Arthur D Little

Study into the Potential Impact of Changes in Technology on the Development of Air Transport in the UK

Final Report to
Department of the Environment, Transport and Regions (DETR)

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Notice

This report was commissioned by the Department of the Environment, Transport and the Regions on terms specifically limiting Arthur D. Little's liability. Our conclusions are the results of the exercise of our best professional judgement, based in part upon materials and information provided to us by the Department of the Environment, Transport and the Regions and others. Use of this report by any third party for whatever purpose should not, and does not, absolve such third party from using due diligence in verifying the report's contents.

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It should be emphasised that this report was commissioned to provide an independent review of the technologies that might be available in the next 30 years. This report is in no way to be regarded as Government acceptance or endorsement of the principal conclusions and findings although it is Arthur D. Little's understanding that it will be used to help inform discussion on the development of Government policy.

Contents

Executive Summary

Arthur D Little has conducted a study into the potential impact of changes in technology on the development of air transport in the UK on behalf of the Department of the Environment, Transport and Regions (the Department).

The context for this study is twofold: the industry is facing significant technical and practical capacity constraints and due to its long-term nature has been slow to address these; and environmental issues are exerting strong pressures on the industry and its ability to grow. Against this backdrop, the UK Government will have to make sensitive decisions regarding its UK airport policy and these choices need to be based on sound judgements.

The aim of this study is to investigate how new technology can enhance airport capacity, and mitigate environmental impacts associated with the demand, development and operation of air services to, from, and within the UK. The work forms part of a programme of preparatory studies which the Department is commissioning to support development of a new airports policy statement announced in the Government's Transport White Paper "*A New Deal for Transport*" in July 1998.

The scope of the study is technologies predicted to enter service before 2030 with emphasis on developments in the 5 to 10 year time period and potential to substantially enhance capacity and mitigate environmental impact at UK airports. Technologies for capacity improvements at the runway, in and around the airport and in *en route* airspace have been addressed along with technologies for global and local environmental mitigation. Within the scope, broad commercial realities have been addressed and a greater understanding provided of the implications for prospective Government policy of future technology take-up.

Our analysis has involved a thorough desktop review, and interviews and workshop exercises with key industry stakeholders. There were a total of two workshops facilitated by Arthur D. Little during the course of this study. The first workshop addressed key technology developments until 2030 and the second addressed the key capacity and environmental issues facing the industry and the implications these have for prospective Government policy. The output from the analysis has been used to screen key future technologies for capacity enhancement and environmental mitigation, interpret their potential to address the key capacity and environmental constraints, identify barriers to take up and appropriate mechanisms to accelerate and finally an assessment of the effectiveness of these mechanisms based on our interpretation of the literature and feedback from the stakeholder consultation.

The results of this process show that in the short-term incremental improvements in capacity at UK airports are expected, with new technologies being important but not key to these improvements. In the medium- to long-term technological advances will be fundamental to introducing substantial capacity improvements, especially wake vortex technologies, sophisticated management systems and datalink technologies. The main capacity constraints are the runway and *en route* airspace, the rest of the ATC infrastructure is over-constrained and this leads to inefficiencies.

Technology developments until 2030 are predicted to continue to materially improve the normative[1] global (CO_2 and NO_x emissions) and local (air quality and noise) impacts of aviation. Development of new technologies for improved aerodynamics, materials, engine efficiencies, and combustors can reduce global emissions, NO_x and noise. Furthermore future development in CNS/ATM and operational procedures such as CDA additionally offer global and local mitigation. Our analysis concludes that future technologies offer fuel efficiency improvements of 2%/annum until 2030, whilst NO_x reduction technology is forecast to deliver 80% reduction from today's LTO emissions by 2030. However, taken together these new technologies cannot offset the additional environmental impact associated with forecast growth in air traffic and therefore the net or overall environmental impact from aviation is predicted to increase from today's levels.

Our analysis of issues that determine technology take up concludes that the take-up of future technologies to enhance capacity can be accelerated through the setting of international standards, European level agreements, and by ensuring that the positive cost benefits of efficiency projects are explicit and transparent to the key stakeholders. This is particularly important given the current emphasis by NATS on increased airport capacity as opposed to efficiency improvements, which are likely to benefit airlines much more, through reduced costs, than they will benefit NATS. The take-up of technologies that address global emissions is essentially driven by financial incentives that ensure operators aim to cut their fuel costs. Our analysis and feedback has indicated that a combined market based approach encompassing emission trading, environmental charges and voluntary agreements of incentives offers an economically and environmentally efficient way to accelerate fuel efficiency driven technologies. Take up of technologies that aim to mitigate local impacts (e.g. noise and air quality) can be driven through ambitious standards for NO_x and noise, together with incentives that reward adoption of best practice. There are a number of implications for prospective Government policy if the take-up of future technologies for capacity enhancement and environmental mitigation is to be encouraged. Capacity and efficiency of airports and airspace can be improved through Government introducing mechanisms promoting benchmarking of ATC providers to raise the standard of all to that of the "best in class"; investment in long-term as well as short-term ATC solutions; and, the take-up of technologies with both a capacity benefit and environmental benefit.

Global and local environmental effects of the aviation industry can be mitigated through Government working with international bodies to agree medium and long-term Kyoto objectives for the sector and contributing to developing market based approaches to encourage fuel efficiency, pressing for tighter international standards on aircraft noise and engine emissions, and introducing noise and emission based charges at UK airports as appropriate. These mechanisms are largely consistent with Government's current programmes, but can be focused further to accelerate technology take-up. However, it remains for Government to consider the merits of these mechanisms within the broader context of Government policy.

To conclude, it must be noted that even with deployment of the most promising future technologies, if demand is unconstrained by capacity then, in absolute terms, the net effect of the aviation industry on the environment is set to increase. The implications are that one must

[1] For example, CO_2 emissions per passenger kilometer is a normative measure of the global impact of aviation.

either manage growth to what technology can deliver or accept that aviation is a high added value component of the UK's transport system.

1 Introduction

This section provides an overview of the context for this study, its objectives and scope, the approach adopted by Arthur D. Little to achieve these objectives and the overall structure of this report.

1.1 Context for this Study

1. Demand for capacity in the aviation sector is outstripping availability: Reports and statements within the industry (e.g. from IATA *(IATA,1999)* and Eurocontrol/CODA *(CODA, 1999)*) show increases of over 100% in the number of aircraft experiencing delays and increases of over 200% in the extent of the delay experienced this year compared with last, delays being an indicator of a lack of capacity. Although the industry has been well aware of forecast traffic growth, typically 5% a year across Europe until 2020[2], as the statistics show capacity has not kept up with demand.

   This situation can be traced back to two underlying and interdependent factors:

(A) The industry is facing significant technical and practical capacity constraints and has been slow in addressing these

2. At an infrastructure level the industry is facing major capacity constraints. These include the lack of runway capacity, shortage of routes, excessive workloads for air traffic controllers, lack of harmony in airspace structure, limitations on terminal manoeuvring and gate allocation, restrictive practices for slot allocation and lack of integrated baggage handling and throughput of passengers.

3. Moreover, the industry is under pressure to change from highly influential stakeholders. Institutions, such as Eurocontrol, are being pressured to resolve the ambiguity of their dual role – regulatory and as an operator, airlines are becoming global operators, ATC service providers are becoming liberalised, airports are looking to operate in a more competitive environment and politicians are being lobbied to take decisive action.

(B) Environmental issues are also exerting strong pressures on the industry and its ability to grow

4. The environmental impact of the industry is becoming increasingly more important as the industry grows. Historically, the most important issues have related to the environmental impacts of airport operations: noise from take-offs and landings; local air quality impacts; vortex damage to buildings and allegations of fuel dumping; congestion of the local road network; and large land-take, including car parking. More recently the industry is having to face up to a set of global issues, most notably its contribution to global climate change, through high altitude emissions and formation of contrails. As a result, establishing new capacity through airport expansions, new airports, and route expansions is being opposed by a diverse set of affected stakeholders.

[2] See Section 2.2 for details.

5. Underlying these factors, the aviation industry, with its complex pattern of commercial competition between providers and users of technology, is subject to national and international regulatory structures. Several high profile and internationally respected UK companies and organisations, with important contributions to the UK economy, have different views on the impact and take up of technology. Thus there are likely to be conflicting opinions on the priorities and timing of the application of technologies for environmental mitigation, both in the UK and internationally.

Objectives and Scope for the Study

1. Against a backdrop of air traffic growth, growing environmental concerns and capacity constraints, the UK Government will have to make politically and industrially sensitive choices in its UK air transport policy, both regionally and in the vital London Terminal Area, with its five airports and overcrowded airspace. These choices need to be based on sound judgements about the scale and timing of the impact of aviation technology on airport capacity and the environment.

2. For these reasons, the Department wants to obtain an authoritative view of where international and UK stakeholders stand on these issues and is asking for assistance in developing a coherent view on the potential of future technologies (out to 2030) to address the capacity and environmental challenges associated with continued growth of the sector.

3. The objectives of this study are therefore to investigate the likely impact of new technology on the demand, development and operation of air services to, from and within the UK, and consequently to advise and raise the Department's understanding of the contribution these technologies can make to:

   - enhancing airport capacity; and
   - mitigating environmental impact

   and hence the implications for prospective Government policy.

Scope of the Study

Within the context of the above mentioned objectives, the following boundaries have been applied to this study:

- Technologies predicted to enter service before 2030 only have been considered. These have been termed "Future Technologies" and classified into short (≤2005), medium (2006-2015) and long-term (2016-2030) time horizons. Annex A provides details on the capacity enhancing technologies considered and Annex B on the environmental mitigation technologies;

- Emphasis is on technology developments in the 5 to 10 year time period and technologies that are either in the process of being deployed or already deployed are not considered;

- The definitions used to describe the "benefits" for future capacity enhancement and environmental mitigation technologies are limited to those that address the most significant capacity and environmental constraints facing the industry. Annex C provides details on the methodology used to define the benefit criteria and the criteria used;

- Future technologies to enhance aircraft capacity at the runway, around the airport and in *en route* airspace, to enhance passenger throughput within airport terminals, and to increase aircraft passenger kilometres have been included;

– Future technologies for global (CO_2 and NO_x) and local (NO_x, noise and land take) environmental mitigation have been included. The impacts of technologies on contrail and cirrus cloud formation is not explicitly evaluated, although the analysis recognises the significant global warming potential of these effects;

– Review and analysis of alternative service providers (e.g. high speed rail) is contextual rather than integral to the study;

– Technology developments are not distinguished between freight or passenger aircraft because they apply equally to each market sector, though where take-up issues differ these have been highlighted;

– The *en route* phase of flight is considered in terms of "gate-to-gate" capacity implications (i.e. from when an aircraft leaves the gate of its departure airport to when it arrives at the gate of its destination airport);

– The implications of commercial realities on technology take up are considered in a broad rather than detailed context, determining the:
  – profile of capacity and environmental impacts with time; and
  – commercial limitations of the technologies, rather than detailed financial appraisal;

– This study will not be defining policy but instead it will provide greater understanding of the implications for prospective Government policy of future new technologies and their take-up; and

– Safety issues have not been addressed directly by this study, it is taken as a given that safety is a top priority for the industry.

Annex D gives more detailed terms of reference for the study.

1.3 Study Approach and Report Structure

The study approach is based upon a five step process illustrated in Figure 1-1 below.

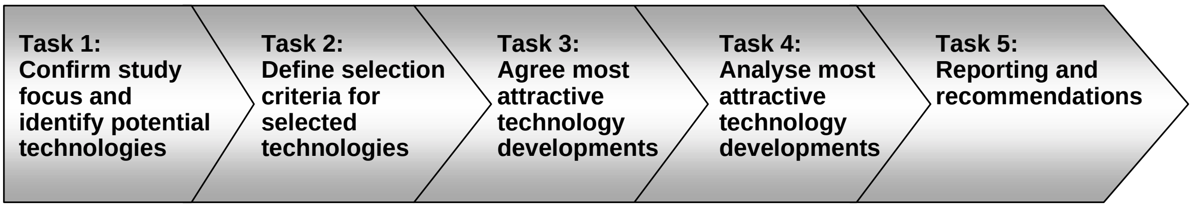

Figure 1-1: Study Approach

For each task the critical objectives, tools and outputs were:

No	Task	Objectives	Tools	Outputs
1	Confirm study focus and identify potential technologies	Ensure a common understanding on scope and focus, produce a list of capacity enhancing and environmental mitigation technologies, and raise study awareness within air transport industry	Kick-off meeting, selected interviews and literature review	Comprehensive list of future technologies for enhancing capacity and mitigating environmental impact
2	Define selection criteria	Set selection criteria to screen technologies to those most significant in terms of study objectives	Selected interviews and visits to key stakeholders and literature review	Defined set of initial and final selection criteria
3	Agree most attractive technology developments	Identify and agree most significant technology developments and elicit wider opinion on critical issues for technology development	Two single day workshops, covering technical issues and future growth scenarios with key stakeholders	Define capacity and environmental mitigation potential of future technologies and identify specific and general take up issues and broader influences
4	Analyse most attractive technology developments	Qualify potential of future capacity enhancing and environmental mitigation technologies to meet future growth and determine take-up issues	Analysis and synthesis of data and information gathered through workshops, visits, interviews and literature review	Performance summary of future technologies for capacity enhancing and environmental mitigation and take-up
5	Reporting and recommendations	Structured and focused report presented in narrative style	Data and information synthesis	Final report and supporting seminar

Annex E provides more details on the workshops in Task 3 and lists participants contributing to the study. It also lists those individuals interviewed during the course of the study.

Report Structure

The key elements underlying the study's objectives have been addressed in separate sections, as follows:

Section 2: Review and summary of the types and scale of capacity and environmental challenges facing the industry;

Sections 3 and 4: Analysis, synthesis and conclusions on the potential of future technologies to provide capacity and environmental benefit respectively;

Sections 5: Analysis, synthesis and conclusions on general and more specific capacity and environmental technology take-up issues, mechanisms to accelerate take-up and interpretation of mechanism effectiveness;

Section 6: Implications for prospective Government policy on development of air transport in the UK through:

- i) the potential of future capacity enhancing and environment mitigation technologies to address the key capacity and environmental constraints;
- ii) take-up issues relating to future technologies; and
- iii) broader non-technological implications for the industry associated with its continued growth;

Section 7: Overview of most promising technologies:

- i) provide the most capacity and environmental benefit;
- ii) have long deployment time horizons or difficult take-up issues; and
- iii) potentially most influenced by future prospective Government policy.

1. Sections 3 to 5 draw extensively on the results of the Technology Workshop (Task 3) and Section 6 on the results of the Scenarios Workshop (also Task 3), supplemented by interviews, literature searches and analysis of the results. The views and opinions of the major stakeholders in the aviation industry were elicited during the course of the study. No judgements have been made as to whether these views are right or wrong, this study has interpreted the importance of different opinions in the context of mechanisms to accelerate the take-up of future technologies, effectiveness of these mechanisms and implications for prospective Government policy.

2. Each section is provided with an overview giving key findings, and each sub-section comprises an introduction giving relevant background information, findings and recommendations based on analysis of results, and, where appropriate, dialogue boxes giving more detailed information about specific areas that help provide more context for the section.

In addition to the main body of the report the annexes provide further supporting material, as follows:

Annex	Contents
A	Description of the capacity enhancing technologies considered by the study until 2030
B	Description of the environmental mitigation technologies considered by the study until 2030
C	Definition of capacity enhancing and environmental mitigation potential ("benefit criteria") of future technologies
D	Summary of study terms of reference, scope of work and working methods
E	Description of workshops and summary of study participants
F	List of references
G	Glossary of abbreviations
H	Glossary of figures

1.4 Peer Review

This report updates an earlier draft and incorporates changes to reflect comments provided by a peer review panel including personnel representing the following organisations:

Peer Review Organisations
DETR – Air and Environment Quality Division
DETR – Aviation Environmental Division
Massachusetts Institute of Technology
Aviation Environment Federation
BAe Systems
Manchester Metropolitan University
Strategic Aviation Special Interest Group
Manchester Airport Plc
Pratt and Whitney
BAA

2 Background to the Aviation Industry

This section provides general background to the aviation industry in terms of present and future traffic and aircraft growth. It also provides more detailed background on the environmental and capacity issues facing the industry together with specific growth figures that are used to illustrate significant and pressing challenges. It therefore provides the necessary backdrop for the rest of this report, putting the findings and recommendations into context.

2.1 Overview

World annual traffic, measured as revenue passenger kilometres is forecast by the industry to grow at 5% per annum (6% per annum for cargo) over the next 20 years. Similarly, passenger numbers at UK airports are projected to grow at 4.25% per annum until 2020. This rate of increase outstrips average European predictions for GDP growth.

