 to 2%	8	Current	1 to 10
Alternative Fuels [d]					
	Biomass to Fuel (BTF) or biojet	60 to 90%	6	2010+	< 0.01
	Hydrogenated oil/fat	negative to 70%	7	2010+	< 0.01
	Gas to Fuel (GTF) or Gas to Liquid (GTL)	negative to 10%	8	Current	< 0.01
	Transesterification fuels	negative to 70%	7	2010+	0.1 to 1

[c] *Engine retrofits: advanced heat-resistant materials, better blade design and more efficient energy management*
[d] *The CO_2 benefits of alternative fuels are considering the entire fuel life cycle. Negative CO_2 reduction values can occur if during the lifecycle of the fuel net CO_2 emissions are higher than for current kerosene. In some cases (soy or palm oil) they can reach approx. 7 times the amount from kerosene.*

The report identifies additional technologies for incorporation on updated versions of production aircraft. These technologies are either too complex or require extensive changes to be used for retrofit. However, they could be used as updates to existing production lines. These technologies are given, again in the rank order of meeting the workshop goals, in Table 3-4.

The technologies available for current production aircraft are fairly mature, can be integrated currently or in the near future, and have great potential to reduce CO_2 emissions. Airframe technology benefits come from a reduction of the aircraft empty weight instead of aerodynamics improvement. The engine technologies are migrating toward the engine core and cycle, which will be more noticeable in the next time horizon.

It is in airlines' interests to invest in this new standard and retrofit all airplanes in their fleets that have a viable operational life before the airplane is to be retired from service. There is always concern that changes to the Air Traffic Management system will force expensive upgrades to the airplane side. By coordinating across all parties and by assuring that on-board systems have enough computing and memory capability to be upgraded, investment risk for the airlines is minimised and future possibilities can be more easily adopted. IATA will continue to support this process.

3.1.3 New Short Range Aircraft

The technologies included in the new aircraft before the 2020 time horizon would require large modifications to existing design, therefore they cannot be applied to current production aircraft. However their technology readiness levels are sufficiently mature to be integrated to new aircraft design before 2020, when a new generation of short-range aircraft (NSR) is planned to enter service. These technologies are given in the rank order of meeting the workshop goals, in Table 3-5.

Designing a new aircraft with a set of technology in mind offers more design freedom to manufacturers and better systems integration on the aircraft. The airframe technologies are starting to diverge from the conventional aircraft with new shapes (e.g. spiroid wingtip), more complex technologies (e.g. hybrid laminar flow), and even new manufacturing processes (e.g. friction stir welding). Within this time frame, the engine technologies include new system architectures, and core concepts with high CO_2 impacts. It can be observed that this table does not include any ATM technologies, since most of the examined technologies can be implemented prior to the 2020 time horizon.

Table 3-4: Technologies available for incorporation on existing production aircraft

Technologies		Fuel burn reduction	TRL	Availability Timeframe
Airframe Technologies				
	Active load alleviation	1 to 5% [e]	9	Current
	CentrAl	1 to 3% [f]	7	Current
	Composite primary structures	1 to 3% [f]	9	Current
	Glare	1 to 3%	9	Current
	Advanced alloys	1 to 3%	8	Current
Engine Technologies				
	Advanced combustor	1 to 2%	8	Current
	Engine replacements	5 to 10%	6	2010+
	Variable geometry chevron	<1%	5	Current
Alternative Fuels [g]				
	Furans	negative to 90%	4	2010+
	Biodiesel	negative to 70%	7	2010+
	Butanol (blend)	negative to 90%	4	2010+

[e] *Based on a structural wing weight reduction of 20%.*
[f] *Assuming 20% wing and fuselage structural weight reduction.*
[g] *The CO_2 benefits of alternative fuels are considering the entire fuel life cycle. Negative CO_2 reduction values can occur if during the lifecycle of the fuel net CO_2 emissions are higher than for current kerosene. In some cases (soy or palm oil) they can reach approx. 7 times the amount from kerosene.*

Table 3-5: Technologies applicable to new aircraft designs prior to 2020

Technologies		Fuel burn reduction	TRL	Availability Timeframe
Airframe Technologies				
	Natural laminar flow	5 to 10%	6	2010+
	Hybrid laminar flow	10 to 15%	6	2010+
	Variable camber with new control surfaces	1 to 5%	5	2010+
	Spiroid wingtip	5 to 10%	7	2010+
	Fly-by-light	1 to 3%	6	2010+
	More Electric Aircraft (MEA) architecture	1 to 5%	7	2010+
	Advanced fly-by-wire	1 to 3%	8	2010+
	Friction stir welding	~1%	7	Current
	Laser beam welding	~1%	8	Current
	Energy harvesting device for wingtip sensors and cabin switches	<1%	4	2010+
Engine Technologies				
	New engine core concepts (2nd GEN)	10 to 15%	2	2020
	Open rotor/unducted fan (system architecture)	15 to 20%	5	2010+
	Advanced direct drive (system architecture)	10 to 15%	5	2010+
	Geared turbofan (system architecture)	10 to 15%	7	2010+
	Counter rotating fan (system architecture)	10 to 15%	3	2010+
	Variable fan nozzle	1 to 2%	7	Current
Alternative Fuels [h]				
	Liquefied petroleum gas	1 to 5%	2	2010+
	Liquid methane	negative to 25%	7	2010+
	Compressed natural gas	negative to 20%	3	2010+
	Ethanol	negative to 70%	8	2010+

Table 3-6: Technologies and concepts applicable to new aircraft designs after 2020

Airframe Technologies		Fuel burn reduction	TRL	Availability Timeframe
Airframe Technologies				
	Truss-braced wing	10 to 15%	2	2020+
	Morphing airframe	5 to 10%	3	2020+
	Hybrid-wing-body	10 to 25%	4	2020+
	Morphing material	1 to 5%	3	2020+
	Proton Exchange Membrane Fuel Cell (PEMFC)	1 to 5%	6	2020+
	Solid Oxide Fuel Cell (SOFC)	1 to 5%	5	2020+
	Cruise-efficient Short Takeoff and Landing (STOL)	<1%	3	2020+
	Wireless Flight Control System (WFCS)	1 to 3%	5	2020+
	Solid Acids Fuel Cell (SAFC)	1 to 2%	1	2020+
Engine Technologies [i]				
	Advanced core (3rd GEN)	15 to 25%	2	2030+
	Adaptive/active flow control	10 to 20%	2	2020+
	Variable cycle (2nd GEN)	10 to 20%	4	2020+
	Ubiquitous composites (2nd GEN)	10 to 15%	3	2020+
	Active stability management	10 to 15%	3	2020+
	Adaptive cycles	5 to 15%	2	2020+
	Pulse detonation	5 to 15%	2	2020+
	Regenerative/recuperative	5 to 10%	2	2020+
	Non-Brayton cycles	5 to 10%	2	2020+
	Thermal management (2nd GEN)	5 to 10%	5	2020+
	Boundary Layer Ingesting (BLI) inlet	1 to 3%	3	2020+
	Embedded Distributed Multi-Fan (2nd GEN System)	<1%	2	2020+
Alternative Fuels [j]				
	Liquid Hydrogen	negative to 100%	7	2020+