To sustain this growth the size of the world-wide aircraft fleet and the number of flights is projected to approximately double in the next 18 years. The impacts of this growth are that:

- **Aviation's contribution is projected to grow from 3.5% up to between 4% and 15% of all anthropogenic generated radiative forcing (a direct measure of its contribution to global warming) by 2050;**
- **Noise and air quality impacts at UK airports are projected to increasingly grow in importance in the future; and**
- **Congestion and delays are forecast to continue to increase at around 4% per annum for domestic flights and 8% for international flights.**

Consequently, environmental and capacity concerns are forecast to become increasingly more important to the industries' stakeholders.

2.2 General Background

World-wide growth in revenue passenger kilometres is forecast to grow at 5% per annum and double within the next 16 years

1. World annual traffic, measured as revenue passenger-kilometres (RPKs), is forecast to grow at 5% per annum (annual cargo is estimated to grow at 6%/annum) over the next 20 years based on both Boeing and Airbus estimates (see Figure 2-1 below). This forecast growth correlates well with the Department's forecasts for passenger numbers at UK airports which are expected to grow at an average of 4.25% per annum between 1998 and 2020 (the Department, 2000). Both of these figures are important, the first is an indicator of the future growth of aviation's global emissions (e.g. CO_2 that is linked directly to fuel consumption and passenger km), and the second is a good indicator of future impacts at a local level at UK airports.

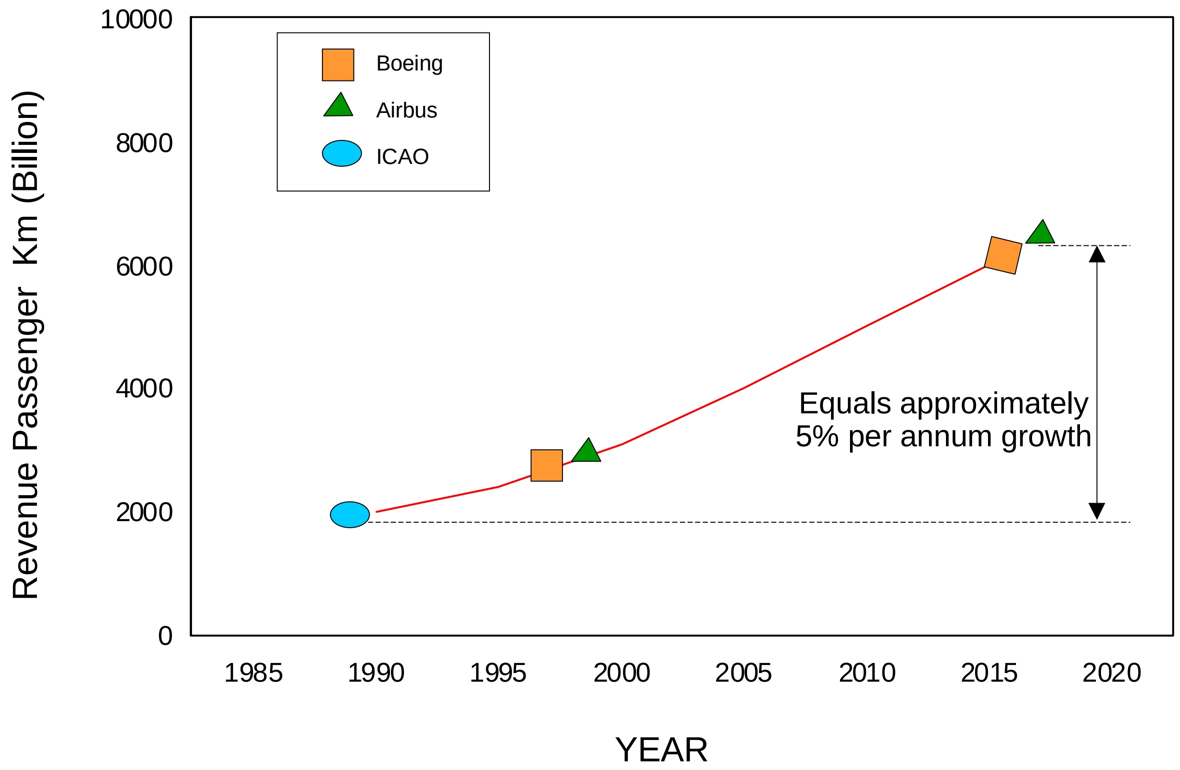

Figure 2-1: Forecast of passenger demand in Aviation *(Deutsches Zentrum fur Luft und Raumfahrt)*

2. This level of growth translates into a doubling of air traffic within 16 years. This development is, despite macroeconomic cycles, expected to continue due to underlying structural reasons including:

   – Continued trade and air liberalisation;

   – Continued growth in the tourist industry;

– High income elasticity of demand, (people place greater preference on leisure time as opposed to additional income, as income increases, therefore increasing demand for leisure activities such as travel);

– Growth in the level of high value goods requiring transport (thereby explaining the higher level of growth of cargo – 6%- versus passenger traffic – 5%); and

– Forecast increase in e-commerce related transport of goods.

The size of the world-wide passenger fleet is predicted to double to approximately 20,000 aircraft by 2018 with a corresponding increase in the total number of passenger flights by 95%

3. The active passenger fleet is predicted to nearly double, growing to nearly 20,000 aircraft by 2018 (see Figure 2-2). To deal with this increase, Airbus estimate that the world's airports and air traffic management systems will have to accommodate an estimated 95% increase in numbers of passenger flights *(Airbus, 1999a).* Clearly this calls for additional capacity both in terms of aircraft and in terms of airport infrastructure.

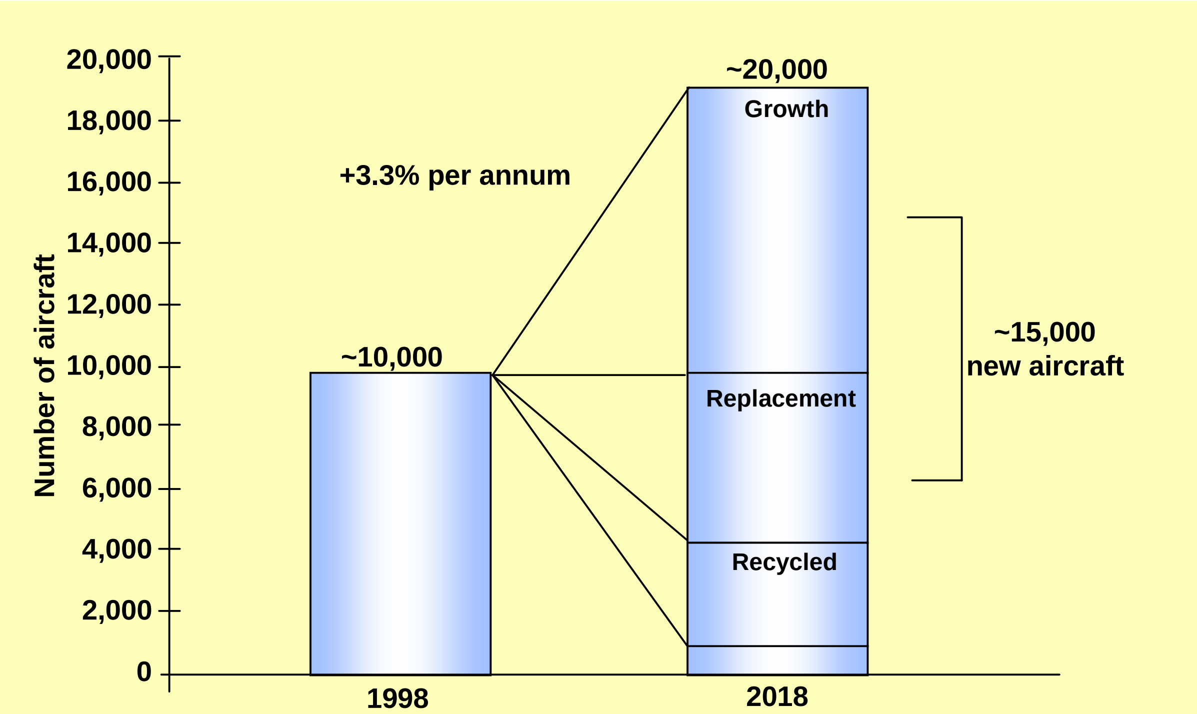

Figure 2-2: Fleet projection to 2018 *(Airbus Industries, 1999a)*

2.3 Review of Current Trends and their Impact

Hub operations at major airports have been a dominant feature of the European airline industry since deregulation and airlines continue to extend their hub operations

1. Since the European airline industry was fully deregulated, airlines have been extending their networks to new destinations and adding frequencies in order to serve more customers and more of the customers' true origin and destination (O&D) requirements (this is one of the major reasons why airlines are forming alliances). Airlines fly non-stop as often as feasible when demand is large enough to justify direct service. Airlines use connecting hubs to serve those customers travelling from one city to another where demand is too low to justify non-stop service.

2. By consolidating passengers from many low-demand markets, a hub provides air service that otherwise would not be available to many travellers. Moreover, a well designed hub enables an airline to take advantage of its market presence and increase profits without expanding the size of its fleet. For example, by providing connections between 20 origin and 15 destination cities through a single hub, an airline can serve as many as 335 different markets. Indeed, because so many markets are small, connecting hubs have become one of the most hotly contested battlefields in the industry. Airlines (and alliances) now compete aggressively to attract passengers through their hubs using attractive core products, fast connections, low prices and other incentives such as frequent flyer programmes.

3. Airlines with large hubs operate a system of "waves" or "banks" whereby flights from origin cities arrive at the hub, passengers change planes, and flights to destination cities depart within a window of 2 to 3 hours. KLM's services at Schiphol are heavily concentrated into several discrete waves, whereas at Heathrow there is an even spread of arrivals and departures across the day. Hub operations place enormous pressure on the finite resource of airport and airspace slots at peak times of the day. For a typical day KLM can achieve more than 6000 flight connections in two hours, only half that number are available to BA at Heathrow. Air France's hub at Roissy-Charles de Gaulle (CDG) airport in Paris operated 6 waves during the summer of 1997, with 40 to 50 arrivals and departures in the largest waves (see figure 2-3 below).

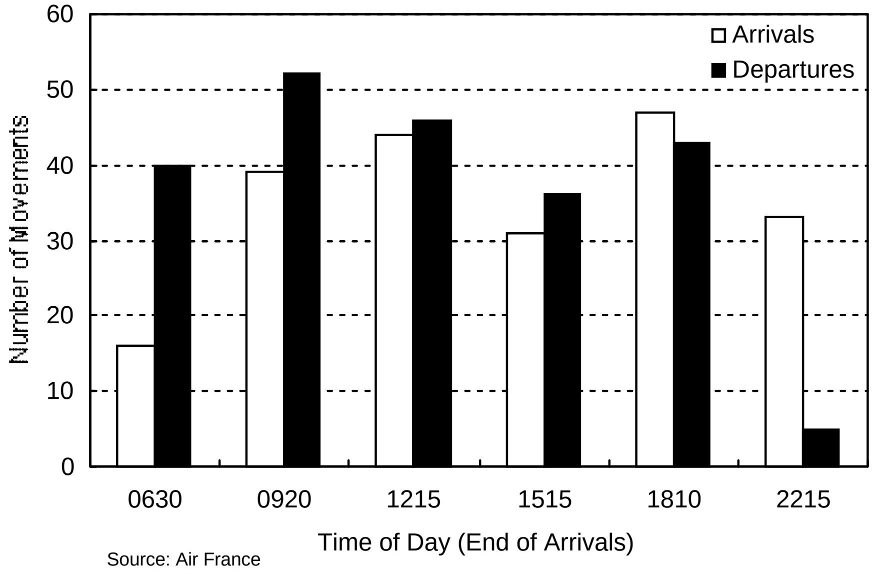

Figure 2-3: Air France CDG Hub Waves – Summer 1997

4. This is a very complex operation that requires substantial airport capacity and highly reliable performance of the entire airport infrastructure to ensure that flights operate as scheduled. It also requires advanced processes and tools to schedule aircraft, and very proficient ground operations to turnaround aircraft and to move passengers and cargo between flights within the wave window. A delay of just one arriving flight can impact all the departures in a wave and disrupt the integrity of subsequent waves as well.

Passenger and freight traffic is increasing at a rate higher than average GDP and increasingly bringing to the fore aviation's environmental impact on both a global and local level

5. The air transport industry, as well as related industries such as the aeronautical industry and tourism, are growing at rates clearly above the average growth rate of the UK and world GDP. At the same time, the air transport industry and the UK and world-wide population are increasingly facing the problems of this expansion at a global and local level:

6. **Globally**: Aviation emissions contribute to the greenhouse effect (see Box 2-1) and to the depletion of the ozone layer, where high altitude emission might be a specific problem. At a more regional level aviation contributes to acidification, eutrophication and to the formation of tropospheric ozone by emissions of air pollutants.

7. **Locally**: In the immediate vicinity of airports concerns focus on the potential health and environmental effects of noise and air pollution from emissions such as oxides of Nitrogen (NO_x), volatile organic compounds and particulates. Habitat loss arising from airport developments in green belt areas is also increasingly becoming a potential constraint on growth.

Box 2-1: Climate Change and the Framework Connection Source: IPCC 1996a

Human activities release greenhouse gases into the atmosphere. The atmospheric concentrations of carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and the tropospheric ozone have all increased over the past century. These rising levels of greenhouse gases are expected to cause climate change. By absorbing infrared radiation, these gases change the natural flow of energy through the climate system. The climate must somehow adjust to this "thickening blanket" of greenhouse gases to maintain the balance between energy arriving from the sun and energy escaping back into space. This relatively simple picture is complicated by increased amounts of sulphate aerosol from human activities that modulate incoming solar radiation and tend to cause a cooling effect on climate, at least on regional and hemispheric scales.

Global mean surface air temperatures have increased by 0.3-0.6°C since the late 19th century, and recent years have been among the warmest on record. Any human-induced effect on climate, however, is superimposed on natural climate variability resulting from climate fluctuations (e.g., El Niño) and external causes such as solar variability and volcanic eruptions. More sophisticated approaches are now being applied to the detection and attribution of the causes of change in climate by looking, for example, for spatial patterns expected from climate-forcing change by greenhouse gases and aerosols. To date, the balance of the evidence suggests that there is a discernible human influence on the global climate.

Model projections of future climate, based on the present understanding of climate processes and using emission scenarios (IS92[3]) based on a range of economic and technological assumptions, estimate a rise in global mean temperature of 1-3.5°C (best estimate 2°C) between 1990 and 2100. In all cases, the average rate of warming would probably be greater than any in the past 10,000 years, though actual annual-to-decadal changes would include considerable natural variability. A general warming is expected to lead to an increase in the occurrence of extremely hot days and a decrease in the occurrence of extremely cold days. Regional temperature changes could differ substantially from the global mean value, and there are many uncertainties about the scale and impacts of climate change, particularly at the regional level. The mean sea level is expected to rise 15-95 cm (best estimate 50 cm) by 2100, with some flooding of low-lying areas. Forests, deserts, rangelands, and other unmanaged ecosystems would face new climatic stresses, partly as a result of changes in the hydrological cycle; many could decline or fragment, with some individual species of flora or fauna becoming extinct. Because of the delaying effect of the oceans, surface temperatures do not respond immediately to greenhouse gas emissions, so climate change would continue for many decades even if atmospheric concentrations were stabilised.

Achieving stabilised atmospheric concentrations of greenhouse gases would demand a major effort. For CO_2 alone, freezing global emissions at their current rates would result in a doubling of its atmospheric concentrations from pre-industrial levels soon after 2100. Eventually, emissions would have to decrease well below current levels for concentrations to stabilise at doubled CO_2 levels, and they would have to continue to fall thereafter to maintain a constant CO_2 concentration. The radiative forcing of greenhouse gas levels (including methane, nitrous oxide, and others, but not aerosols) could equal that caused by a doubling of pre-industrial CO_2 concentrations by 2030 and a trebling or more by 2100.

The international community is tackling this challenge through the United Nations Framework Convention on Climate Change (UNFCCC). Adopted in 1992, the Convention seeks to stabilise atmospheric concentrations of greenhouse gases at safe levels. More than 170 countries have become Parties to the Convention. Developed countries have agreed to take voluntary measures aimed at returning their emissions to 1990 levels by the year 2000, with further legally binding emissions cuts after the year 2000 proposed at Kyoto in late 1997. Developed countries have also agreed to promote financial and technological transfers to developing countries to help them address climate change.

[3] See IPCC, 1999 for definition of this scenario.

Emissions from aviation contribute to changes in local air quality, in climate and for supersonic flight in stratospheric ozone loss

8. The environmental impacts of air transport arise from emissions of gases and particulate from aircraft engines resulting in changes in local air quality, in climate and for supersonic flight in stratospheric ozone loss, thus affecting the UV-B radiation at the surface. These emissions take the following form:

– carbon dioxide (CO_2);
– water vapour (H_2O);
– nitrogen oxides (NO_x);
– particulate (mainly soots);
– sulphur oxides;
– carbon monoxide;
– various hydrocarbons (HC); and
– radicals such as OH.

9. These emissions and their role in major local, regional and global effects are summarised in Figure 2-4. Reference to Figure 2-4 shows three regions of impact. The major effect in the stratosphere (18km and above) is stratospheric ozone loss due to NO_x and water vapour emissions from supersonic aircraft, resulting in higher UV-B radiation at the earth's surface.

10. In the troposphere, emissions of radiative forcing[5] substances (e.g. CO_2 and H_2O); emissions of chemical species that produce or destroy radiative forcing substances (such as NO_x, which modifies ozone concentrations, or SO_2, which oxidises the sulphate aerosols); and emissions of substances (e.g. H_2O, soot) that trigger the generation of contrails[6] and cirrus clouds are the principle elements that can effect climate change by affecting the earth's radiative balance. Similarly cloud formation in the troposphere reduces UV-B penetration.

11. At ground level NO_x and VOC emissions produce ozone and lead to formation of photochemical smog which is harmful to human health as are CO and particulate emissions.

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[4]The climate impacts of different anthopogenic emissions can be compared using the concept of radiative forcing. Aircraft contribute to global change approximately in proportion to their contribution to radiative forcing.

[5]The climate impacts of different anthopogenic emissions can be compared using the concept of radiative forcing. Aircraft contribute to global change approximately in proportion to their contribution to radiative forcing.

[6] Contrails or condensation trails are formed though aircraft emission of water vapour crystallising as ice. Although contrails reflect a little sunlight away from earth, they reflect back to earth much more invisible infra-red radiation which would otherwise escape to space – and therefore they have an overall positive radiative forcing effect.

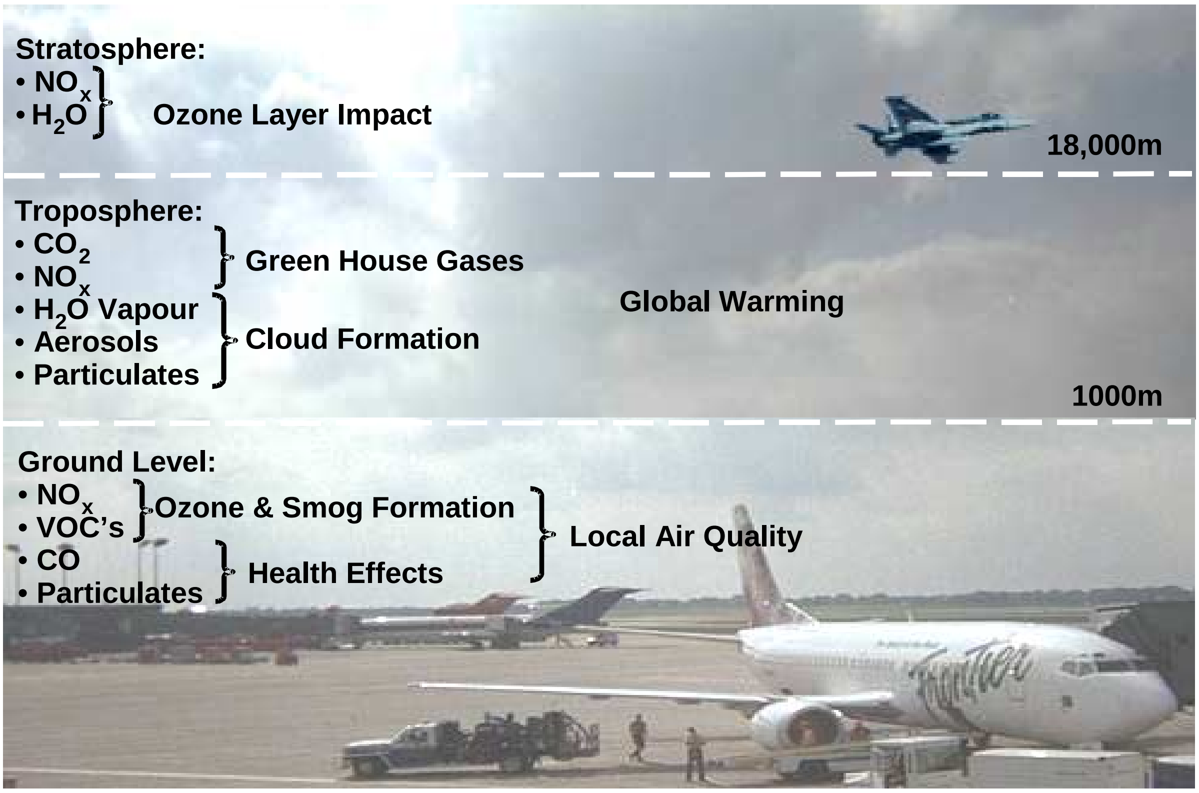

Figure 2-4: Environmental Impact of Aircraft Emissions

Anticipated growth of the sector indicates that aviation's contribution is projected to grow from 3.5% to between 4% and 15% of all anthropogenic generated radiative forcing by 2050 even after accounting for potential energy efficiency benefits from future aviation technologies

12. The present fleet of subsonic aircraft consumes roughly 130 to 160 Tg (millions of tonnes) of aviation fuel per year. This equates to roughly 2-3% of the total fossil fuels used world-wide, of this total more than 80% is used by civil aviation.

13. By comparison, the whole transportation sector currently accounts for 20-25% of all fossil fuel consumption. Thus, the aviation sector consumes 13% of the fossil fuel used in transportation, and is the second ranked sector after road transportation, which consumes 80% (IPCC, 1996b).

14. The impact of aviation's emissions is estimated by the IPCC[7] (1999) in the present (base year 1992) and for future possible scenarios (in 2050). In summary these assessments conclude that:

   – Present emission inventories from aviation are small but significant when compared to anthropogenic sources. In 1992 these were projected to account for 3.5% of the total radiative forcing of all anthropogenic activities; and

[7] IPCC projections include the predicted effects of contrails on radiative forcing

– The contribution to radiative forcing due to aviation is projected to increase, despite technology and operational improvements with estimates for 2050 ranging between 4% and 15% with the most likely impact being 5-6% of all anthropogenic sources[8].

15. These IPCC estimates of radiative forcing combine the effects from changes in concentrations of carbon dioxide, ozone, methane, water vapour, contrails and aerosols, but do not include possible changes in cirrus clouds (IPCC, 1999).

16. In modelling future global impacts of aviation the IPCC report does not include any potential benefits from future technologies and/or operational improvements aimed at mitigating contrails and cloud formation, although it does factor in predicted benefits for technologies that aim to improve the energy efficiency of aviation.

17. It is important to note that in the IPCC study all future scenarios were constructed by assuming that the necessary infrastructure (e.g. airports, air traffic control) will be developed as needed and that fuel supplies will be available. Therefore no account is taken of any potential system capacity constraints or policy mitigation measures. In other words, the projections are based on the demand side projections and not balanced by supply side factors.

Noise and local air quality impact of aviation at major UK airports is becoming an increasingly more important issue as air traffic and passenger numbers increase, and local stakeholder concerns become more pronounced, vocal and directed

18. Aircraft emissions, noise from aircraft take-off and landing, congestion near airports and worsening local air quality are the primary local environmental impacts associated with aviation and of concern to local and national stakeholders.

19. Historic and forecast growth of passenger traffic[9] at UK airports has resulted in, and will continue to contribute to, some specific challenges and problems.

20. **Noise:** Published figures for the number of people living within the noise contour[10] modelling the onset of disturbance continues to fall despite increasing aircraft traffic (see for example Figure 2-5). However continued opposition to airport expansion (e.g. Heathrow Terminal 5) and alternative factual and anecdotal evidence suggests that noise is and continues to be a major issue for people working and living near airports. Indeed, results from a random noise survey carried out between 1986-1991 show that in particularly densely populated European Union member states that about 15% of the population are affected by aircraft noise (LEN, 1994).

[8] These forecasts do not account for the potential impact of the Kyoto protocol reducing emission in other sectors.

[9] For example the Department forecast average growth in passenger numbers at UK airports of 4.25% per annum over the period 1998-2020.

[10] In the UK, 57 leq describes the onset of noise disturbance.

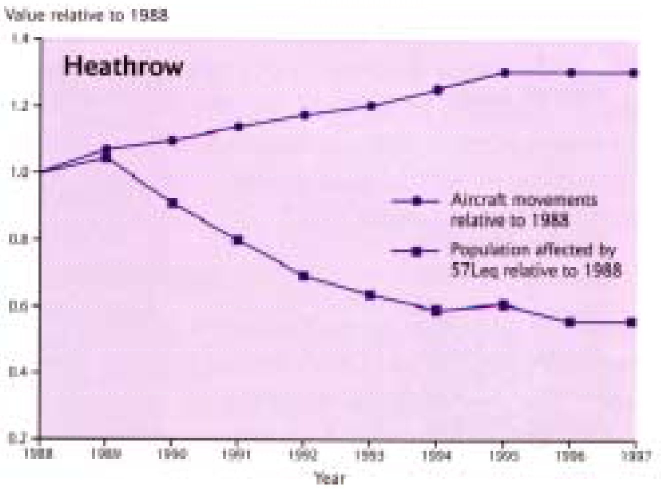

Figure 2-5: Change in population numbers affected by noise at Heathrow *(British Airways, 1999)*

21. **Local Air Quality:** Air quality measurements at Heathrow indicate that 1996 levels of NO_x and PM10 exceed National Air Quality Strategy (NAQS) levels, now superseded by the *Air Quality Strategy for England, Scotland, Wales and Northern Ireland* (UK AQS). Whilst this appears to be the case in most areas of London, nonetheless it indicates that local air quality will continue to be an important issue for airport and airline operators.

22. **Land Take:** Past evidence suggests that opposition to new airport developments is not likely to diminish. Partly this resistance stems from local objections to land take, particularly the additional parking requirements associated with capacity increases. In this respect the Government has set targets for future brownfield site developments, and is imposing restrictions on Greenfield developments.

23. **Integrated Transport:** Transport to and from airports is increasingly becoming an important issue. With rising levels of airport utilisation, additional road traffic near airports has resulted in additional congestion and worsening of local air quality. In response the Government's Transport White Paper *"A New Deal for Transport"* has indicated ambitious targets for increasing the level of public transport with emphasis on transferring public and freight transport from road and air to rail.

Capacity constraints at UK airports result from three main sources, a lack of runway capacity, en route capacity and airport infrastructure

24. The primary constraint on capacity at the UK's busiest airports is the lack of runway capacity. Both Heathrow and Gatwick are expected to become capacity limited because future increases in runway capacity are not anticipated to keep up with demand from airlines. Passenger capacity can still increase significantly at these airports but will be dependent upon larger aircraft with more seats using the airport. The trend today is for airlines to demand greater frequency of service rather than wanting to fly bigger aircraft, but based on past experience this trend could change.

25. For airports whose capacity is not limited by the runway or environmental constraints, *en route* capacity is a major constraint. The main impact is *en route* delays and estimates from Eurocontrol indicate that about half the total delays experienced by aircraft are due to *en route* capacity limits (the other half being due to runway constraints).

26. Finally, the airport infrastructure can be a constraint on capacity, both on the ground and inside the terminal. Many airports have limited scope for expanding their site (e.g. Manchester airport) and if traffic increases as forecast it will be very difficult to provide the necessary gates and manoeuvring areas to accommodate this volume of traffic. Many airports have limited scope for terminal expansion (e.g. the uncertainty on approval of plans for Heathrow Terminal 5) and this potentially constrains passenger capacity. One major impact is a deterioration in the quality of service experienced by air travellers.

27. The use of e-commerce for purchasing flight tickets is an area of strong growth, with increasing numbers of websites available and airlines quoting substantial increases in the number of internet flight bookings. It is not possible to ascertain whether the availability of e-commerce is stimulating the market or whether travellers are simply changing their booking habits for reasons of increased flexibility and choice.

European Air Traffic Control is very fragmented, with 49 ATC centres operating within national boundaries

28. There are in Europe a total of 49 ATC centres across 31 national systems, with 18 hardware suppliers of 22 operating systems utilising 30 different programming languages. Not surprisingly, this results in a highly fragmented European ATC service and for many years Eurocontrol has been pressing ahead with harmonisation programmes, such as EATCHIP, in an attempt to achieve greater uniformity across the European states. There is also a lot of pressure to reduce the number of ATC centres, it is considered by many to be very inefficient to have so many. However, national interests make progress on such matters very difficult.

ATFM delays have been massive and predictions are that delays will continue to grow disproportionate to capacity increases

29. Based on statistics compiled by CODA (CODA, 1999) on behalf of Eurocontrol, traffic growth for the ECAC region as a whole for 1999 was up by about 7% on 1998 figures, with around 4% increase in domestic flights and 8% in international flights. Domestic flights account for around 40% of the total traffic. For those aircraft experiencing a delay, the average delay per movement in 1999 was typically 8 minutes. Flights delayed by more than 15 minutes went up by almost 100% on 1998 figures and flights delayed by 60 minutes or more increased by over 300% (this group now accounts for over 3% of the air traffic). The total number of aircraft experiencing a delay also increased. The main reasons cited for delays are all ATC related and include technical problems, staff shortages, industrial action, etc. Figure

2-6 shows a comparison of the various Air Traffic Flow Management (ATFM) delay indicators.

These figures show the percentage rise in each category for 1999 when compared with 1998. At a Eurocontrol level, statistics on the environmental cost of these increased delays is not calculated.

30. Eurocontrol have recently set up a performance review council in an attempt to try to tackle the most critical performance problems for ATM. The most important issue is ATC induced delays, as indicated by the above mentioned statistics. Over the period from the summer of 1997 to the summer of 1998 delays increased by some 40% and this trend has continued into 1999 (though military operations in the former Federal Republic of Yugoslavia are mitigating circumstances). Another important issue is one of inadequate capacity planning and implementation, the ATC system in Europe is unable to anticipate future traffic growth and implement the required capacity. In addition, an increasing number of European airports are congested at some time in the day, constraining the ability to satisfy demand.

31. All these performance limitations culminate to produce an ATM infrastructure that is not able to cope with the demands placed on it by users, and there do not appear to be any short-term solutions to this situation.