[h] *The CO_2 benefits of alternative fuels are considering the entire fuel life cycle. Negative CO_2 reduction values can occur if during the lifecycle of the fuel net CO_2 emissions are higher than for current kerosene.*
[i] *The engine technologies can be applied to multiple engine concepts for potential fuel reduction benefits.*
[j] *The CO_2 benefits of alternative fuels are considering the entire fuel life cycle. Negative CO_2 reduction values can occur if during the lifecycle of the fuel net CO_2 emissions are higher than for current kerosene.*

3.1.4 Long-term, Later New Aircraft

The long-term new design aircraft technologies start to diverge significantly from today's system architectures. Most of the technologies have low maturity levels requiring more than two decades to be implemented on a commercial aircraft. Significant R&D investments will be needed to develop and integrate the technologies listed, the rank order of meeting the workshop goals, in Table 3-6.

Low maturity technologies are difficult to assess due to the uncertainty surrounding the forecasting of their benefits and drawbacks. In Table 3-6, new configurations are considered (e.g. hybrid wing body) implying the need for fundamental research to understand and quantify their CO_2 impacts. During this time frame, it can be noticed that some airframe technologies include higher energy secondary power sources to reduce the energy demand from the engines. The engine technologies include second and third generation concepts to improve engine cycle thermal efficiency. Furthermore, revolutionary technologies such as pulse detonation and non-Brayton cycles may also be conceivable considering the post 2020 time horizon. Some of these engine technologies such as Adaptive/Active Flow control and Ubiquitous composites may be included in the future implementation of second and third generation engines. Consequently, their impacts would be embedded in future generation, which reinforces the notion that the impact of technologies should not be combined without further analysis. This is particularly true for low TRL technologies since they require further investigation to quantify their overall benefits and drawbacks.

3.2 Fuel Reduction Benefits

Since the effects of the different technologies are not independent, the cumulative impact of technologies cannot normally be obtained by simple addition. Estimates of the total impact for each of the four time horizons have been made in other studies[1,2,3,4,5], which compare reasonably well with a conservative addition of a reduced set of technology benefits. A specific set of technologies was selected in Table 3-7 to approximate the fuel reduction benefits potential.

Table 3-7 only includes technologies that are under the direct control of the OEMs. No ATM technologies are listed in Table 3-7 even though their immediate market penetration is currently possible. The implementation of ATM technologies does not depend directly on the OEMs, but mainly depends on the regulators, which have to consider passenger safety and other social-economics aspects such as noise and local air quality.

The results of Table 3-7 should be interpreted with caution. For instance, the benefits of the composite primary structures technology may already include some of the benefits of the composite secondary structures. As we forecast further in time, the uncertainty surrounding technology benefits increases and consequently more variability surrounds the total technological impacts. Figure 3-2 summarizes the results of Table 3-7 by illustrating the percentage fuel burn saving for each of the time horizon.

Table 3-7: Expected cumulated fuel burn reductions at various time horizons

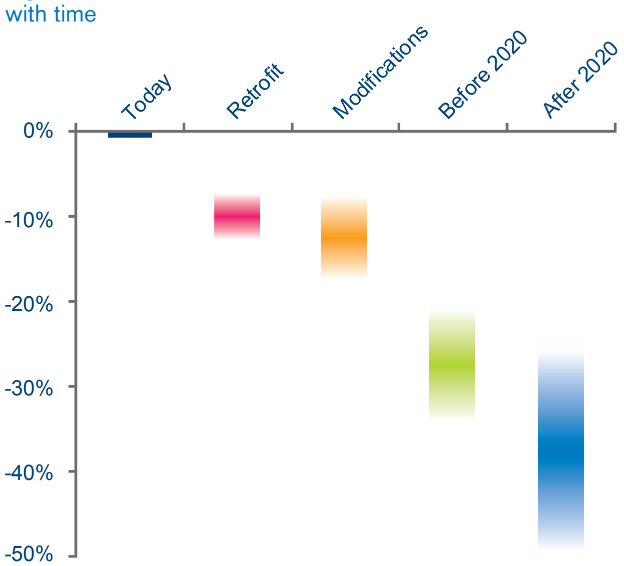
Time Horizon	Years	TRL	Technology	Fuel Reduction Benefits	Total Impact
Retrofit	Current	9	Wingtip technologies [k]	3 to 6%	**7 to 13%**
Retrofit	Current	9	More efficient gas turbine APU	1 to 3%	
Retrofit	Current	8	Engine retrofit	1 to 2%	
Retrofit	Current	9	Composite secondary structures	~1%	
Retrofit	Current	9	High power LEDs for cabin lighting	~1%	
Retrofit	2010-2020	6	Wireless optical connections for IFE		
Production Aircraft	Current	9	Composite primary structures [l]	1 to 3%	**7 to 18%**
Production Aircraft	Current	8	Engine replacement	5 to 10%[m]	
Production Aircraft	Current	9	Active load alleviation	1 to 5%	
New Design before 2020	2010-2020	5	New engine systems architecture [n]	15 to 20% [o]	**25 to 35%** [p]
New Design before 2020	2010-2020	6	Hybrid laminar flow	10 to15%	
New Design before 2020	2010-2020	6	Natural laminar flow	5 to 10%	
New Design after 2020	2020-2030	4	Variable cycle (2nd GEN)	10 to 20%	**25 to 50%** [q]
New Design after 2020	2020-2030	4	Hybrid-wing-body	10 to 25%	
New Design after 2020	2020-2030	2	Truss-braced wing	10 to 15%	
New Design after 2020	2020-2030	5	Fuel cell system	1 to 5%	

[k] *Include fence, raked and blended wingtips.* [l] *Assume to include Glare and CentrAl.* [m] *Include the advanced combustor.*
[n] *Include geared turbofan, counter rotating fan and open rotor/unducted fan.* [o] *20% correspond to the open rotor/unducted fan.*
[p] *Combine the new engine architecture and the hybrid laminar flow.* [q] *Combine Hybrid-Wing-Body, Variable Cycle engine and fuel cell system.*

3.3 Parallel Efforts by Stakeholders

In addition to the technologies that have now been evaluated by the TERESA project, a diverse mix of technical advances is being pursued by various stakeholder groups within the commercial aviation sector. There is a large amount of interest in not only adopting more immediately applicable technologies, but also supporting more fundamental research programmes that will pay dividends beyond the 2020 timeframe. As a supplement to the roadmaps and strategies at the national and/or inter-governmental levels described in Chapter 1.4, what follows is a succinct overview of some of the leading OEMs' approaches to making further improvements in the areas of airframe, engine, ATM, and alternative fuel.

Figure 3-2: Estimated evolution of fuel burn reduction with time



3.3.1 Airframe

All major airframe manufacturers (Airbus, Boeing, Bombardier and Embraer) are undertaking strong efforts to use greener technologies (see Figure 3-3). The airframe manufacturer strategy is to address the challenging environmental targets set by ACARE and ICAO not only by introducing new technologies and innovations, but also by espousing a more holistic approach. This involves optimising the aircraft as a whole, promoting innovative aircraft configuration and systems architecture, simplifying and streamlining.

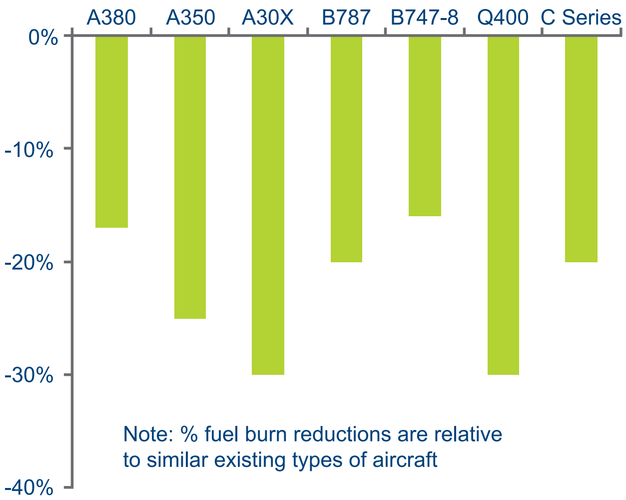
The Airbus latest entry into service series, the A380, burns 17% less fuel per seat than other large aircraft in today's fleet. This is the most significant step forward in reducing aircraft fuel burn and resultant emissions in four decades. The A380 produces only 75 g of CO_2 per passenger and per km. The Airbus A350 XWB, scheduled to enter service in 2013, is expected to offer fuel efficiency improvements of up to 25% per seat with respect to similar existing aircraft. The airframe will be made of more than 60% new materials, chosen for their superior weight and strength properties. This design also allows weight savings via optimum fibre lay-up and skin thickness tailored to the requirements of the location. The Airbus A30X, scheduled to enter service in 2017, is expected to reduce fuel burn and CO_2 emissions in excess of 30% compared to the A320, while more than halving NO_x emissions.

Boeing is also dedicated to meet the environmental challenges of tomorrow. The longer range 777 airplanes already incorporate wing and system modifications, such as raked wingtip, to reduce airplane drag and improve overall aerodynamic efficiency. The Boeing 787 Dreamliner, scheduled to enter service in late 2009, is designed with an expected 20% improvement in fuel burn and an equivalent reduction in CO_2 emissions compared to similarly sized airplanes. The 787 is expected to achieve these goals by incorporating four innovative technologies: new engines, increased use of lightweight composite materials, high-efficiency systems applications, and modern aerodynamics. The larger size Boeing 747-8 is expected to reduce fuel burn and CO_2 emissions by 16% over the 747-400. It provides the lowest operating empty weight per seat of any large airplane. Its wing design incorporates the latest aerodynamic airfoils, raked wingtips and lightweight flap design, which all serve to improve fuel efficiency. The new generation of Boeing 737 uses blended winglets that lower fuel burn by as much as 4%. This technology also reduces noise on takeoff and approach, and reduces emissions through lower cruise thrust.

Bombardier's family of aircraft, including the CRJ and the new C Series, will also lower the environmental footprint. The latest CRJ edition, the 1000 series will be certified to Chapter 4 ICAO noise standard with an effective perceived noise margin of 3.2 dB expected. The Bombardier Q400 turboprop, with its lower noise levels using a specially developed noise and vibration system, offers approximately 30% reduction in fuel-burn compared to similar sized jet aircraft. The CSeries, scheduled to enter service in 2013, is expected to offer a 20% fuel burn CO_2 emissions reduction compared with current aircraft. This environmental advantage of the C Series has been achieved through several technology advances: the use of advanced structural materials, making up 70% of the airframe and advanced aerodynamic design, featuring a numerically optimised fourth generation transonic wing. In addition the aircraft will use the Pratt & Whitney geared turbofan, which is expected to deliver lower specific fuel consumption (SFC), emissions and noise footprint.

Independently of entry into service dates for new aircraft types, all manufacturers continually release product improvement service bulletins for retrofits to the existing fleet, which provide weight savings or efficiency improvements. These are not necessarily "new technologies" but improvements to existing technologies.

Figure 3-3: Expected fuel burn reductions of new and coming aircraft types



3.3.2 Engine

Building on its track record of delivering 0.8% reduction in SFC per year since the early 1970s, GE Aviation continues to push the boundaries of the conventional turbofan engine architecture with its GE90, GP7200, and GEnx families of high-bypass turbofan engines. Notable technical advancements that characterise these engine families include: composite fan blades and cases; high-efficiency core; and the low-emissions, single annular combustor. The company's exploration of alternate engine architectures (such as counter-rotating fans, open rotors[6]), as well as research on more advanced aerodynamics, materials, and combustor technologies are being addressed under LEAP56, which is the advanced technology acquisition program of the consortium CFM International, consisting of GE and SNECMA. In contrast, Pratt & Whitney has settled on a future technology path that at this point exclusively focuses on its Geared Turbofan engine architecture. The company is hopeful that its spiral upgrade plan[7] to deliver 1% reduction per year in SFC between 2013 and 2020 will keep the Geared Turbofan competitive enough to be considered for Boeing's and Airbus' single-aisle replacements.

3.3.3 Air Traffic Management

Technologies that will allow the full utilisation of a modern aircraft's precision navigation capabilities will enable the implementation of fuel-saving and noise-mitigating operations, especially during an aircraft's take-off and landing manoeuvres. A good example of an OEM-led development in this area is the Tailored Arrivals concept advocated by Boeing's ATM systems laboratories[8]. Savings of up to 500 gallons of fuel per flight are possible due to the replacement of the current step-down descent with a more continuous and predictable descent path.

3.3.4 Alternative Fuels

The first demonstration of biofuels' feasibility as a future commercial aviation fuel took place in February 2008, when a Virgin Atlantic 747-400 flew on a blend of sustainable biomass-to-liquid fuel and traditional kerosene-based jet fuel[9]. It was a culmination of the collaborative laboratory and static-engine testing efforts between Boeing, GE Aviation and the Seattle-based company, Imperium Renewables, which provided the biofuel blend of babassu oil and coconut oil. The fact that no modifications were needed to either the airframe or the engines of the test-flight aircraft is encouraging news for those who are looking to introduce alternative fuels to an existing fleet of aircraft. Similar Boeing-led demonstration flights are planned for the near future, including one with Air New Zealand and Rolls-Royce in December 2008 and another one in 2009 with GE Aviation and Continental Airlines. Beyond first-generation biofuels that compete with food crops for land, advanced generation non-food crops, such as Jatropha Curcas[10] and algae[11], are likely to become the leading contenders for sustainable and alternative sources of aviation fuel.

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New technologies that reduce CO_2 emissions must meet often conflicting technical and operational requirements in aviation.”