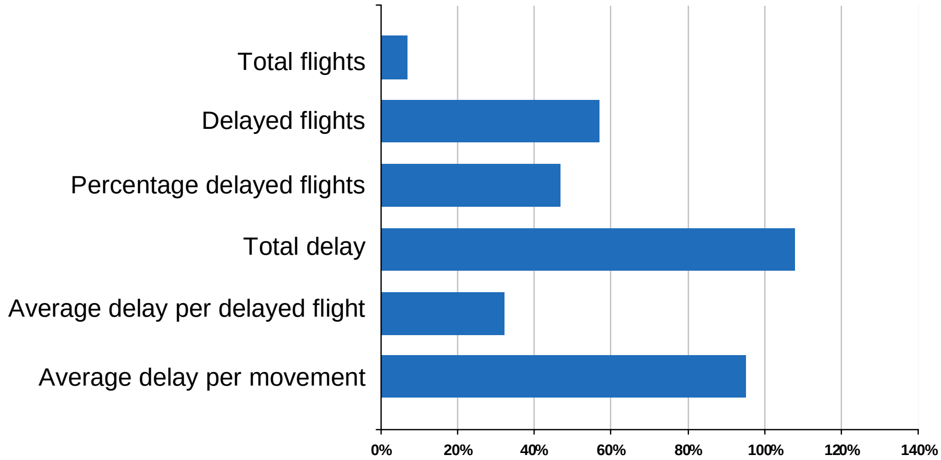

Figure 2-6: Percentage rise in ATFM delay indicators in the period May 1999 to May 1998 *(CODA, 1999)*

Eurocontrol, under the auspices of the ECAC member states, have developed major strategies for the future development of ATM/CNS to resolve the severe problems of congestion and delays

32. In response to the growing problems of congestion and delays in *en route* airspace Eurocontrol have developed a number of strategies which link into the all embracing ATM 2000+ strategy. The ATM 2000+ strategy is intended to provide an effective framework of change within which national plans can be developed. This umbrella strategy embraces and co-ordinates the more detailed individual strategies and the linkages between them are as shown in Figure 2-7 below:

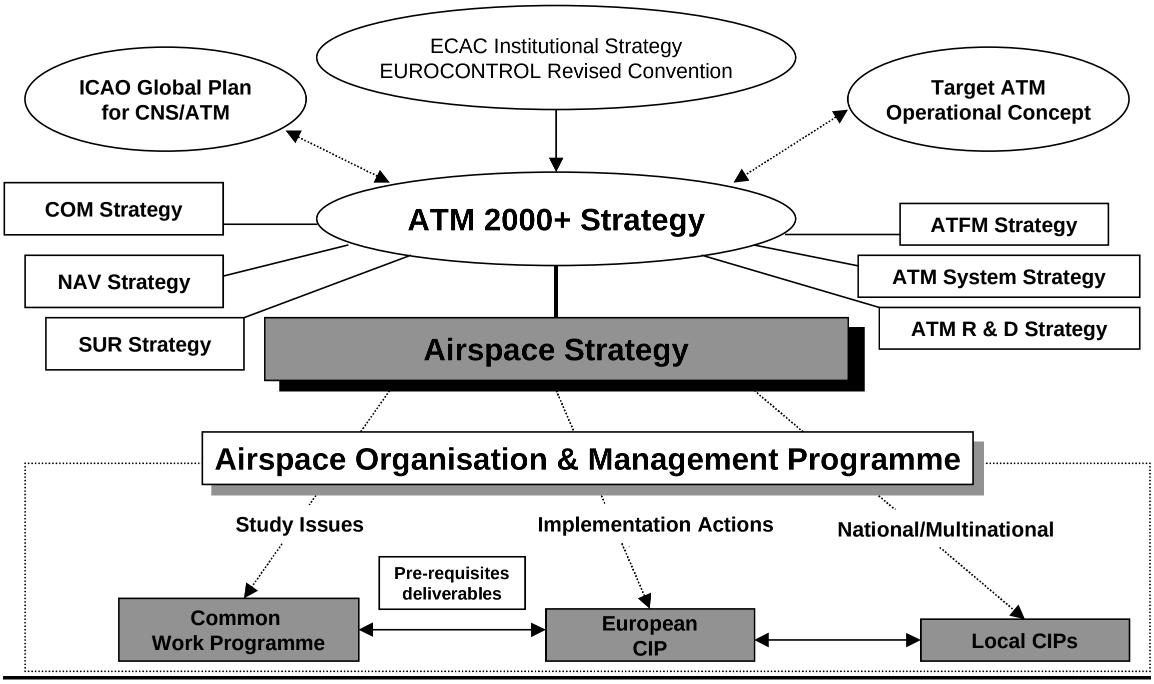

Figure 2-7: The ATM 2000+ Strategy *(Eurocontrol, 1999)*

The principal drivers for technology take-up are commercial and regulatory, these have resulted in significant historical emission and noise pollution improvements

33. Historically, the drivers for take-up of technologies to mitigate environmental impacts from aviation have been commercial and take the form of either direct cost savings (e.g. through fuel cost savings) or indirect benefits such as noise reduction permitting more flights. Underlying this are other drivers for take-up such as Government policy and environmental legislation. It is expected that these same drivers will be equally important for the future take-up of technologies.

34. Against this backdrop commercial aviation has seen many technology breakthroughs over the past 40 years bringing both positive economic benefits and in most cases environmental improvements.

35. For example, ATAG report that (ATAG, 1999) airline fuel efficiency, as measured by the amount of fuel used to transport a given number of passengers, has improved at an average annual rate of 3-4% since the mid 1970's. Similarly, on a like for like basis, jet engines built after 1982 emit approximately 85% less unburned hydrocarbons and 70% less carbon monoxide than engines built in the 1970's, although improvements in NO_x emissions have been much less dramatic. ATAG (1999) also report considerable historic reductions in the level of noise pollution produced by similar aircraft. For example, on take-off, a 1960's Boeing 727 created an intrusive "footprint" of noise that covered an area exceeding 14 square kilometres. In contrast, a modern commercial jet of similar capacity but with greater take-off power, now creates a comparable noise "footprint" covering approximately 1.5 square kilometres.

Similarly, in the United States, the Federal Aviation Administration (FAA) estimates that the number of people significantly affected by aircraft noise is expected to be around 600,000 by the year 2000, compared to about seven million in 1975.

Technology developments are not forecast to keep pace with anticipated growth of aviation

36. Nevertheless, absolute global emissions and fuel consumption continue to grow since demand for air travel continues. Emissions are forecast to grow at a rate of approximately 5%/annum whilst, on the other hand, technology advancements are estimated to offer annual 1-2% fuel efficiency improvements (i.e. fuel use is estimated to grow at 3% per annum) (IPCC, 1999).

37. Indeed, in a recent communication from the European commission (Commission of the European Communities, 1999), the committee conclude that:

"…the air transport industry is growing faster than we are currently producing and introducing technological and operational advances to reduce environmental impact at source."

The implication being that:

"…this trend is unsustainable and must be reversed because of its impact on climate and the quality of life and the health of European Citizens. "

and therefore:

"The long-term goal, therefore, must be to achieve improvements to the environmental performance of air transport operations that outweigh the environmental impacts of the growth of this sector. "

38. Further, in a very recent communications to the United States House of Representatives Committee on Transportation and Infrastructure (United States General Accounting Office, 2000), similar conclusions are drawn to those in the IPCC study:

"Experts in the aviation, scientific, and environmental communities agree that the aviation industry will continue to grow globally and contribute increasingly to human-generated emissions. The experts differ, however, in the rates of growth they project and the effects they anticipate."

and therefore:

"A range of options to better understand and mitigate aviation's impact as the industry grows have been identified:

i) continuing research to improve the scientific understanding of aviation's effects on the global atmosphere as a basis for guiding the development of aircraft and engine technology to reduce these effects;

ii) *promoting more efficient air traffic operations through the introduction of new technologies and procedures; and*

iii) *expanding the use of regulatory and economic measures to encourage reductions in emissions. Governments are pursuing these options, although they have not agreed on specific regulatory and economic measures."*

3 Future Capacity Enhancing Technologies

1. This section addresses future new technologies with the potential to substantially enhance capacity. The time frame of interest is out to 2030, with particular emphasis on the 5 to 10 year time horizon. For technologies that relate to the ATM infrastructure European strategies and plans only extend to 2015, anything beyond this time horizon becomes highly speculative.

2. Technologies that are close to deployment in the near term, i.e. within the next 5 years, have not been considered. It is recognised that those technologies close to deployment could still face institutional and political barriers to their deployment. It is also recognised that many technologies available today can add to the capacity, efficiency and environmental gains in the future. For example, many US ATC technologies could enhance capacity utilisation at UK airports if ICAO rules allowed them to be adopted, or the UK, or Europe, were prepared to seek derogation. However, the purpose of this study is to focus on future new technologies and hence those close to deployment have not been addressed.

3. When considering the application of technologies to enhance capacity usually what is meant is the provision of technologies to improve efficiency and productivity, which in turn translates into more landings and take-offs per unit time at an airport. The capacity at busy airports is usually limited by its runway utilisation, which is dependent upon two factors: runway occupancy time and aircraft separations. If either of these can be reduced through the application of future new technologies then the maximum hourly movement rate will go up. As long as the other parts of the airport system are "feeding" the runway to its limit any other advances in technologies will translate into reduced delays for passengers and cost savings for the service providers through efficiency gains. Strictly speaking, this is not an improvement in airport capacity, though as the capacity of the runway system goes up so the rest of the airport infrastructure must accommodate the increased traffic, therefore technologies to improve efficiency have been included in this study.

4. The term “new technology” is often incorrectly applied to future concepts of operation and new functionality for pilots and controllers, which can often be achieved through better use of existing technologies. These are not new technologies, though where new functions and operations rely upon the availability of new technologies they have been included within the scope of this study (e.g. runway managers depend upon improved future surveillance technologies and have been included).

5. This section discusses the future new technologies that have been identified as the most promising ones for delivering capacity benefit. The most promising ones have been identified through workshops, interviews with stakeholders, literature searches and analysis. Where necessary, "umbrella" terminologies have been used to classify a group of technologies (e.g. AMS embraces all types of arrival managers enabled by future new technologies). It is very common for individual states to have their own specific terminologies for the same technology or portion there-of (e.g. FAST

is a stack to runway consistency tool located at Heathrow, providing one portion of the functionality of an AMS).

6. Within this section, outline descriptions of the key features of future new technologies is provided. The reader should refer to Annex A for a more detailed description of the complete set of technologies addressed by this study for potential capacity benefit.

7. In the following two sub-sections an overview of the findings for future capacity enhancing technologies is given, followed by an explanation of the different types of capacity benefit that exist and how they relate to each other. There are five remaining sub-sections which are divided by where in the journey process the capacity benefit is achieved:

   i) during landing, take-off and runway use;

   ii) whilst manoeuvring aircraft around the airport;

   iii) through utilising the ATC infrastructure;

   iv) through better use by passengers of the terminal; and, finally

   v) through advances in aircraft designs or changes in the way people travel.

3.1 Overview

This study has shown that one essential ingredient to enable capacity enhancement is the introduction of new technologies. There are many potential new technologies and in the short- to medium-term the expectation is that their introduction will enable incremental capacity improvements at UK airports. In the long-term there may be more substantial improvements through technology advances, these will depend upon fundamental changes to concepts of operation. New communication, navigation and surveillance technologies are key enablers of many future concepts and their implementation is essential if capacity is to be increased substantially.

At many of the UK's busiest airports the fundamental limitation on capacity is the runway(s). The short-term focus is on minimising runway occupancy times of aircraft by improving operational consistency between aircraft and between controllers, this does not rely on new technological advances. In the medium- to long-term technology advances in wake vortex effects and runway managers have the potential to improve runway utilisation significantly, the capacity benefit depending upon the extent to which operations have been optimised already.

***En route* capacity (or usable *en route* capacity) is the bottleneck where runway capacity is not the major constraint. It is estimated that, of the total delay experienced by passengers, airspace-related problems account for about 20% of them with air traffic flow restrictions *en route* accounting for about half of these. New concepts like direct/free routing are claimed to provide 17% to 40% more capacity and new controller tools to reduce average workload per aircraft are anticipated to increase *en route* capacity substantially, no reliable figures relating workload to *en route* capacity are quoted. These future concepts require new CNS enabling technologies for their function, most promising candidates are VHF datalinks, satellite based systems and ADS-B. Future concepts also rely on new airspace structures across Europe to provide maximum capacity benefit.**

New technologies also offer efficiency improvements at airports and in the airspace. Surface managers, approach and departure managers can all increase efficiency. Many UK airports are over-constrained with bottlenecks at a lot of points in the system. New management systems help relieve some of the bottlenecks and, taken holistically, will lead to substantial future capacity improvements. Within the airport terminal there is scope for improving passenger throughput through application of smart cards and e-services. These technologies exist today, it is a matter of achieving increased penetration in this market sector. In the medium- to long-term, new biometric technologies for passenger identification could further improve passenger throughput.

In summary, the main capacity constraints are the runway and *en route* airspace, airport-related problems accounting for about 20% of the total delay experienced by passengers with air traffic flow restrictions *en route* accounting for about half of these. The rest of the air transport system is also over-constrained and this leads to inefficiencies. Technologies focussed on improved runway utilisation and increased usability of the *en route* airspace will increase capacity directly. Technologies focussed on other parts of the ATM system will improve efficiency through relieving bottlenecks, taken together they can also increase capacity substantially. In the short-term incremental improvements in capacity at UK airports is expected, with new technologies playing an important part but often not being key to the success of these improvements. In the medium- to long-term technological advances will be fundamental to introducing substantial capacity improvements.

3.2 Definition of Capacity Benefit

1. Providing a rigorous definition of capacity benefit for air travel is particularly difficult. Capacity benefit can be achieved at many different stages of air travel, for example through increasing the number of movements on the runway or through increasing the arrival rate of aircraft into the TMA. However, each stage of air travel is closely coupled to other stages and cannot be considered in isolation. Take the above example, if the runway capacity is limited then across the ATM system as a whole no capacity benefit will be experienced through increasing the arrival rate into the TMA, though there would be gains in efficiency. Typically what happens is that improvements in one part of the ATM system introduces bottlenecks in other parts of the same system.

2. In practice, this means it is more useful to consider both capacity and efficiency in terms of the benefits future technologies can provide rather than just focussing on capacity. Again, taking the above example, there could be a significant efficiency gain as a result of increasing the arrival rate of aircraft into the TMA. If the bottleneck, in this example the runway, can be removed then this gain in efficiency will translate into a capacity increase.

3. For this study the interest is in enhancing the capacity of UK airports and hence the focus will be on technologies that relate to improved capacity and efficiency in and around the airport, on the taxiways, the runway and during landing and take-off. Capacity enhancements in the *en route* flight phase will be considered to the extent that they have a beneficial impact on airport capacity, recognising the fact that *en route* airspace is becoming increasingly congested and the effects are being felt on the ground through increased delays.

4. Measures of total and peak numbers of aircraft arrivals and departures are provided by airports. These measures depend upon many factors such as runway layout, whether considering hub airports, major regional or smaller regional airports, ratio of arrivals to departures, weather conditions, operating restrictions, and so on. For this study the detailed relationship between the different factors that build up to provide an airport's capacity have not been considered since they are very airport specific and could be misleading when considering the potential capacity benefit offered by a new future technology.

5. Passenger throughput at an airport will depend upon the number of origin and destination passengers and transfer passengers. The ratio of these different types of passengers will vary enormously between airports, for example connecting hub airports by their very nature have many more transfer passengers than regional airports. Typically, measures are provided for total and peak numbers of passengers handled by an airport. For this study, no distinction has been made between the different types of passengers since future new technologies have the potential to benefit all.

3.3 Landing, Take-off and Runway Utilisation

This sub-section addresses those future new technologies that are most promising for enhancing capacity and efficiency during landing, take-off and runway usage. Technologies which are either in the process of being deployed or will be deployed in the next few years (e.g. MLS, RVSM and 8.33KHz channel spacing) have not been addressed. Also, new operational procedures enabled by existing technologies have not been addressed. The technologies covered are ones that address wake vortex effects, arrival, departure and runway managers, satellite landing systems, and ADS-B[11] for parallel approaches. Further technical details on these and other technologies relating to enhanced capacity during landing, take-off and runway use can be found in Annex A.

Findings

The findings with respect to future capacity enhancing technologies during landing, take-off and runway usage are discussed below.

The introduction of technologies to address wake vortex effects could improve airport capacity through reduced aircraft separations

1. Wake vortices are generated whenever an aircraft wing produces lift and the strength of the vortex depends on many factors including aircraft weight and its speed. In general, large aircraft flying slowly will produce the greatest strength vortices, though some aircraft produce a stronger vortex than their size and weight would imply.

2. Under certain weather conditions these vortices can be slow to decay, causing turbulence for the following aircraft. To reduce the effects, aircraft are sequenced to ensure large aircraft are not followed by small ones. However, separation standards have to be applied on the basis that vortices could exist and this in turn affects capacity. A technology that can track vortices and predict their occurrence has significant potential capacity benefit since it allows the controller to optimise the spacing between aircraft based on a real understanding of the vortices generated and their dispersal. It may therefore be possible to reduce the spacing between aircraft and hence increase the number of movements that take place.

3. This technology is especially applicable to major airports where there are a large number of daily movements particularly of large heavy aircraft. The extent of the capacity benefit is not easily quantified, partly because application of the technology is still at the study stage and partly because it will depend a lot on the operational environment into which it is placed. At Heathrow, where traffic flows on approach have been substantially optimised already, NATS suggest this technology would increase the number of movements by just 1-2 per hour. At other multiple runway airports where segregated or partly segregated operating modes could apply, for example in the future Manchester airport, the incremental gain may be greater since to date the optimisation of operations has not been as extensive.

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[11] The ADS-B technology is discussed in more detail in section 3.5 under ATC Infrastructure technologies.

Turbulence warning systems provide an initial technological step towards the effective control of wake vortex effects, whereby the presence of vortices is identified and the controller is warned.

4. Recently, Boeing have announced the development of aerodynamic techniques which cause the wing tip wake vortices from an aircraft to collide with each other a short distance behind the aircraft, resulting in them dissipating more quickly (New Scientist, 2000). Their results indicate that typically the wake vortices collapse within 3nm (nautical miles) of the aircraft, this compares with separations of up to 5nm being required when a small aircraft follows a heavy aircraft. This Boeing development is still at the trials stage and therefore detailed performance capabilities have not been established.

Implementation of a good arrivals manager could bring up to a 20% improvement in aircraft separations, and hence capacity increases

5. An arrivals management system (AMS) is an air traffic management automation tool designed to optimise traffic flow in and around the Terminal Manoeuvring Area (TMA). An AMS is especially relevant for TMAs with high traffic levels, congestion problems and a complex airspace structure. The improvements will result from decreased average congestion period, increased runway rate and a decrease in the holding pattern. Existing technologies can enable an AMS, though there is a need for integration with other systems such as RDPS and FDPS. Also, new concepts, such as trajectory prediction, would enhance the function of AMS.