4. Implementation

4.1 Challenges

In the last chapter we saw that there is a high potential for CO_2 emissions reduction by technological progress in all areas of airframe and engine design, ATM and alternative fuels. Nevertheless, the path from technology development to implementation in aircraft and air traffic and market penetration is not at all straightforward.

New technologies that reduce CO_2 emissions must at the same time meet all other – often conflicting – technical and operational requirements in aviation. Safety must never be compromised in aviation. Other important targets are reliability, maintainability and other environmental aspects (noise, local air quality). These criteria were part of the evaluation during the Workshop and influenced the ranking of considered technologies.

Since saving CO_2 emissions and saving fuel have a direct relationship, the considered technologies have both an ecological and an economic benefit. However, each introduction of a new technology needs a business case, which depends on the necessary investment for technology development, certification and implementation as well as non-fuel operational costs (e.g. maintenance, crew costs, airport and ground handling charges). Rough orders of magnitude for these parameters have been estimated during the evaluation workshop.

Last but not least, an appropriate political framework is needed.

- Effective instruments for public research and technology funding in aeronautics and related fields have existed for a long time both in Europe (JTI Clean Sky[1] and SESAR[2], as well as numerous projects through the R&T Framework Programmes[3] and national programmes[4]) and in the USA (mainly through the Joint Planning and Development Office[5] [6]). Most of them are based on close cooperation between research and industry partners to foster a smooth transition from technology development to application. A steady continuation of research funding is necessary to achieve constant progress of environmental efficiency.
- Specific political support is needed in terms of airspace administration and ATM as well as legislation regarding alternative fuels, as described below.

4.1.1 Airframe/Engine

As seen in Chapter 4, the largest fuel saving potential expected for the future will come from technological improvements in aircraft:

- Engines (e.g. geared turbofan, open rotor)
- Structure and materials (e.g. composites, alloys)
- Aerodynamic design (e.g. laminar flow, winglets, active load alleviation)
- Systems (e.g. APU, avionics)
- New Concepts (e.g. blended-wing body)

4.1.1.1 Method and Timing of Implementation

Regarding implementation, the technologies investigated in TERESA are divided in the following groups:

- Retrofits for flying aircraft
- Modifications in current serial production
- For new aircraft types (time horizon 2020)
- For new aircraft types (longer-term)

Some technologies can be retrofitted onto flying aircraft during a major overhaul (via a service bulletin), or introduced into the serial production of existing aircraft types as a modification. (IATA has prepared a database on available retrofits.) Unfortunately, only fuel savings of a few percent can be achieved with these retrofits and modifications. On the other hand the benefits can be realised quickly.

In principle it is possible to retrofit flying aircraft with new engines. Although substantial fuel savings can be achieved, the retrofit is, however, often not beneficial, since the investment and mounting costs of the new engine will only be realised after a long time. For old aircraft, where the efficiency gain would be greatest, this is often not worth the effort.

Most technologies with a large saving potential can only be implemented in new aircraft types. The realisation of the respective benefits therefore strongly depends on the entry into service of these new aircraft. Currently two major steps are expected in the next decade:

- The entry into service of the new long-range aircraft Boeing 787 (2009) and Airbus A350 (2013), both with numerous technological improvements, in particular a full carbon-fibre fuselage;

- The introduction of the New Short Range aircraft from both Airbus and Boeing, expected to enter into service towards the end of the decade 2010-2020, as well as short-range aircraft from Bombardier, Embraer and emerging manufacturers from Japan, China and Russia. These aircraft are expected to deliver substantial performance improvements in terms of engines, materials, aerodynamics and systems as well as an improved airport compatibility that also helps reduce operational fuel burn per mission.

Considering fuel burn reduction at a worldwide fleet level, the effect of a new aircraft type is not immediate, but slowly increases with market penetration of the new type.

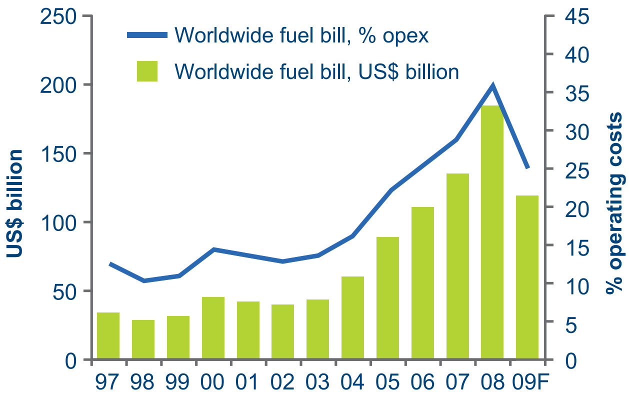
4.1.1.2 Future Design Optimisation

Fuel is the airlines' highest single cost item, some 30 to 40% of total costs (see Figure 4-1). The pressure to save fuel means that the airlines' demand for fuel-saving technologies has strongly increased, and the expectations for an early launch of the new short-range aircraft are high.

Some technologies were discarded in the past because the fuel savings they generated were more than outweighed by, for example, high investment or maintenance costs. These have now regained interest, at least for some customers. An example is the "zonal dryer", a device that, by dehumidifying cabin air, avoids water condensation in the cabin insulation blankets and thus an increase in aircraft operational weight.

In future it may be advantageous to optimise the design parameters of new aircraft differently from today. While it makes no sense flying today's aircraft slower (below the design speed) because, contrary to cars, this saves no fuel, a future aircraft designed for a lower cruise speed would consume less fuel. For the open rotor engine a lower design speed is envisaged. However, flexibility is required from ATM to cope with a dense traffic of aircraft with substantially different speeds.

Figure 4-1: Fuel costs as part of worldwide operating cost



Moreover, total fuel burn for a single long-haul trip is always higher than if the same distance is flown in two legs, since in the second case the fuel for the second segment does not need to be carried during the first one. Although additional stopovers conflict with passenger comfort, this principle is often used for cargo networks (e.g. Lufthansa Cargo having a hub in Astana (Kazakhstan) for its Europe-Asia traffic). This might lead to new requirements for the design range of future aircraft.

In general, there may be a trend to build future aircraft series in an increased number of sub-versions, each designed for a specific range, in order to optimise fuel burn for each market requirement. With increasing worldwide air traffic a sufficient quantity for each sub-version can be expected.

4.1.2 Air Traffic Management

Air Traffic Management (ATM) is being redefined by two major programmes, NextGen in the U.S. and the Single European Sky Air Traffic Management Research (SESAR) in Europe. Both are based on the following concepts:[2][6]

- System Wide Information Management (SWIM)
- Collaborative decision-making
- 4D trajectory-based operations
- Self-spacing and merging
- Capacity enhancements
- Automation support

The implementation timelines for SESAR and NextGen start in 2008 and go through 2025 onwards with the introduction of advanced applications such as full application of self-separation and 4D trajectory contracts.

Collaborative Decision Making (CDM) is one of the most important concepts of the future ATM system, improving flight predictability and efficiency. CDM is primarily enabled by the System-Wide Information Management (SWIM) system. SWIM is an information network architecture, currently under development, that will allow the seamless distribution of air traffic management data to airspace users and managers. SWIM will manage security, weather, surveillance, airspace status, flight data, as well as airport and terrain databases.

Future CNS/ATM technologies include the following:

- Digital data link will replace voice as the primary means of communication for air-to-air, air-to-ground, and ground-to-ground communications.
- The future navigation concept will be based on performance based navigation standards rather than specific navigation aids and equipage requirements and represents a big transition from ATC to ATM with pilot monitoring.
- Performance Based Navigation (PBN) concepts include a globally harmonised Area Navigation (RNAV) and Required Navigation Performance (RNP) values. RNAV enables aircraft operation on any desired flight path allowing user preferred routings and trajectories. RNP requires on-board monitoring and alerting, and it is a statement of the aircraft navigation performance defined in terms of accuracy, integrity, availability, and continuity of service necessary for operation. PBN is the platforms for a seamless, harmonised, and cost-effective navigational service from departure to touchdown.
- The Global Navigation Satellite System (GNSS) is at the heart of the future globally interoperable navigation infrastructure. GNSS provides standardised positioning information to the aircraft systems to support precise global navigation and surveillance. Further, GNSS will make it possible to replace the 2D Instrument Landing System (ILS) approaches with 3D precision approaches through a combination of PBN procedures and GNSS Landing System (GLS) capabilities supported by a Ground-Based Augmentation System (GBAS).
- Although GNSS will be the primary means of navigation, IRS/IRUs will remain an integral part of the long range navigation solution. Continental operations will also have a backup to GNSS in the form of DME or e-LORAN.
- Automatic Dependent Surveillance Broadcast (ADS-B) is a surveillance technology by which an aircraft is able to broadcast (ADS-B OUT functionality) as well as receive, process, and display aircraft information broadcast by another ADS-B equipped aircraft (ADS-IN functionality). Information that is broadcast, such as state vector and identification, is displayed on a Cockpit Display of Traffic Information (CDTI) on the flight deck and on controllers' screens. The implementation of ADS-B will greatly improve cockpit situational awareness and provide the potential for spacing, merging and possibly shared separation responsibility between ATC and pilots.
- Another surveillance system at the core of the future ATM concept is Multilateration (MLAT). MLAT is a ground-based surveillance system that uses transmissions from a transponder, Traffic Collision Avoidance System (TCAS), ADS-B, or military IFF transmissions to triangulate the position of a cooperative target. MLAT's major applications will be surveillance for high density terminal airspace, airport surface movements and the monitoring of height keeping performance for RVSM.

The successful implementation of SESAR and NextGen requires large up-front investment in avionics and infrastructure as well as the coordinated development of policies and procedures. The estimated investment in new avionics and aircraft systems for scheduled airlines under SESAR and NextGen is about US$ 40 billion. Harmonising avionics is critical as the industry cannot afford to have multiple technology solutions. A transition to a single avionics package serving the entire world is the final vision of the Global Air Navigation Plan. Benefits for NextGen and SESAR are summarised in Tables 4-1 and 4-2 (IATA internal study).

Achieving the environmental and efficiency targets that will be made possible by the future ATM environment depends on progressing globally harmonised solutions reached through collaborative decision-making. Likewise, a commitment by Air Navigation Service Providers (ANSPs) to make the necessary investments and deliver results is necessary. Further, the CNS/ATM elements of SESAR and NextGen need to be harmonised and integrated (as required) according to ICAO's Global Air Navigation Plan.

Table 4-1: Savings with NextGen

	Units	2010	2020	2030
Fuel savings	Million tonnes per year	0	5.3	10.8
CO_2 savings	Million tonnes per year	0	16.7	33.9
Net cost saving	$ Billions			
Jet fuel @ $85/b		0	7.1	15.1
Jet fuel @ $165/b		0	11.1	24.3

Note: Net cost savings include infrastructure capital, crew training and ATM operating costs minus savings from reduced fuel and block hour related costs.

Table 4-2: Savings with SESAR

Measure	Units	2010	2020	2030
Fuel savings	Million tonnes per year	0.3	3.9	5.6
CO_2 savings	Million tonnes per year	0.8	12.2	17.7
Net cost saving	$ Billions			
Jet fuel @ $85/b		0.5	7.6	10.3
Jet fuel @ $165/b		0.6	10.3	14.3

Note: Net cost savings include infrastructure capital and operating costs minus savings from reduced fuel and block hour related costs.

4.1.3 Alternative Fuels

Alternative fuels can be produced in several different ways. Raw or intermediate products from biomass could be fed into current refineries together with petrochemical oil; a new plant could be established (most likely near to the feedstock source or near infrastructure) or it could be integrated in other industrial plants. Today it is commonly agreed that only so-called "drop-in" fuels have a chance to replace petrochemical jet fuel within short term, i.e. those that can be used for current aircraft engines without modifications, and be blended with current jet fuel. For the implementation of non-drop-in fuels (e.g. liquefied gas) there are considerable challenges to overcome. This section will describe these challenges.

To incorporate a fuel that is not eligible to be certified in the current certification process, the aircraft needs a new fuel system design (and most likely a specific aircraft design), a new fuel certification and specialised infrastructure.

4.1.3.1 Impact on Airports

Engineering

Most airports have a single hydrant fuel system, which is only capable of delivering one type of fuel to aircraft. The challenge of engineering a new fuel system becomes more difficult with the complexity of the fuel. At normal temperature and pressure liquid fuels do not require the high engineering performance that liquefied gases do. Liquefied gases require high-pressure systems and/or low temperature handling systems.

Safety

Safety depends on the engineering design. If the flash point of a fuel is lower, the safety requirements need to increase to reach the same operational safety level as fuels with a higher flash point.

Operational consequence

A non drop-in fuel requires new training of personnel, a new/modified fuel quality monitoring system and an evaluation tool to optimise the system.

4.1.3.2 Impact on Airplanes

The current fleet of airplanes is designed to operate on liquid fuels with a low freezing point (< -40 °C or -47 °C), a high flash point (> 38 °C), high specific energy content and other specific properties[7].

Engineering

Incorporating a liquid fuel, which does not meet the current fuel specification, requires a modified fuel system. When fuels do not meet the maximum freezing point requirement, then tanks need to be heated to maintain the flow capability of fuel.

Gaseous fuels require a new fuels systems design, new storage designs and most likely new aircraft aerodynamic designs due to the lower density of fuel. A lower density fuel requires additional storage and, in the case of liquefied hydrogen, a volumetric storage capacity of about 4 times larger than conventional jet fuel tanks is required (depending on the specific fuel consumption).

Safety

A fuel that does not meet or cannot be incorporated in the current fuel specification requires a different certification process to maintain the quality control of the fuel.

Operational consequences

Operating an aircraft will be affected by the specific energy content and the volumetric energy content. A lower specific energy content will reduce the range and/or payload of the aircraft because more fuel needs to be carried. The volumetric energy content will affect the range on long-haul flights where the amount of fuel is limited by the maximum volume of fuel that can be carried.