6. There are several research centres across Europe involved in the development of arrival managers and associated tools. At present, such systems are at the prototype stage with just a few basic systems starting to be deployed, for example at Frankfurt airport, and hence any performance estimates should be interpreted with care. The UK has not developed an AMS, though there is the FAST system located at Heathrow. FAST goes into operational trials in December 2000 and it is anticipated that in the short to medium-term FAST will be developed into a full arrivals manager.

Departure manager systems are only concepts though their optimisation of airspace and runway utilisation means they could offer substantial capacity improvements

7. A DMS is a ground based air traffic management automation tool designed to optimise traffic flows in and around the TMA. The tool would be introduced into the working environment of approach and area controllers. Basically, it generates advisories for the controller in order to meet the planned departure sequence, thus optimising the metering and sequencing (i.e. spacing and ordering) of the outbound traffic. The only example today of this kind of tool is at Schiphol airport, where the Automatic Slot Assignment system has been developed. Apart from this, there are a few European studies (e.g. the PHARE programme) which propose some early demonstrators of a departure management planning function.

8. DMS applicability is the same as for AMS, it offers benefits in terms of capacity and efficiency through airspace conflict free trajectory planning, reduction in

controller workload and reduced fuel consumption. The main technical difficulty for implementing such systems is developing the operational concept within which they will be introduced into the controller work environment.

This also requires the integration of many input data sources, such as flight data, CFMU slot, stand allocations, choice of runway, flight parameters (e.g. SIDs), runway departure rates, and so on. It is anticipated that DMS will be developed after AMS and implemented in the medium to long-term.

Future evolution of DMS and AMS into an integrated common modular planning system consistent with future Eurocontrol strategies for ATM

9. A natural progression in the development of arrivals and departure managers is to integrate them into a common system. This would provide substantial further improvements over those for separate systems, through the integrated flow of traffic into and out of the TMA. The integration of AMS and DMS is a long-term prospect, especially considering that DMS is mainly a concept.

10. Looking further ahead still, the GTG concept considers the evolution of DMS to manage the so called "integrated slot" concept, where an overarching management system embraces surface, gate and runway managers as well as arrival and departure managers. Integration of AMS and DMS consistent with the GTG concept should be considered as very long-term.

Runway management systems are just concepts today but they will be required in the future if the management of a flight is to be all inclusive, from gate to gate

11. Runway management systems are decision assistance tools for controllers in which the optimising of the aircraft sequence for take-off will be the main function. At present RMS is only a concept and there are a few European lead studies to develop demonstrators for such systems. The focus of current research is mostly on tools which assist the controller during approach and departure, however it will be necessary to extend to runway management systems so that growth in runway operations can be accommodated without increases in delays on the ground.

Satellite landing systems could offer an alternative new technology for Cat I landings either at busy airports prone to frequency limitations and/or interference of existing systems or at small airports without guidance systems

12. A SLS is a precision guidance system which uses information transmitted by either GPS or GLONASS, or both. For landing systems, the guidance information is calculated on board the aircraft and is based on the aircraft's current position and the co-ordinates of the runway.

13. As long ago as 1983 ICAO established that satellites could provide navigation and approach services for runways which need not be equipped with a ground based precision guidance system such as MLS or ILS. Major flight trials have been carried out to evaluate the SLS concept and such systems have applicability at all airports requiring precision guidance to Cat I levels. Future developments of the technology

to provide approach systems that meet Cat II or Cat III requirements are planned, but such systems would be a long-term prospect.

14. The benefits of SLS differ depending upon the type of airport being considered. First, at very busy, sophisticated airports where there are frequency allocation limitations or the potential for interference of the unprotected ILS signal, these systems may offer an alternative to ILS for Cat I approaches; with different solutions for Cat II and Cat III being required. At remote airfields this technology could be used to provide for Cat I approaches where introducing other forms of guidance systems would be too costly.

ADS-B could enable the simultaneous operation of closely spaced parallel runways, providing a potential twofold increase in throughput

15. ADS-B can be used to provide accurate surveillance data that enables the simultaneous use of closely spaced parallel runways. At Heathrow NATS already operate parallel approaches to a limited extent without the need for an ADS-B based system, and NATS is not convinced of the benefits of ADS-B in high-density traffic areas such as UK airspace. However, where an airport is considering introducing a new runway but is constrained to have it closely spaced to an existing one it may be the case that this technology could enable the simultaneous operation of both. Across the industry there is doubt as to whether the capacity advantages of this technology can be realised, mainly because of the high take-up barriers (see §5.5).

16. At NASA Langley Research Centre the technical feasibility of using ADS-B to enable parallel operations of closely spaced runways has been demonstrated. The basic system is called AILS, though it has yet to be developed for use in a real operational environment and this is likely to take some years to achieve. Such systems also require other technologies, for example to provide accurate landing guidance during approach and land. Depending upon the airport and airspace complexity, systems such as AILS have the potential to provide up to a twofold increase in throughput since they enable independent IFR approaches to airports with closely spaced runways.

3.4 Taxiways, Manoeuvring Areas and Gates

This sub-section addresses those future new technologies which are most promising for enhancing capacity and efficiency around the airport taxiways, manoeuvring areas and gates. Technologies which are either in the process of being deployed or will be deployed in the next few years have not been addressed. Also, new operational procedures enabled by existing technologies have not been addressed. When considering future new technologies for capacity enhancement the notion of "acceptable delay" is important and particularly relevant at the airport where there are many potential sources of delay. Whilst minimising delay is not the same as enhancing capacity, achievable capacity, or throughput, will rise as the acceptability of delay (i.e. queuing) rises. Therefore, achieving a reduction in delay will be a contributory factor to achieving higher throughput. Two technologies are covered, surface managers and A-SMGCS. Further technical details on these and other technologies relating to enhanced capacity around the airport can be found in Annex A.

Findings

The findings with respect to future capacity enhancing technologies around the airport are as follows:

Surface management systems mainly improve the efficiency of surface movements by reducing taxi times and supporting timely delivery of departing aircraft to the runway

1. Surface management systems are the routing and planning tools for ground movements, addressing the scheduling and routing of aircraft and other airport vehicles that could influence aircraft movements. The system operates between the gate and the runway and can be considered as the routing and planning functions of A-SMGCS.

2. To date, these systems are only concepts and, like runway management systems, there are a few European lead studies underway. Their implementation timeframe is long-term and they are most applicable to major airports with high volumes of traffic and complex taxiways and manoeuvring area layout, implying many alternatives for routing. The benefits of SMS are similar to those for RMS, the rationale being that as traffic growth continues some form of surface management will be required if the airport's effective capacity is to be maximised and delays on the ground are to be minimised.

A-SMGCS have the ability to improve airport capacity and are especially useful in low visibility conditions

3. An area where ATC service provision does limit airport capacity is when visibility is poor. Although low visibility is not very common at UK airports, typically affects Gatwick and Heathrow airports up to 30 and 5 days a year respectively, its impact is very large and can reduce airport capacity dramatically. In addition, there is a knock-on effect to other airports and into subsequent days since airlines find their aircraft and/or crews are not in the right place for normal operations to resume.

4. The introduction of new technologies to provide better surveillance information for controllers can improve capacity in low visibility conditions. A-SMGCS is a technology that provides situation awareness to the controller and also to those aircraft and vehicles that are liable to come into proximity with each other in conditions when their speeds prevent such separations being maintained visually. In other words, it increases the operating envelope over which airport operations can be maintained at their normal levels. As purely a provider of surveillance information, A-SMGCS is reasonably cheap to implement.

5. Looking to the future and to greater levels of sophistication, A-SMGCS can also be used for guidance control and planning, where complex traffic flows require greater management of aircraft and other vehicles in the movement area. Performance of such systems is still under investigation and therefore it is difficult to determine the capacity benefit this level of complexity would bring. Also, such systems would be dependent upon many enabling technologies, making them difficult to certify. That said, with traffic flows becoming more complex around our busiest airports and the need to maintain operations in low visibility conditions this suggests that it is a technology that can have a significant positive impact on capacity.

3.5 ATC Infrastructure

This sub-section addresses those future new technologies which are most promising for enhancing capacity and efficiency within the ATC infrastructure, this includes CNS enabling technologies, new technologies that enable new future operational concepts and it also touches on those technologies which apply to *en route* airspace. Technologies that are either in the process of being deployed or will be deployed in the next few years (e.g. VDL Mode 2) have not been addressed. The technologies are covered are VHF datalinks, ADS-B, satellite technologies, direct/free routing and controller tools. Further technical details on these and other technologies relating to enhanced capacity within the ATC infrastructure can be found in Annex A.

Findings

The findings with respect to future capacity enhancing technologies within the ATC infrastructure are as follows:

A large number of ATC services depend upon the implementation of a sophisticated VHF datalink, in the medium-term this will be Mode 2 and candidates for the long-term are Mode 3 and Mode 4

1. The provision of datalink services is a key element to reducing controller workload. Datalink can be used to communicate information on a whole range of aircraft parameters from the aircraft to the ground, information that existing communication links cannot provide. This information can be fed into computer tools and used to provide substantial improvements in situation awareness for controllers. It is anticipated that across the UK the increased capacity through provision of datalink services will be significant, since this technology enables many new future concepts (e.g. controller tools).

2. In the medium-term VHF Datalink (VDL) Mode 2 will be deployed, major industry consensus for transitioning to VDL Mode 2 was reached in 1997 and standards for ground and airborne equipment have been developed. Its benefits over what exists today are the higher throughput, hence the ability to support the growth in traffic, better use of the frequency spectrum, which is a major problem in heavily congested airspace – the additional bandwidth to be allocated to datalink purposes, and its compliance with the future ATN environment.

3. Looking to the future, there is a need to progress to more sophisticated datalink technologies to support future applications that require a datalink service. The main limitation of VDL Mode 2 is that it is not compatible with critical ATC datalink applications requirements, and the two candidates for the future VHF system are VDL Mode 3 and Mode 4. VDL Mode 3 integrates digital voice and data, supporting the near term need for increased voice capacity whilst providing for evolution towards a mixed voice and data environment.

VDL Mode 4, promoted by the Swedish CAA, provides a data only environment through the use of discrete time slots as the fundamental shared resource along with a set of protocols that allow users to mediate access to these time slots. VDL Mode 4 operations require either a GNSS receiver or ADS-B capabilities for the determination of user position and timing information.

4. Both candidate future VHF systems have limitations that constrain their performance. The integrated voice and data approach for VDL Mode 3 is not flexible and this imposes serious operational limitations since the quality of service requirements for the voice part and the data part are so different. For VDL Mode 4 there is a lack of determinism and robustness in the channel management, requirements for a multiplicity of airborne equipment, and the problem associated with using GPS that there exists a common mode of failure of navigation, communication and even surveillance. Finally, for some datalink enabled applications where high reporting rates are required (e.g. ADS-B for ground surveillance) there are concerns that the transfer delay is unacceptably large. The ground implementation for both candidate systems requires major architectural changes, which is costly, making them relevant only for important investments.

5. The inherent limitations of both future VHF datalink systems means it is likely that other datalink solutions will emerge. Also, the lack of consensus across the industry about which to adopt will make it difficult to progress a common solution. To date, the cost of VHF communications is relatively low when compared with satellite communications. However, with the emergence of the new LEO constellations this will make satellite communications more competitive with VHF.

ADS-B is an enabling technology with broad applicability across a wide range of concepts, however there are often alternative ways of achieving the same thing

6. ADS-B is a function on an aircraft or surface vehicle that periodically broadcasts its position and velocity as well as other information about the vehicle's identity and intent. ADS-B has applicability to all flight phases including the TMA, approach, landing and taxiing. Its expected use is to provide enhanced situation awareness for pilots via the CDTI and surveillance information to controllers. ASAS requires ADS-B to be available and ADS-B potentially reduces the need for primary and secondary radars since it provides additional surveillance information.

7. ADS-B has the potential to support many future concepts, for example surface surveillance applications such as go around detection and surface movement control, and other concepts such as longitudinal station keeping, medium-term conflict detection and short-term conflict alert. However, in many cases there exist alternative technologies to support the same concept and in some cases ADS-B can only be considered as a replacement technology for what exists already. For this reason it is often difficult to quantify the technical benefit of investing in this technology over others, especially considering that it requires all vehicles to be equipped. In addition, NATS is not convinced that the potential benefits of ADS-B can be realised in high-density airspace.

The use of GNSS for position and accurate timing information is common to many future concepts but raises issues of availability, integrity and a single point of failure

8. Many future concepts, for example ADS-B, APALS and CDTI, depend upon the use of GNSS, usually GPS, for position and timing information. This does raise issues of availability and integrity since these systems are not owned by those making use of the information provided. It also raises the issue of safety integrity since the use of GNSS derived position information can introduce a single point of failure if both the ground systems and airborne systems are basing their surveillance, navigation and /or communications information on the same source. Resolving these issues is likely to delay the implementation of future concepts which rely on GPS derived position data since developing the safety case for such applications will be very difficult.

Simulations suggest that the Direct/Free Routing concept can provide between a 17% and 40% gain in en route capacity

9. It is estimated that airspace-related problems experienced by aircraft operators account for about 20% of delays, with air traffic flow restrictions accounting for about half of these . It is very common for aircraft to be waiting on the ground because an *en route* slot cannot be negotiated for the chosen route, delays are a serious problem. Delays are a function of capacity, though the relationship is complex and there are many contributing factors. The fact that *en route* delays are increasing year on year suggests that the system is barely able to cope with the traffic volumes.

10. One future concept that could potentially enhance *en route* capacity is Direct / Free Routing. It has been shown through simulations to provide anywhere between a 17% and 40% gain in *en route* capacity. The exact figure depends greatly on the assumptions made about the operational environment and the airspace structure, for example the highest figure assumes a uniform airspace without the encumbrance of sovereign boundaries. This concept, as with most, depends upon the implementation of new technologies such as air-ground datalinks, GPS, sophisticated flight management systems and advanced automation tools. The basic technologies are available today but still need to be developed into systems which support a new operational environment, which will likely take many years.

11. It should be noted that not all ATC service providers believe the Direct / Free Routing concept would provide any capacity benefit *en route*. One difficulty is transitioning aircraft from airspace where they can direct route to airspace (e.g. in the vicinity if airports) where they are following procedures similar to those in place today. Another difficulty is that when a potential conflict arises the responsibility will still rest with the controller to resolve the conflict. With a pre-defined route structure the points in space where a conflict could occur are well defined and known, with direct / free routing conflicts could occur at any point making situation awareness for the controller much more difficult.

The airspace structure across Europe is a significant impediment to achieving the potential capacity gains new technologies can provide in en route airspace

12. The airspace structure across Europe has evolved with time from a start point of air routes defined in relation to ground based navigation aids to produce a fixed route network. By its very nature, this route structure is very inflexible and cannot be expanded easily to accommodate the anticipated increase in traffic.

13. New technologies onboard the aircraft, such as sophisticated flight management systems and enhanced navigation capabilities, combined with advanced automation tools to support the controller on the ground, could pave the way to much more effective use of the available airspace. Aircraft no longer have to fly pre-determined routes based on fixed locations on the ground and this offers enormous potential for additional capacity.

14. There are essentially three concept options for the future airspace structure across Europe, each being a further extension away from what is in place today. The first is Structured Routes whereby the Flexible Use of Airspace (FUA) is introduced and within this aircraft fly along a fixed set of routes. The joint use of military and civil airspace offers significant increases in available airspace for civil operations, and hence capacity improvements. In UK airspace the benefit of FUA is probably quite small since for many years there has been significant co-operation between civil and military airspace users. However, there is a knock-on benefit for UK airspace if FUA were introduced fully across Europe, especially in some of the core areas.

15. The second of these is Free Routing, as discussed above. This concept assumes a Free Route Airspace exists which allows users to plan their routes between an entry point and an exit point without reference to the ATS route network in place today. Free Route Airspace would still be subject to Air Traffic Control.

16. The third concept is Free Flight and Autonomous Operations. This concept assumes a Free Flight Airspace in which suitably equipped aircraft can fly user preferred trajectories. In this regime the pilot will be responsible for separation assurance from other aircraft operating in the same airspace. Advanced automation tools in the cockpit are essential to assist the pilot in identifying aircraft in potential conflict and suggesting possible resolutions.

17. All these concepts recognise the need to improve the airspace structure since it is a significant limitation on airspace capacity. New technologies exist already which can enable these future concepts.

Controller workload is the major limiting factor on airspace capacity, new controller tools have the potential to improve capacity but no one seems to know by how much

18. The traditional approach to increasing airspace capacity is to resectorise, this is required when controller workload has reached its peak and as a consequence further traffic demand cannot be satisfied without compromising safety. This approach is still used today, a recent example being the Clacton sector, and will be used in the future since it is a very effective means of optimising airspace capacity. However, there is a law of diminishing return on this approach since the productivity gains to be had, by enabling a controller to maintain situation awareness over a smaller volume of airspace with more aircraft flying through, are offset by the additional workload created by the need for more frequent sector handovers between controllers. Exactly where this limit sits is difficult to determine, resectorisation and the associated development of new operational procedures is a very complex activity.