4.1.3.3 Impact on Engines

Current engines are highly integrated systems in which the fuel is used to increase the efficiency of the engine. Fuels that are stored under a lower temperature than conventional jet fuel have the potential to increase efficiency even further.

Engineering

To design a gas turbine engine to operate on a different fuel means redesigning two areas: the combustor and the fuel systems. The combustor requires an evaluation or redesign due to the difference in burning properties of the fuel. For example, the flame speed of hydrogen is higher than for kerosene and thus requires a different flame control. The fuel systems require a different design due to the different fuel properties. For example, a liquefied gas needs an evaporation phase in the heating process; this requires the application of different heat exchangers.

Safety

The engine requires a specific certification to fly on a fuel that is not incorporated in the current certification.

Operational consequence

An additional challenge of applying liquefied gases with an extremely low boiling point would be the icing of heat exchangers for converting the liquid into gas.

4.2 Facilitation

4.2.1 Common Level of Knowledge

This report is intended to offer airlines detailed information about the technologies helping to reduce fuel burn and CO_2 emissions that are available or under development. The information contained therein, could evolve into a reference manual for data about the technology readiness and the emissions reduction potential of specific technologies. In this sense it would need to remain a "living document" with regular updates, regarding the fast progress in this area.

It is hoped that it will also enhance the dialogue between manufacturers and operators about the applicability of new technologies in real operations, and about the challenges for implementing them.

4.2.2 Joint Action Plan

The implementation of a number of technologies needs a harmonised approach between different stakeholders, as described above.

The most striking case is the ATM area, where it is necessary to synchronise the development and availability of ground-based ANSP equipment and on-board avionics systems. Both SESAR[2] and NextGen[6] provide planning for this harmonised approach, but it is the task of IATA to inform all concerned airlines about the implications in terms of investments, regulations and expected benefits. Moreover IATA is in the situation to represent the airlines' interests in negotiations about implementation plans.

The necessary steps for the implementation of biofuels need to be coordinated between airlines, aircraft manufacturers, fuel suppliers and certification authorities[8]. IATA is actively facilitating these activities, among others through a participation in CAAFI (the Commercial Aviation Alternative Fuels Initiative), which assembles all relevant stakeholders with a focus on US activities.

The network built up in the TERESA project will be used to work on joint action plans for these issues.

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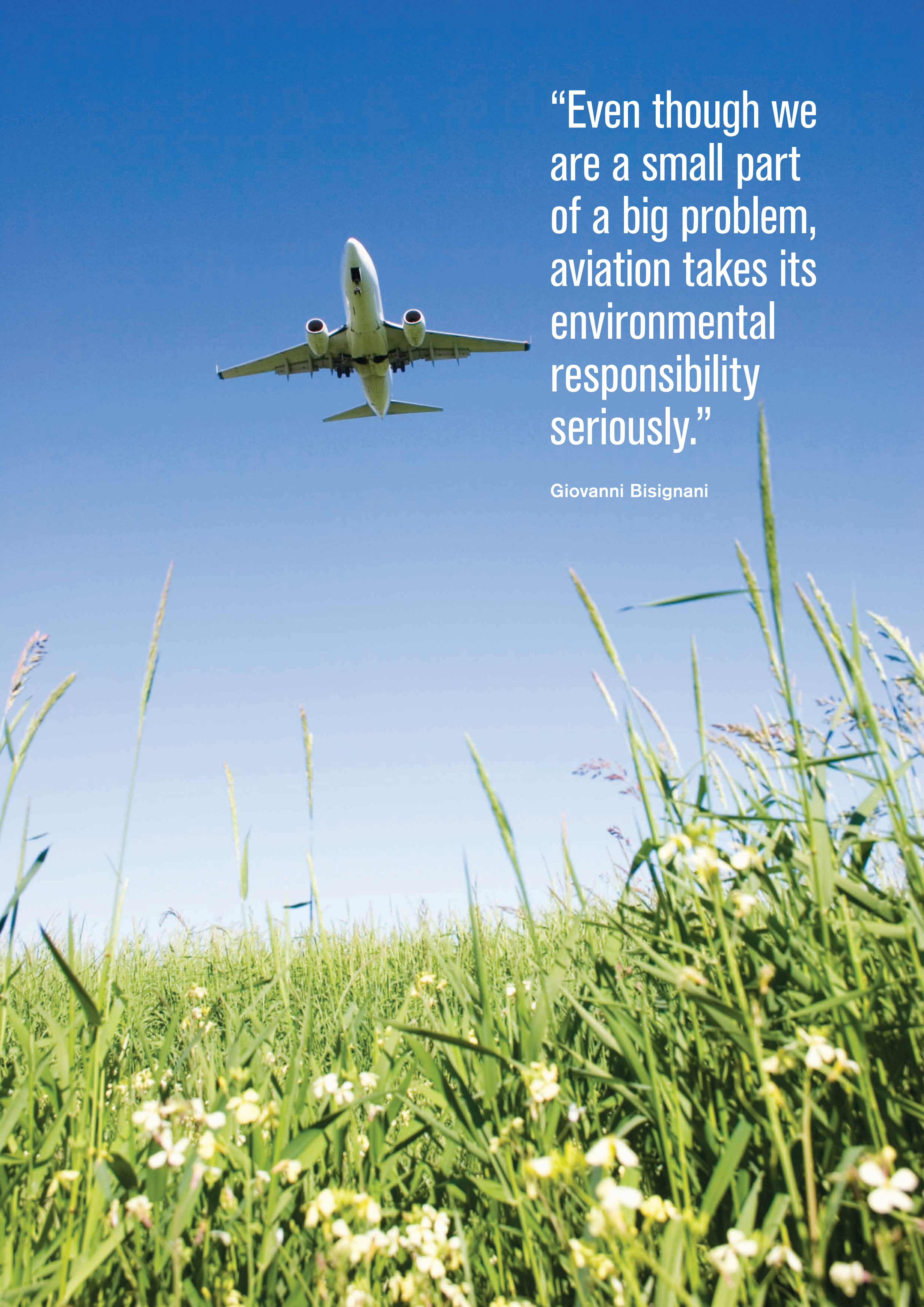

"Even though we are a small part of a big problem, aviation takes its environmental responsibility seriously."

Giovanni Bisignani

5. Conclusion

The aviation industry is critical to the success of the global economy. The industry connects the world to allow people to work together, to travel for pleasure, to become aware of regions outside their home countries and also to provide a means to rapidly carry freight from one part of the world to another. It is anticipated that aviation will continue to grow at 5% per year which means that every 14 or so years, the industry doubles.

Over the last decade, the impact of greenhouse gases on the atmosphere and the potential of global warming has become recognised as fact. Since planes burn hydrocarbon-based fuel, their emissions contribute 2% of CO_2 and 3% of the global greenhouse gases per year. The IPCC forecasts that by 2050, aviation will be contributing 3% of CO_2 emissions and 5% of overall greenhouse gases. It is imperative that those industries that emit these gases take steps not only to stabilise their net output but to make every effort to reverse the trend so that in time, their net contribution is zero.