19. On the assumption that it will not be possible in future to apply resectorisation indefinitely, other means of reducing controller workload are needed to cope with increased traffic demand. The focus has been on developing computer tools to assist the controller and there are many examples – trajectory predictors, conformance monitors, conflict probes, and so on. The basic concept is to enable the computer to have a degree of situation awareness, shifting the role of the controller away from its tactical nature to one which is more strategic. The majority of concepts put forward as candidate applications have yet to mature into detailed specifications, and until this happens the detailed performance requirements cannot be specified fully. Also, the potential reduction in controller workload and corresponding increase in airspace capacity cannot be ascertained. Implementation of these computer assistance tools is considered to be long-term.

Moving the responsibility for aircraft separation to the pilot is another way of reducing controller workload and hence increasing airspace capacity

20. A number of future concepts, such as ASAS, are based on the idea of reducing controller workload through delegating some of the responsibility to the pilot. These concepts depend upon new technologies such as CDTI for presenting traffic information to the pilot and ADS-B, which is just one option, for obtaining this traffic information. The potential operational uses for ASAS include final approach spacing, departure spacing and closely spaced parallel runway approaches.

21. There are many issues to be resolved before such concepts can be implemented, therefore they are very long-term prospects. Issues include the fact that ASAS will increase pilot workload at the busiest time of a flight. Also, the system requires co-operating aircraft and hence there are major transitioning issues over the period when not all aircraft are equipped.

3.6 Terminal Utilisation

Long-term growth in passenger numbers is forecast at around 5% per annum and this will add significantly to the congestion already experienced by travellers. Agreed plans for extensions to existing airports are wholly inadequate to cope with the forecast demand. Also, getting to airports is a major problem with congested roads, limited alternative modes of transport, and very expensive airport parking.

There is intense pressure for airports to be more efficient and to provide a better overall quality of service to customers through improved ticketing, passenger management, security systems and baggage and freight processing. There is also pressure from the airlines for improved passenger throughput since a delayed passenger can cost the airline substantially through losing a runway slot. This is especially true of hub operations that place a lot of demands on the airport infrastructure to meet airline created peak requirements. Many airports also derive substantial revenues from parking and retailing which are best served through having passengers spend significant amounts of time in the airport terminal. The important factor throughout is how time is spent at an airport and if technology can eliminate queues, enable passengers to enjoy the airport experience and still ensure they arrive in good time for their flight departure then terminal utilisation will improve. The technologies covered in this sub-section are e-ticketing, chip cards and RF tags, and biometrics.

Findings

The findings for technologies to improve the throughput of passengers within airport terminals are as follows:

E-ticketing exists today and its use is increasing in popularity, offering more efficient check-in and reduced air fares

1. Electronic ticketing is available today and Internet booking of seats is increasing substantially. Many airlines have dispensed with the need for tickets altogether on some routes. E-ticketing makes airport check-in more efficient and ensures airline fares are low. The drawbacks are that passengers usually still need to stop at a ticket machine, check-in counter or gate to show ID and receive a piece of paper. Also, for international flights or multiline codeshare itineraries e-ticketing is frequently not available. Looking further into the future, international progress is being made towards Common Use Self Service Systems (CUSS) such that implementation of multi-sector / multi-airline check-in could be feasible in the medium-term.

Use of chip cards and RF tags for passenger and baggage ID is expected, optimising passenger flows and leading to lower congestion, reduced waiting times and enabling a higher passenger throughput at existing terminals

2. Magnetic cards, boarding passes and tickets are widely used by the airline industry. However, with rapidly falling prices, greater memory capacity and security attributes, chip cards are being developed to replace magnetic ones. Essentially, a chip card has a micro-processor integrated circuit embedded within it which has a

memory capability for storing information. Chip cards are also called smart cards or contact cards.

3. The technology for contact cards already exists and is in common use in, for example, the banking industry. It will still take time for this technology to find its way into airport terminals since the kiosks have to be installed and the necessary infrastructure provided. Estimates from the airlines industry suggest that the use of smart card technologies for passenger check in and baggage handling could result in a 50% to 80% reduction in transaction time.

4. Contactless chip cards are the next future step in chip card / smart card technology that can be applied at airports to improve passenger throughput. Here the card no longer needs to be inserted into a slot at a kiosk but instead either holding the card in close proximity to a reader or walking past a reader at a distance of a metre or so will suffice. This type of card would, in theory, enable passengers to walk through check-in, passport control and gate boarding. Contactless chip cards have an RF transmitter inside them and different RF transmission frequencies are used depending upon the application. There are many manufacturers of contactless chip cards today, future concepts for application at airports exist, the need is for these to be integrated into a system and for such systems to be implemented at airports. The industry view is that this will happen in the medium-term.

5. Chip cards and RF tags can also be used to improve baggage handling. The same technologies as with contactless cards for passengers apply. Also, the same technical and operational considerations exist, basically the airlines and airports have to decide where their installations will start and how far they will extend.

Future developments of screening techniques and passenger identification systems is expected to include the use of advanced biometric technologies

6. Biometrics is the use of personal characteristics to identify specific people uniquely. Today there are signatures, PIN numbers and photographs. These enhance security but are easily deceived and often slow to execute. Future advances in technologies for security systems applicable to the air transport industry include face, eye and fingerprint identification (more futuristic still, serious work is proceeding on odour, ear, vein and many other forms of biometric measures). At present there exist scientific prototypes, these have to be proven and further developed into commercially available and affordable products. Application of these technologies at airports is a long-term prospect.

3.7 Future Aircraft Enabling New Forms of Air Travel

This sub-section addresses future new aircraft which are most promising for enabling the introduction of new types of air travel that are not available today and have the potential to increase capacity. The technologies covered are VLAs (Very Large Aircraft) and small turboprop aircraft especially designed for use at small regional airfields. Encouraging passengers to use other regional airports in preference to major airports in the south-east has not been addressed. Although this would potentially increase capacity and reduce congestion it does not relate to future new technologies and is therefore not within the scope of this study. Further technical details on VLAs and small turboprop aircraft can be found in Annex A.

Findings

The findings with respect to future capacity enhancing technologies within the ATC infrastructure are as follows:

The demand for VLAs is expected to grow from less than 100 today to more than a 1000 in the next 20 years, initially with an average capacity of 600 seats and rising to nearly 1000

1. Forecasts by Airbus for 1999-2018 indicate that the average size of aircraft will increase with the average number of seats per passenger aircraft growing by 38 seats, to reach 218 seats per aircraft by the end of 2018 *(Airbus, 1999a)*. During the same period, the average capacity of the dedicated freighter fleet is also predicted to increase from 44 to more than 52 tonnes. Partly feeding this trend will be the development of VLAs with seating capacities of over 600, offering efficiency improvements and gains in environmental impacts per passenger *(Airbus, 1999a).*[12]

2. VLA concept development is in response to a market need expressed by the airlines, production of the A3XX family will not commence until suitable launch orders have been obtained from several airlines involved in the A3XX definition. Current predictions by Airbus are that development will commence in 2002 with aircraft entering into service in 2005.

3. From a technology perspective, VLAs will take advantage of the latest airframe, engine and aircraft technologies, as well as advanced computational tools and production facilities available at the time of development; these technologies are discussed in the following section. The performance claims made in terms of noise and emissions for the A3XX are:

   – Noise reduction over existing 747 designs even though seating 30-50% more passengers;

   – Compliance with CAEP/4 NO_x emissions; and

[12] Both Boeing and Airbus expect there to be a market for VLAs, however their forecasts for absolute aircraft size and total numbers of aircraft vary. Boeing see the market expanding more in the medium to large sized aircraft whereas Airbus see a much bigger market for very large aircraft, eventually with capacities of up to 1000 passengers.

– Burning up to 20% less fuel per passenger per kilometre than the 747-400.

4. Clearly the claimed environmental benefits of VLA aircraft such as the A3XX are highly dependant on achieved occupancy levels, since on a per flight basis absolute fuel consumption and noise impact are fixed and both are on average higher than for a smaller aircraft of similar age.

5. From a capacity perspective VLAs could substantially increase passenger numbers per aircraft movement at major hub airports. Based on Airbus figures, operation of these aircraft is expected to be highly concentrated with half the world's fleet used on flights from the top ten airports, which includes Heathrow. In 20 years from now, this equates to nearly 100 aircraft serving Heathrow with a capacity in excess of 500 seats. Accommodating VLAs with such large numbers of passengers is a major concern, existing airport infrastructures are expected to require major changes to cope with the large influx of passengers and to cope with large wingspan aircraft needing to use the taxiways, manoeuvring areas and gates.

Emergence of turboprop aircraft technologies coupled with the development of point-to-point business models could increase both passenger and aircraft capacity

6. New turbo-prop designs such as the Farnborough F1 offer the opportunity for inexpensive flights from small regional airports. The F1 (and similar proposals by Boeing) are being designed to minimise noise through using lower propeller speed and steep take-off and landing paths. This technology will not only reduce flyover noise to 70dB at 1000ft, which is quieter then either a chain saw, a lawn mower or a car passing at 20ft, but also ensure the aircraft is at sufficiently high altitude to minimise noise even as it reaches the airport perimeter. It should also be noted that due in part to the lower capacity of turboprop aircraft, emissions per passenger km tend to be higher than for larger aircraft.

7. It is too early to predict whether this new form of travel will be successful, though if industry claims are to be believed there are a very large number of small airfields from which these 5 to 10 seater aircraft could fly, providing the potential for a significant increase in both passenger and aircraft throughput The types of passengers who will take-up of this new form of travel is very unpredictable, whether it will be people who would otherwise travel from major regional airports or whether a new market will emerge, as has happened in the case of the low-cost carriers.

8. In the event that there is a major take-up of this new form of travel enabled by the emergence of turboprops, this will put more pressure on ATC services particularly for the provision of *en-route* control. Also, to the extent that these small aircraft may seek access to hubs (small airport to small airport routes being less viable), they may actually serve to reduce the effective utilisation of capacity.

3.8 Overall Capacity Benefit

This sub-section summarises the benefits offered by new technologies in terms of where the capacity occurs, whether at the airport or in the airspace, and over what time frame. The end of this sub-section comments on the quantification of capacity benefit derived from future technologies.

New technologies and advances in management systems can offer substantial increases in runway capacity as well as reductions in noise and emissions

1. Technology advances to better predict wake vortices or help them decay more rapidly have good potential to increase runway capacity through reducing aircraft separations. Their introduction is likely to be in the medium to long-term. Figures quoted by industry suggest separations can be reduced by up to 40%, though this has yet to be proven. NATS perspective is that at airports where substantial optimisation of runway operations has already taken place (e.g. Heathrow) the potential for capacity benefit will be much less, typically increasing the number of movements by one or two per hour.

2. Advances in arrival, departure and runway managers offer substantial gains in efficiency which, for arrival managers alone, are predicted to provide a 20% improvement in aircraft separations. This can be translated into an increased runway rate and a decrease in holding patterns, increasing capacity and reducing noise and emissions.

Advances in surface management and guidance systems will substantially enhance airport capacity and reduce noise and emissions

3. Future technologies have the ability to offer substantial capacity gains within the airport infrastructure, especially through the introduction of integrated airport managers that better manage the sequencing and flow of aircraft around an airport. New surface managers offer the opportunity to integrate information from different detection sources (e.g. radars, DGPS and visual aids) and manage this data to automate many of the air traffic management processes. It has not been possible to quantify the capacity benefit, mainly because it is strongly airport layout dependent. Surface managers are especially relevant for complex and highly congested airports and their introduction is expected in the long-term.

4. Complementing surface management systems, guidance systems offer substantial improvements in aircraft ground movements during low visibility conditions, though once again the benefit cannot be quantified because it is dependent upon so many other airport specific factors. Introduction of these systems is not expected until the long-term.

New ATC infrastructure technologies are key enablers of future concepts and provide the basis for enhanced capacity on the ground, at the runway and in the airspace

5. VHF datalinks, satellite systems and ADS-B are all essential enablers of future concepts for increasing capacity, such as controller tools which utilise information from an aircraft's FMS. In each case there exist candidate options with their respective advantages and drawbacks, it is difficult to be confident about which candidates will be chosen by the aviation community.

6. It is predicted by Eurocontrol that the capacity of *en route* airspace can be substantially increased through the introduction of Direct / Free routing, new controller tools to reduce workload and new airspace designs and FUA. Figures between 17% and 40% capacity gains for Direct / Free routing have been quoted, though care must be taken when interpreting such figures to ensure the underlying assumptions are understood correctly. These changes are consistent with the ATM2000+ strategy promoted by Eurocontrol. Increased capacity of the *en route* airspace does not automatically translate into an increased capacity at UK airports, which will depend upon other airport constraints.

E-ticketing, smart cards, RF tags and advanced biometrics could substantially enhance passenger capacity of airports

7. Industry figures quote anywhere between 50% and 80% reduction in transaction time for passengers with baggage through the application of smart card technologies. Technologies and individual products for e-ticketing, smart cards and RF tagging exist today but are not routinely used in airports or by airline operators. Concepts for their operation in airports exist and system integration is required before many of these technologies are in common use at UK airports, industry suppliers expect this to happen in the short to medium-term. The precise combination of technologies that will make up these future systems will vary between suppliers and from airport to airport, it is likely that initial systems will be fairly limited in the technologies they use but will be capable of upgrade. One issue these technologies to reduce transaction times at airports raise is that reducing the amount of time passengers spend in airport terminals also reduces retail opportunities on which many airports rely for revenue.

8. The use of advanced biometric measures for security systems is much more long-term, they still have to be developed from scientific prototypes that exist today.

At two ends of the spectrum VLAs and small turboprop aircraft are expected to enable new forms of air travel in the future

9. VLAs could substantially increase the number of passengers per aircraft movement at our major hub airport, Heathrow. If industry predictions are correct there could be nearly 100 aircraft each capable of carrying in excess of 500 passengers regularly using Heathrow by 2018. Coping with VLAs will require major improvements to the airport infrastructure both on the ground and in the terminal building.

10. At the other extreme, small turboprop aircraft offer opportunities for low cost, low noise point-to-point travel for 5 to 10 passengers from small airfields. In the USA this form of travel is popular and growing and, although the UK have in the past tended to follow American trends (e.g. the low cost carrier), it is unclear whether this will be the case for small turboprops given the different geographical size and different travel patterns.

Comments on quantifying the Capacity Benefit of Future Technologies

11. The capacity benefit derived from a new technology is strongly dependent upon the operational environment into which it is placed and other constraints elsewhere in the ATC system which limit the maximum available capacity benefit. This makes it extremely difficult to distil out a reliable set of quantifiable capacity benefits and link them to individual future technologies.

12. In the knowledge that capacity benefits through operational improvements are very difficult to quantify, a three step approach has been adopted by Eurocontrol:

    i) Produce performance targets derived from the CFMU and forecast data from the aviation community to ascertain the capacity demand at an ATC unit level (i.e. airports, lower airspace sectors, upper airspace, etc.);

    ii) Extract potential capacity improvements available from future operational concepts (32 in total) across four main areas:

        – airspace organisation and management;
        – airspace utilisation;
        – productivity; and
        – airport utilisation;

    iii) Link the results of (1) and (2) and from this relate target operational improvements at ATC unit level.

13. The intention is to create a more balanced target setting process at ATC unit level through step (3), with Eurocontrol steering the direction of future operational improvements. This will better inform the process of selecting and developing future new technologies.

4 Future Environmental Mitigation Technologies

This section aims to qualify (quantitatively and qualitatively) the potential for future environmental technologies to mitigate the predicted future impact of aviation based on its continued growth (described in Section 2). It includes the following two main subsections.

1. **Definition of Environmental Benefits:** This sub-section defines indicators that model the potential environmental benefits from future environmental mitigating technologies. Annex C provides background and details on the environmental benefit indicators used throughout this study.

2. **Environmental Technology Assessment:** This section applies the technology environmental benefit criteria to assess predicted environmental mitigation of future engine and airframe technologies until 2030 and compares these benefits to future growth scenarios. This assessment includes a discussion of:

    i) Technology Groups: In most cases it is unrealistic to consider "stand-alone" technology advances and the benefits are often inter dependent on other advances. Individual technology elements are described in Annex B.

    ii) Environmental Benefits: The impact of these clusters partitioned in terms of the type of environmental benefit offered (global CO_2 emissions, local noise, local air quality, land take).

    iii) Technology Inter-Relationships: Discussion of inter-relationships with other technologies in terms of how this influences realisation of the benefit (i.e. maximum benefit versus sub-optimal benefit).

    iv) Capacity Gains: Any capacity implications arising from the technologies, though reference should be made to Section 3 for a more detailed discussion of technologies for capacity benefit.

The qualification of the environmental benefits associated with individual technologies has been based on independent desktop research and interviews with industry stakeholders, including airlines, airport operators and aircraft and aero-engine manufacturers. As far as possible, industry claims on a technology’s environmental performance have been cross-checked with independent research (e.g. by NASA, EU research programmes, IPCC) however it has not been possible to individually validate manufacturers performance claims. Detailed description of environmental mitigation technologies is provided in Annex B.

4.1 Overview

The global (CO_2 and NO_x emissions and contrail formation) and local (noise and local air quality pollution) impacts of aviation are becoming increasingly more important due to continued growth of the sector and increasing stakeholder concerns.

Future critical technologies to mitigate these impacts continue to be researched and developed and include:

- **The development of technologies for improving aerodynamics, research on structures and materials to reduce weight, and development of new engine designs with improved efficiency;**
- **Development of new combustor concepts to achieve substantial NO_x reductions;**
- **Noise reduction technologies to minimise noise at source generated by engines, and the airframe itself; and**
- **Advances in on-board systems and equipment contributing to improved ATM systems and operational procedures that improve fuel efficiency and community noise.**

Taken together these technology developments are expected to reduce significantly the global and local normative impacts of aviation with respect to today's levels. At a global level fuel efficiency improvements, and therefore CO_2 and NO_x emissions reductions of up to 2%/annum are forecast by this study from engine, airframe and operational developments. However, these improvements will not offset fully the global impacts of predicted growth in air traffic, since at a global level air traffic is predicted to grow at an average of 5%/annum and double in roughly 16 years. Consequently, the net global warming potential of aviation is predicted to grow.

At a local level integrated noise reduction covering engine, airframe and operational developments is forecast to halve the noise from aircraft in 10 to 15 years compared to today's aircraft. Whilst noise modelling at UK airports indicates that the size of the 57 dBA leq contour is decreasing, noise perception indicators such as noise surveys, and continued resistance to capacity expansion (e.g. Terminal 5 at Heathrow), indicate that sensitivities to noise continue to be a major issue. Therefore there remains uncertainty whether future noise reduction techniques can cancel anticipated capacity growth noise annoyance, as substantiated by the following quote:

> **"*Incremental improvements in engine and airframe technology will help to reduce noise, but are unlikely to provide much headroom against the forecast growth in demand for air travel.* " (The Department, 1997)**

Lastly, NO_x reduction technology is forecast to improve individual aircraft NO_x emissions by up to 80% per LTO cycle by 2030. However, increased air, airport and surrounding traffic growth may potentially cancel these benefits. Indeed, continued local sensitivities will ensure that local air quality remains a significant issue, and could unless resolved (especially at high volume airports and those that are currently not in compliance with the UK AQS) result in local restrictions on future growth. Furthermore, future advancements in low NO_x technology must be offset against the continuing development of higher pressure ratio engines, which improve fuel efficiency but also lead to higher NO_x per unit of burnt fuel.

4.2 Definition of Environmental Benefit

This sub-section details the definitions used by this study for environmental benefit, including the derivation of this definition and reasons why some environmental contributions are not included.

This study has applied a screening methodology to identify and define the significant environmental benefit criteria for describing the environmental benefits of future aviation technologies

1. The significant environmental impacts of aviation are identified and reviewed in order to define indicators that model the potential environmental benefits from future environmental mitigating technologies. A four step screening methodology is used to limit the final list of benefits criteria and this is summarised in Annex C.

The significant 'Global' environmental technology benefits defined from this study are CO_2 and NO_x emissions per passenger kilometre

2. In terms of the global impact of aviation, CO_2 and NO_x[14] emissions per passenger km are defined as the most significant environmental benefit criteria. In this context significant refers not only to the radiative forcing potential of the emission but also to the availability, potential and certainty for future technologies to mitigate the emission. The impact of aviation on global UV-B irradiance is not considered explicitly since it applies predominantly to supersonic travel that is not expected at a statistically significant level during the 2030 timeframe of this study.

The 'Global' impacts of contrail and cloud formation effects are significant, however the technology mitigation potential remains largely uncertain and unverified.

3. This study recognises that contrail and cirrus cloud formation are identified as major contributors to the radiative forcing effect of aviation *(see Box 4-1.).* Whilst operational procedures and to certain extent technology developments are being developed to mitigate contrail formation, specific information from technology developers on these options remain vague and the levels and certainty of the mitigation potential remain largely un-quantified. Furthermore significant uncertainty remains on the potential impacts of aviation-induced cirrus clouds and to a lesser extent contrails. Given these uncertainties and lack of verifiable performance data for the mitigation potential of future aircraft technologies against contrail and cirrus cloud formation, the technological assessment has not explicitly assesses technology performance with respect to contrail and cirrus cloud formation. However, this study does recognise the importance of these effects and these are

[14] High level NO_x emissions act to decrease high level concentrations of methane while also increasing concentrations of ozone. Both methane and ozone are radiatively actively substances, however the decrease in methane does not necessarily cancel the increases of ozone since the geographical distribution of each of these substances differs. Changes in Ozone are mainly located near the flight routes in the northern hemisphere, while those of methane are globally mixed. This implies that global emissions of NO_x continue to be a problem in the upper troposphere.

considered when assessing the implications for future Government policy (see section 7).

Box 4.1 – Relative Contribution of Contrails and Cirrus Clouds to Global Aviation Impact

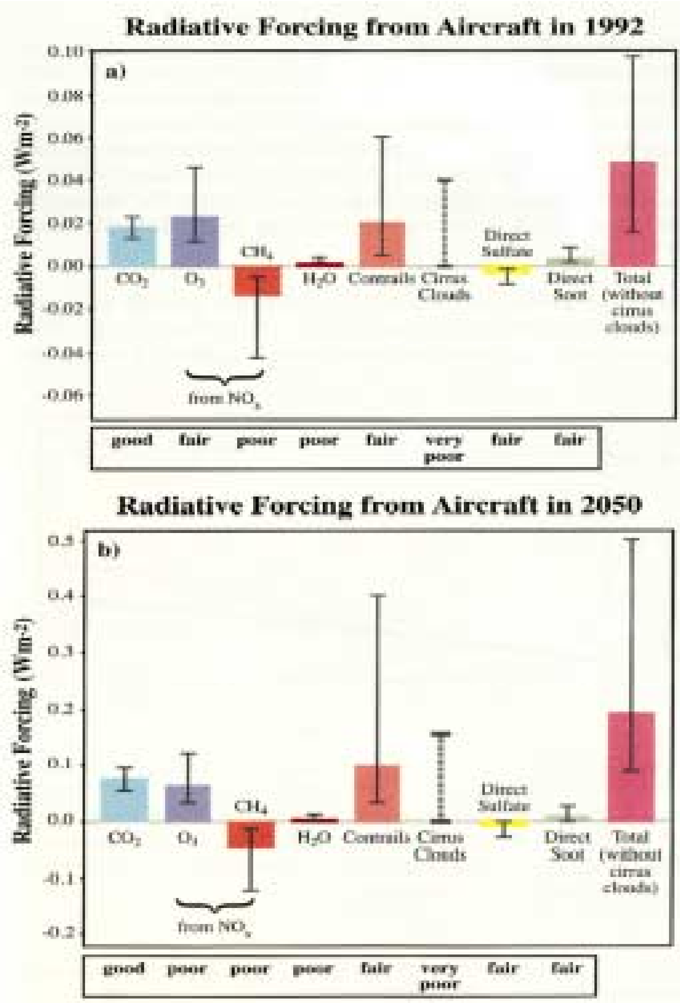
The IPCC (1999) estimate that in 1992 aircraft line-shaped contrails covered approximately 0.1% of the earth's surface on an annually averaged basis with larger regional values. Based on future projection of air travel growth (Fa1 scenario) contrail cover is expected to grow to 0.5% by 2050, at a rate which is faster than the rate of growth in aviation fuel consumption.

This faster growth rate in contrail cover is expected because air traffic growth is forecast to increase mainly in the upper troposphere where contrails form preferentially, and may also occur as a result of improvements in aircraft fuel efficiency. Similar growth in cirrus cloud cover is predicted with a fourfold increase in aircraft induced cirrus clouds predicted between 1992 and 2050.

The IPCC (1999) estimate[15] the radiative impact of contrails in 1992 as 0.02 Wm^{-2}. Given a total radiative forcing estimate for aircraft emissions of 0.05 Wm^{-2} (excluding cirrus cloud effects), this implies that contrails contribute approximately 40% of total forecast radiative forcing in 1992.

Projections for 2050 indicate that the radiative impacts of contrails are estimated to increase to 0.1 Wm^{-2} (50% of total radiative forcing of 0.19 Wm^{-2} forecast for the Fa1 scenario in 2050).

The radiative forcing impacts of cirrus clouds remains largely uncertain with ranges predicted of 0 to 0.04 Wm^{-2} for the 1992 scenario an 0 to 0.16 Wm^{-2} for the 2050 scenario. Due to "very poor" scientific understanding of cirrus cloud impacts, total radiative forcing excludes the impact of these effects.



Source: IPCC 1999

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[15] The bars indicate the best estimate of radiative forcing while the line associated with each bar is a two thirds uncertainty range developed using best knowledge and tools available at present time. Two thirds uncertainty range means there is a 67% probability that the true value falls within this range. The evaluations below the graph ("good", "fair" etc) are a relative appraisal associated with each component and indicate the level of scientific understanding.

The significant 'local' benefits defined for this study are local air quality characterised through aircraft NO_x emissions, and noise pollution characterised through aircraft and community noise measures

4. Noise from day and night time aircraft landing and take-off (LTO) and to a lesser extent from airport operations is becoming increasingly important issues in capacity expansion plans at UK airports. Whilst reactions to noise are highly subjective efforts to characterise noise have resulted in a number of measures including leq contours (the 57 leq contour used in the UK is considered to define the onset of significant community disturbance).

5. Similar local concerns apply to local air quality and local air quality indicators are routinely reported at UK airports. As with noise it is difficult to model the air quality impacts of individual technologies, however aircraft NO_x emissions are deemed to be of most concern as evidenced by continuing CAEP regulations to certify engine NO_x emissions over the LTO cycle. VOC and PM10 emissions are also of concern at airports, however the major contributors of these emissions in the locality of airports are land based equipment and vehicles. Furthermore the focus of this study is on aircraft technology and modern aero-engines are not significant emitters of VOC and PM10 emissions.

6. Inter-modal integration and land take effects of technologies are considered but only indirectly, whilst airport and airline performance in terms of energy efficiency, waste disposal, impact on sensitive ecology and water emissions are not considered significant within the scope of this study.

4.3 Engine Technologies

This sub-section details potential future technological advances in engine technology which could provide an environmental benefit. The table at the end of this section summarises the key technologies identified in the short, medium and longer term and the identified environmental mitigation benefits forecast in each case. Annex B provides details on the future engine technologies for environmental mitigation referred to in this section.

Findings

The findings with respect to future engine technology developments are as follows:

Engine technology developments focus on improving fuel efficiency, NO_x emission reduction and noise minimisation

Engine technology developments focus on three interdependent issues:

1. **Fuel Efficiency[17]:** Innovations that improve fuel efficiency and therefore all other things remaining equal reduce the amount of fuel burned and therefore the mass of global warming emissions per passenger km. These technologies focus on improvements to engine core thermal and propulsive efficiencies.

2. **NO_x reduction:** Developments that alter the percentage concentrations of particular exhaust gases. In this case the emphasis is on reducing NO_x for a given mass of burnt fuel. These developments focus on changes to the combustor design and can be currently certified through Volume II of Annex 16 to the Convention on International Civil Aviation.

3. **Noise reduction:** Engine developments that reduce take-off noise and which can be certified through practices first adopted by the ICAO Council. ICAO established international noise certification standards in the 1970s. These are contained in Annex 16 to the Convention on International Civil Aviation. The initial standards for jet aircraft designed before 1977 are known as Chapter 2. Newer aircraft are required to meet the stricter standards contained in Chapter 3 of Annex 16, while more recently ICAO and the aviation industry are exploring the scope for a revised noise standard for new aircraft designs that is tougher than that contained in Chapter 3[18].

In the short to medium-term fuel efficiency gains of 10-20% are predicted and in the longer term, subject to significant technological breakthrough up to 30% gains are forecast

4. Near terms developments to improve the overall efficiencies of aero-engines focus on incremental changes to raise core thermal efficiency and propulsive efficiency. In

[17] It is important to note that current technologies for improving fuel efficiency focus on raising the pressure ratio and this increases the production of NO_x per unit of fuel burnt.

[18] The new noise restrictions are expected to be considered by ICAO at the next full meeting of CAEP which will take place in early 2001, thereafter by the ICAO Assembly in September 2001.

terms of propulsive efficiency improvements, developments focus on increasing the By-Pass Ratio (BPR), in other words enlarging the diameter of the propulsor. Current practical constraints of aero-engine designs mean that it is possible to increase the BPR up to 10. Enlarging the BPR above this but below 15 is possible through the introduction of a gearbox to the powertrain.
Whilst there are significant practical difficulties associated with this, plans for such a design have recently been announced[19] and are predicted to offer up to 15% fuel efficiency improvement on current designs. More futuristic designs focus on propless or unducted fan engines offering BPR's of up to 30 and are predicted to deliver fuel efficiency improvements reaching 25-30%. Although early prototypes have been flight tested, commercial take-up of this technology is unlikely before 2020, since it requires aircraft and airport structural changes.

5. Core thermal efficiency improvements centre on increases in the pressure ratio of compression, higher temperature hot sections with reduced or eliminated cooling requirements, and improved component efficiencies. Improvements are also possible to reduce engine weight through improved aerodynamics and materials.

Incremental fuel efficiency gains are reaching a plateau as the marginal benefit curve flattens out

6. Fuel efficiency developments have followed a steady path resulting in continuous but steadily decelerating amount of improvements over the past 40 to 45 years. As Figure 4-1 shows, specific fuel consumption[20] of aero-engines has improved by over 50% in the last 40 to 45 years, however the slope of the curve is flattening out and future gains will become increasingly more difficult as the benefit curve reaches a plateau. Research into alternative future new fuels which are not fossil-based is ongoing. However, for the aviation industry the problems are fundamental and hence these fuel types have not been considered within the scope of this study.

[19] For example MTU are planning to develop a geared fan European Low Emission Recuperated Engine (EULER) as part of the European Union's Fifth Framework research programme.
[20] Specific Fuel Consumption means the amount of fuel weight flow to an engine's combustor in kg per hour (kg/h) divided by the amount of thrust produced by the engine in dekanewton (daN=10N)

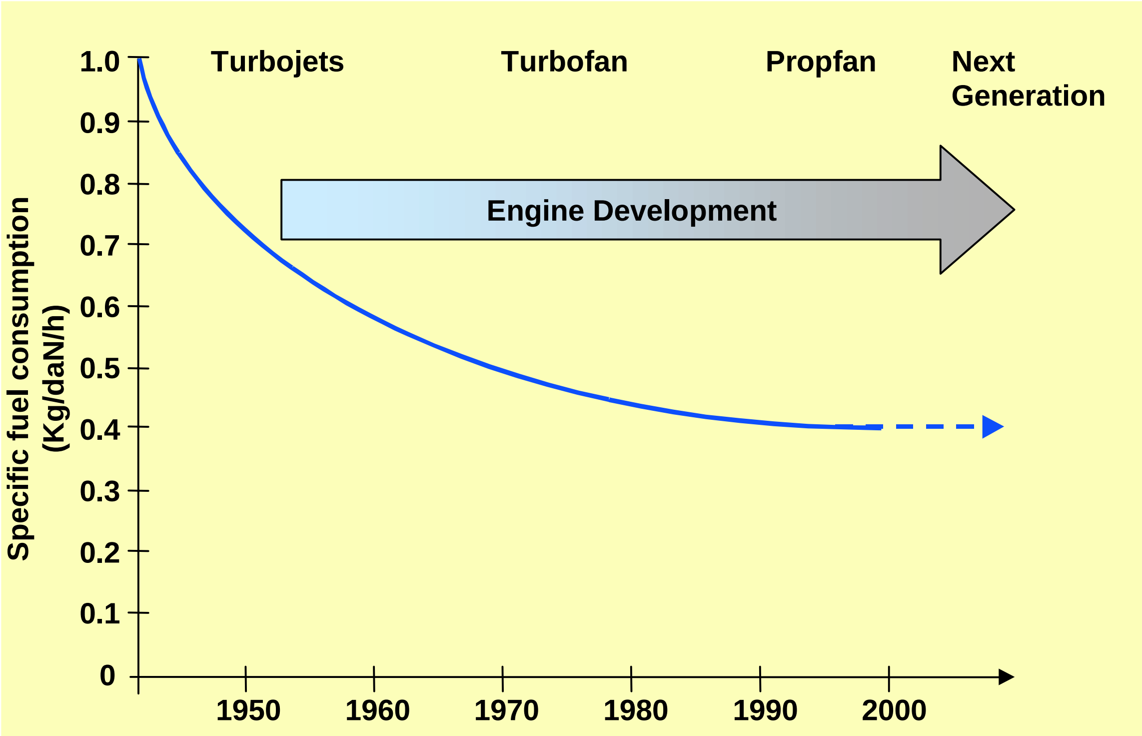

Figure 4-1: Aero Engine Fuel Efficiency Development (Commission of the European Communities, 1999)

Near term improvements of up to 30% NO_x reduction are forecast, whilst longer term Ultra Low NO_x technology is estimated to achieve up to 80% reduction in NO_x

7. Near term combustor improvements are focusing on two parallel strategies. The first favoured by MTU[21]is concentrating on advanced conventional single annular designs, whilst the second strategy, favoured by Rolls Royce and GE are focusing on double annular combustors[22]. Both these technology options are currently under development with initial designs entering production, and according to figures provided by their respective manufacturers will offer up to 30% reduction in NO_x to conventional designs. Longer-term developments centre on Ultra Low NO_x technologies such as Lean Premixed Prevapourised (LPP) combustors that aim to deliver up to 80% reduction in NO_x emissions. Currently LPP technology is not envisaged for high-pressure ratio aero-engines, although it does offer potential for supersonic aircraft where operating pressures are lower.