IATA has taken leadership to drive the aviation industry to become a net zero contributor to these emissions. This goal is complementary with the requirement to reduce fuel use. The less fuel used, the fewer the green house gases emitted and the lower the costs to the airlines. IATA's Four Pillar Strategy, which is the basis for this report is an approach that the industry is committed to follow to achieve the "zero greenhouse gases" goal.

The TERESA project initiated by IATA brings together industry experts including OEMs, equipment suppliers, industry research organisations, fuel/alternative fuels experts and academic institutions. Their task is to identify technologies, procedures and alternative fuels that will reduce greenhouse gases and the dependence on oil. This study has divided up each of these areas into technologies that can be applied to the existing fleet, planes in production and the next generation of planes.

The report should motivate the industry to work together to make the current fleet more efficient and to work with OEMs to design and deliver new planes that meet stringent efficiency requirements.

Uniform and universal upgrades to the worldwide air traffic management systems are essential to achieve efficiencies. Governments must invest and cooperate in the development of improved systems. Achieving the environmental and efficiency targets that will be made possible by the future ATM environment depends on progressing with globally harmonized solutions reached through collaborative decision-making. Likewise, a commitment by Air Navigation Service Providers (ANSPs) to make the necessary investments and deliver results is necessary.

The next phase of this project will be accomplished in 2009 where costs and cost/benefit analyses will be applied to the technologies. Action must be taken now to mitigate the problems that would occur in the future if nothing is done now.


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6. Future Work

This report covers Steps 1 to 4 of the TERESA project planning (Table 2-2). The following activities, covering Steps 5 to 9 as well as some open points from the current work phase, are planned for 2009.

The interdependencies between various technologies will be described in more detail, to estimate the cumulated effect of various technologies. The report will explore how each technology benefit translates into fuel saving over a whole mission, depending on aircraft size and mission length.

All data in relevant technologies will be fed into a generic aircraft design model to obtain the cumulated fuel efficiency increase. Flights in future airspace structures will also be modelled for 2020 technology aircraft as well as for more advanced configurations.

Rough order of magnitude cost impacts, which were collated during the assessment workshop, will be combined with IATA's economic Aviation Carbon Model (ACM) to define the economic viability of carbon reduction options and business cases for new technologies. This model will be combined with the fuel burn projection model established for IATA's Environment Committee (ENCOM) to project the effect of technology on the future worldwide fleet.

To improve the long-term view, more detailed investigations will be made to assess the potential of revolutionary technologies expected after 2020 for approaching a zero-emissions future for aviation.

To facilitate further discussions with OEMs and technology developers, a document summarising the main generic requirements for future environmentally friendly aircraft from an airline operator's perspective will be created. Moreover, action plans will be developed that show how to meet all pre-requisites for timely implementation of new technologies.

Cooperation with manufacturing industry and research partners will continue. Technology and environment experts from various airlines will be closely involved, to obtain assessments from a broad variety of operators.

A report on future outcomes of the TERESA project will be issued at the end of 2009.

Glossary

The applied definitions and acronyms used throughout the report are listed below in alphabetical order.

Definitions

Active load alleviation	= synchronization of control surfaces to different aerodynamic loading conditions for bending moment alleviation
Active stability management	= enhances full-speed surge margin and part-speed operability of engine
Adaptive cycles	= engine that can adapt its operating condition during flight to the given mission, thereby optimising component and cycle behaviour
Advanced alloys	= aluminium alloys with lower density, higher strength, and similar fracture toughness
Advanced core	= further evolution of core engine, high-pressure components including compressor, combustor, and turbine
Advanced direct drive	= advanced two or three-spool turbofan design, evolution of current fan architecture
Advanced fly-by-wire	= digital flight control systems enabling flight management, navigation, guidance, flight control, system health, and maintenance indication
Blended winglet	= blending of wing and vertical winglet for further induced-drag reduction
Boundary layer ingesting inlet	= suction of boundary layer over aircraft surface to prevent flow separation
CentrAl	= laminated hybrid material sandwiching Glare-type fibre-metal-laminate between thick layers of advanced aluminium alloys
Continuous climb departure	= facilitates aircraft fuel-burn reduction by enabling it to climb at optimal lift-to-drag ratio
Continuous descent arrival	= individually designed approach for each aircraft, airport combination to minimise fuel burn on arrival
Counter-rotating fan	= multi-stage fan system in which the fan stages rotate in opposite directions
Crossing and passing	= allows an aircraft to cross or pass a target aircraft, including lateral, as well as vertical crossing and passing manoeuvres
Cruise-efficient Short Takeoff and Landing	= intended to enhance the operational feasibility and flexibility of narrow-body fleet for small regional airports
Drop-in fuel	= fuel with similar properties as crude derived jet fuel, mixable in all proportions with current jet fuel, needing no engine modifications
Distributed multi-fan	= multiple propulsive fans, embedded in airframe, sharing a common turbofan core
Energy intensity	= ratio of energy consumption to economic or physical output
Fluoropolymers	= polymer materials containing fluorine that allow the reduction of exhaust and evaporative emissions when applied to seals and hoses of a fuel system
Fly-by-light	= fibre-optic links transmit data from flight control computer to actuators
Formation flying	= flying in the upwash generated by the outer half of the wingtip vortex from the aircraft ahead which can lead to fuel savings
Friction stir welding	= solid-state welding technology that joins metals through mechanical deformation, extending weldability and yielding higher weld strength
Furans	= heteroaromatic compounds, the aromatic ring containing an oxygen atom
Geared turbofan	= ultra high engine bypass ratio is enabled by a gear-driven, low-speed fan
Glare	= fibre-metal-laminate hybrid material combining aluminium sheets with reinforcement of glass fibres
High-Strength Glass microspheres	= hollow borosilicate glass made to be between 15 and 30 microns and have a crush strength up to 207 mega Pascal

Hybrid laminar flow	= active maintenance of laminar flow over a large portion of aircraft by directly manipulating the boundary layer
Hybrid-wing-body	= intended for significantly increased fuel economy and environmental friendliness through blended wing-body aircraft configuration
Hydrogenated oil/fat	= oil/fat treated by hydrogen to purify the carbon chain from non-hydrogen and non-carbon atoms
Independent parallel or converging approaches	= approach scheme allowing closely spaced parallel runways to be used independently
Laser beam welding	= manufacturing method using extremely concentrated laser heat source for superior weld quality with smaller distortion
More electric aircraft	= aircraft system architecture replacing traditional pneumatic and hydraulic powered aircraft equipment architecture systems with electrical subsystems
Morphing airframe	= aircraft structures that can morph shapes to optimise vehicle performance to multiple, dissimilar mission segments
Morphing material	= a broad range of substances that can shorten, elongate, flex, and otherwise respond mechanically to electricity, heat, light, or magnetic fields
Multilateration	= a ground-based surveillance system that uses transmissions from a transponder
Natural laminar flow	= reducing skin friction drag by extending and maintaining laminar flow region on major lifting surfaces and engine inlets without active flow control
New engine core concepts	= evolution of core engine, high-pressure components including compressor, combustor, and turbine
Non drop-in fuel	= fuel that requires changes in existing aircraft fuel systems and supporting infrastructure
Non-Brayton cycle engine	= gas turbine whose thermodynamic cycle deviates from the conventional "Brayton cycle", can involve constant volume combustors, have higher theoretical thermal efficiencies, etc.
Open rotor/unducted fan	= engine architecture in which jet exhaust drives two counter-rotating turbines that are directly coupled to the fan blades that are placed outside the nacelle
Proton exchange membrane fuel cell	= low-temperature electrochemical energy conversion device with polymer electrolyte membrane
Pulse detonation	= constant volume combustion-based engine, compression is achieved through trapped supersonic shock waves, combustion velocities are greater than the speed of sound
Raked wingtip	= swept-back wing extension device reducing induced drag by increased aspect ratio
Regenerative/recuperative engine core	= compressor inter-cooling and recuperation of the core exhaust temperature to pre-heat combustor entrance air
Trajectory based operations	= allows a properly equipped aircraft to fly a complicated approach path very precisely by automated means
Riblets	= skin friction reduction technology for turbulent boundary layer using an array of small grooves or protrusions on aerodynamic surfaces
Sequencing and merging	= enables the merging and spacing from designated aircraft as stipulated in new controller instructions
Solid acid fuel cell	= intermediate-temperature fuel cell technology with solid acid-based membranes
Solid oxide fuel cell	= high-temperature fuel cell type with solid-state, ion-conducting ceramic membrane

Spiroid wingtip	= spiral-shaped wingtip device that looks attached to the wing's upper surface
Steep approach	= approaching the runway at a steeper glide slope than the standard 3°
Terminal area management	= control the landing time of aircraft entering the terminal area by using a scheduler and a profile descent advisor
Transesterification fuels	= fuel produced by reacting a triglyceride with an alcohol to form esters
Truss-braced wing	= struts or trusses are placed under the wing to significantly increase its aspect ratio with minimal increase in structural weight
Ubiquitous composites	= second generation of engine composite structures, higher percentage of total engine structural components, includes engine case and blade structure
Variable area fan nozzle	= capable of tuning fan pressure ratios based on propulsive needs
Variable camber with new/ existing control surfaces	= synchronisation of a seamless, continuous variation of section airfoil shape to each flight segment for maximum aerodynamic efficiency of lifting surfaces
Variable cycle	= engine that operates two or more thermodynamic cycles depending on flight regime
Variable geometry chevron	= suppressing both turbulent jet-mixing noise at take-off and shock-cell noise at cruise by attaching heat-activated morphing chevron at nacelle trailing edge
Variable glide slope	= allows an aircraft to avoid the wake vortices caused by preceding aircraft
Weather data acquisition and distribution	= weather data processing for optimised hazard avoidance through a combination of datalink technologies and trajectory management applications
Wingtip fence	= winglet variant with surfaces extending both upward and downward from the wingtip
Wireless flight control system	= electric wires for primary links between flight computer and control surface actuators are replaced with wireless communication techniques
Wireless optical connections for in-flight entertainment	= reduces the cost of maintaining in-flight entertainment systems without imparting any interference to on-board electronics
Zonal dryer	= device removing the humidity out of the cabin air to avoid condensation and thus weight-adding, in the insulation blankets

Acronyms

ACARE	= Advisory Council on Aeronautics Research in Europe
ACI	= Airports Council International
ACM	= Aviation Carbon Model
ADS-B	= Automatic Dependent Surveillance Broadcast
ADS-C	= Automatic Dependent Surveillance Contract
ANSP	= Air Navigation Service Provider
APU	= Auxiliary Power Unit
ASDL	= Aerospace Systems Design Laboratory
ASMGCS	= Advanced Surface Management Guidance and Control System
ATAG	= Air Transport Action Group
ATC	= Air Traffic Control
ATM	= Air Traffic Management
BLI	= Boundary Layer Ingesting
BTF	= Biomass to Fuel
CAAFI	= Commercial Aviation Alternative Fuels Initiative
CAEP	= Committee on Aviation Environmental Protection
CANSO	= Civil Air Navigation Services Organisation
C&P	= Crossing and Passing
CCD	= Continuous Climb Departure
CDA	= Continuous Descent Arrival
CDM	= Collaborative Decision Making
CDTI	= Cockpit Display of Traffic Information
CNS	= Communications, Navigation, and Surveillance
CO_2	= Carbon Dioxide
DME	= Distance Measuring Equipment
ENCOM	= Environment Committee
FMS	= Flight Management System
GBAS	= Ground-Based Augmentation System
GE	= General Electric
GIACC	= Group on International Aviation and Climate Change
GLS	= GNSS Landing System
GNSS	= Global Navigation Satellite System
GTF	= Gas to Fuel
GTL	= Gas to Liquid
HF	= High Frequency
ICAO	= International Civil Aviation Organisation
ICCAIA	= International Coordinating Council of Aerospace Industries Associations
IFF	= Identification Friend or Foe
ILS	= Instrument Landing System
IPCC	= Intergovernmental Panel on Climate Change
IRS	= Inertial Reference System
IRU	= Inertial Reference Unit
JPDO	= Joint Planning and Development Office
JTI	= Joint Technology Initiative
LED	= Lights-Emitting Diode
LORAN	= Long Range Aid to Navigation
LTO	= Landing and Takeoff cycle
MEA	= More Electric Aircraft
MLAT	= Multilateration
NAS	= National Air Space
NASA	= National Aeronautics and Space Administration
NO_x	= Nitrogen Oxides
NSR	= New Short Range
OEM	= Original Equipment Manufacturer
PBN	= Performance Based Navigation
PEMFC	= Proton Exchange Membrane Fuel Cell
R&D	= Research and Development
R&T	= Research and Technology
RNAV	= Area Navigation
RNP	= Required Navigation Performance
RTA	= Required Time of Arrival
RVSM	= Reduced Vertical Separation Minima
S&M	= Sequencing & Merging
SAFC	= Solid Acid Fuel Cell
SESAR	= Single European Sky Air Traffic Management Research
SFC	= Specific Fuel Consumption
SOFC	= Solid Oxide Fuel Cell
STOL	= Short Takeoff and Landing
SRA	= Strategic Research Agenda
SWIM	=System Wide Information Management
TAM	= Terminal Area Management
TCAS	= Traffic Collision Avoidance System
TERESA	= TEchnology Roadmap for Environmentally Sustainable Aviation
TMA	= Terminal Manoeuvring Area
TRL	= Technology Readiness Level
UNFCCC	= United Nations Framework Convention on Climate Change
VDL	= VHF Data Link
VHF	= Very High Frequency
WFCS	= Wireless Flight Control System

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