[21] German engine manufacturer
[22] Sometimes also referred to as staged combutors

Historic noise improvement gains have been significant and accrued from the trend towards increased by-pass ratio engines

8. Noise reduction gains to date have tended to ensue from engine developments based on increasing by-pass ratios. Indeed such developments in the past 30 years have resulted in aero-engines that are 20 dBA quieter on take-off and landing (Rolls Royce, 1999a). This means that only 1% of the acoustic power is being generated by modern designs compared with the first commercial turbojet. Figure 4-2 below summarises noise improvements over the last 30 years.

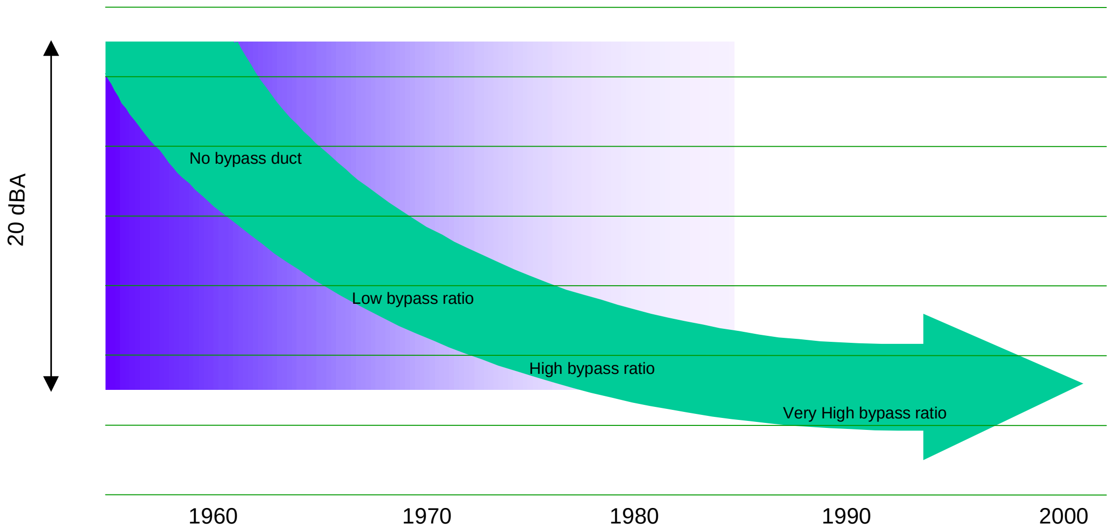

Figure 4-2: Noise reduction improvements from aircraft engines *(Rolls Royce, 1999a)*

Future noise reduction gains are predicted to be incremental and estimated to offer up to 10dB cumulative improvement in the next 10 years

9. Noise reduction gains through increased BPR engines are reaching optimal levels and other strategies are being pursued. In the short to medium-term these include low noise fan rotors and stators (used to direct flow), improved fan case liners and optimised acoustic liners, new low-noise turbine and nozzle shapes, and a nacelle (the casing that contains the engine) with a specially-shaped inlet duct that directs noise upwards, away from the ground. Whilst in the longer-term passive and active noise control are being researched.

10. The impact of these technology advances varies, however Rolls Royce (1999a) have set themselves a target of reducing aero-engine noise by 10dB by 2010. Similarly, technology programmes specified under BRITE/EURAM, e.g. "RAIN, RESOUND and RANNTAC" (see Annex B for details) aim to achieve an overall aircraft noise reduction of at least 6dB in eight years. This compares with estimates of 20dB cumulative noise reduction forecast by NASAs Environmental Compatibility Assessment programme between 1997 and 2017 (*Stephens, 1998*) and shown below in figure 4.3.

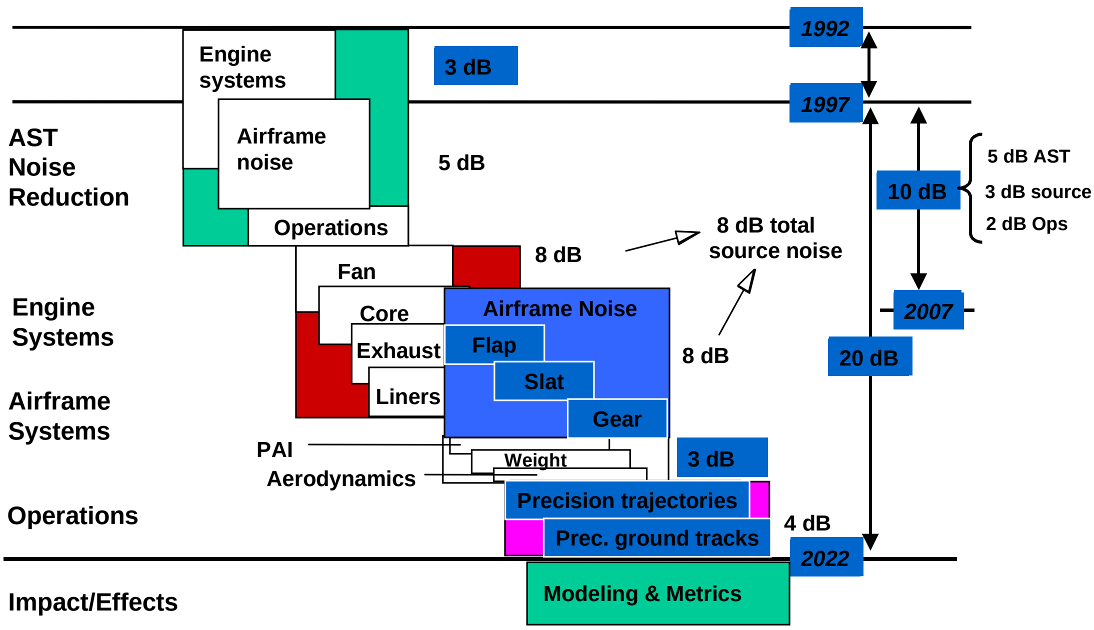

Figure 4-3: NASA ECoA Noise reduction waterfall (Stephens, 1998)

11. The variance between these estimates is to large extent due to differences expected at the component level (e.g. for an engine) and at the system level where component noise reductions are not necessarily cumulative.

Noise reduction gains in the next 10 years are not predicted to be commensurate with historic gains

12. Needless to say these technology benefits do not offer commensurate gains at source achieved over the past twenty years with the introduction of high-by-pass ratio engines. Furthermore, quoting from the Heathrow Terminal 5 Proof of Evidence, this states that:

"Incremental improvement in engine and airframe technology will help to reduce noise, but are unlikely to provide much headroom against the forecast growth in demand for air travel. " (The Department, 1997, p12-13).

There are intrinsic trade-offs between technologies that reduce CO_2, NO_x and noise, although longer term advances are working towards minimising these trade-offs

13. One of the clear lessons from early emission reduction programs was that changes to reduce NO_x emissions could produce adverse effects on other performance characteristics including reduced fuel efficiency, therefore introducing a trade-off between NO_x and CO_2 emissions for any given engine. Theoretically combustor technology can reduce NO_x levels for varying pressure ratios, however there will still remain some trade-off between CO_2 and NO_x, although this will be at lower NO_x levels. Even with very advanced combustion technologies that minimise NO_x formation by pre-mixing fuel and air to control combustion temperatures there remain trade-offs between CO_2 and NO_x as a result of high combustor exit temperatures.

14. On the noise side there are also significant interdependencies. These are between different noise sources (e.g. noise reduction technologies are not cumulative and may even in the worst case cancel each other out), whilst there are also trade-offs between noise exposure and fuel efficiency (for example unducted engines would improve fuel efficiency but potentially increase engine noise).

Long-term engine technologies are expected to deliver up to 30% fuel savings, 80% fall in NO_x emissions and 10dB noise fall at the component level

15. The cumulative environmental benefits predicted from future engine technology developments in the short, medium and long-term are summarised in the table below.

ENGINE DEVELOPMENTS	SHORT-TERM <2005	MEDIUM-TERM 2006-2015	LONG-TERM 2016-2030
High altitude CO_2 and NO_x emissions	Incremental improvements to: 1) raise core thermal efficiency through continued increases in the pressure ratio of compression, higher temperature hot sections with reduced cooling, and improved component efficiencies 2) Increases of the by-pass ratio up to maximum of 10	Increases of the by-pass ratio above 10 through the incorporation of in line gearbox and continued development of technologies for engine airframe integration (to reduce drag)and material developments to reduce engine weight	Futuristic engine designs incorporating as yet unproven technologies such as unducted very high by pass ratio engines, integrated to the aircraft body and improved low weight materials
	Potential Gains[23] 10-15% cumulative reduction in specific fuel consumption.	**Potential Gains** 15-20% cumulative reduction in specific fuel consumption	**Potential Gains** 20-30% cumulative reduction in specific fuel consumption
Local Air Quality	Staged conventional and advanced single annular combustors	Second phase developments of staged and advanced single annular combustors	Lean Pre-mixed Pre-vaporised fuel (LPP technology)
	Potential Gains Up to 30% fall in LTO NO_x	**Potential Gains** Intermediate gain prior to LPP technology (see 2030 developments), but notional improvements of up to 50% are forecast	**Potential Gains** Up to 80% fall in LTO NO_x
Community Noise	Continued gains from increasing engine BPR	Low noise fan rotors and stators, improved fan case liners and improved low noise turbine and nozzle system	Active and passive noise reduction technology
	Potential Gains Limited future potential but cumulative gains of 2-3dB possible	**Potential Gains** Cumulative noise reduction of up to 10dB	**Potential Gains** Unknown but cumulative effect is predicted in excess of 10dB

[23] All potential gains are based on Arthur D Little analysis and quoted as cumulative and relative to current technology

4.4 Airframe Technology

This sub-section presents potential future technological advances in airframe technology that could provide an environmental benefit. The table at the end of this section summarises the key technologies identified in the short, medium and longer term and the identified environmental mitigation benefits forecast in each case. Annex B provides details on the future airframe technologies for environmental mitigation referred to in this section.

Findings

The findings with respect to future airframe technology developments are as follows:

Airframe developments focus on aerodynamic improvement and weight reduction strategies and have resulted in 30% fuel efficiency improvements in the past 40 years

1. Airframe developments for fuel and noise efficiency centre on weight reduction and aerodynamic developments. Historically airframe improvements have focused more on fuel efficiency improvements and have resulted in 30% fuel efficiency (ASK kg^{-1} fuel) improvement between 1950 and 1997 *(IPCC, 1999).*

Increased use of composite materials throughout the airframe offer continued fuel saving opportunities

2. With increased availability and cost competitiveness of advanced lighter and stronger materials significant weight savings have and are being achieved through the replacement of airframe components with new aluminium alloys, titanium components and composite materials for secondary (non-load bearing) structures.

3. The medium and longer-term challenge is the introduction and, more critically, certification of composite materials into primary structures such as the wing, fuselage and empennage. Furthermore, introduction of composites promotes further weight reduction through improved manufacturing processes and underpins proposed developments of composite wings incorporating Active Aeroelastic Wing (AAW) technology aimed at reducing drag. Taken together, NASA estimate that composite material technology and AAW can offer up to 30% reduction in take-off gross weight and associated fuel saving. *(Brown, 1998).*

Short to medium-term aerodynamic improvement offer up to 20% fuel efficiency gains, whilst longer term, more uncertain technologies could additionally offer up to 15% fuel efficiency gains

4. Aerodynamic improvements can also add to fuel savings. Short to medium-term improvement relate to integration of riblets into the fuselage, passive control devices to enhance laminar flow, improved wing surface smoothness and improved engine airframe integration which could cumulatively offer up to 20% fuel savings. In addition, Boeing has recently announced their new winglet technology that can be retrofitted to existing aircraft.

Winglets are claimed to have the potential to reduce aerodynamic drag, increase cruise performance, improve fuel burn, extend range and allow heavier payloads. Fuel savings of 2-3% are quoted, though performance improvement will depend upon the aircraft model and route flown.

5. Longer term development centre on active laminar flow devices which are predicted to additionally deliver up to 15% fuel efficiency (ASK kg^{-1} fuel) improvement, however the net benefits remain unknown due to possible operational inefficiencies and the introduction of additional weight to the aircraft.

Airframe technologies are predicted to achieve up to 10dB noise gains in the next 10 years

6. Future noise reduction will need to focus on noise sources from airframes, these are becoming more noticeable as engine noise decreases, especially during the landing phase. Noise reduction strategies to minimise airframe noise centre on technologies associated with minimising noise from high lift devices (slats and flaps) and the landing gear. Research being carried out under the BRITE/EURAM 4th Framework Reduction of Airframe and Installation Noise (RAIN) cluster indicates that noise reduction at the component level of between 5dB and 10dB could be expected. However, the full impact will only be realised when the new airframe related technologies are integrated with that of the engine, a much smaller noise net gain is expected following integration. However, in service demonstrated performance has been found to lag NASA's technology programme goals, therefore noise reduction forecasts may be optimistic.

7. Additional noise reductions will also accrue from fuel saving technologies focused on improving aerodynamics and airframe weight. For example, winglet technologies will reduce noise due to the need for less take-off thrust and associated requirement for lighter engines with less engine noise and fuel consumption.

Long-term airframe technologies are expected to deliver up to 40% fuel efficiency improvements and a theoretical 10dB noise reduction at the component level

8. The environmental benefits predicted from future airframe technology developments in the short, medium and long-term are summarised below:

AIRFRAME DEVELOPMENTS	SHORT-TERM <2005	MEDIUM-TERM 2006-2015	LONG-TERM 2016-2030
High Altitude CO_2 and NO_x Emissions	Improved engine airframe integration, improved materials and systems design for low weight optimised with reduced aerodynamic drag design	Improved passive laminar flow design, increased use of composites for primary and secondary structures, and improved metallic/system design for low weight	Active laminar flow, composite materials throughout airframe and AAW technology
	Potential Gains[24] Cumulative net fuel efficiency gain of 10% ASK kg^{-1} fuel	**Potential Gains** Cumulative net fuel efficiency gain of between 10 – 20% ASK kg^{-1} fuel	**Potential Gains** Cumulative net fuel efficiency gain of 30-40% ASK kg^{-1} fuel
Local Air Quality	Not directly applicable although there will be some indirect impact through reduced fuel consumption	Not directly applicable although there will be some indirect impact through reduced fuel consumption	Not directly applicable although there will be some indirect impact through reduced fuel consumption
	Potential Gains Not quantifiable	**Potential Gains** Not quantifiable	**Potential Gains** Not quantifiable
Community Noise	Landing gear and highlift devices aeroacoustic improvements. Improved engine/airframe integration	Integrated airframe noise reduction based upon technologies to minimise noise from high lift devices and landing gear	Advanced future designs, e.g. Blended Wing Body
	Potential Gains 2-3dB	**Potential Gains** 5 to 10dB cumulative noise reduction at the component level	**Potential Gains** Unknown

[24] All potential gains are based on Arthur D Little analysis and quoted as cumulative and relative to current technology.

4.5 CNS/ATM Infrastructure and Operational Developments

This sub-section addresses the application of new technologies to the CNS/ATM infrastructure and the extent to which they can provide environmental mitigation. Although these technologies are aimed primarily at capacity enhancement there is often an important environmental benefit to be had, which is discussed here.

Findings

The findings with respect to future environmental mitigation technologies within CNS/ATM and operational improvements are as follows:

Better ground operations through the introduction of A-SMGCS and surface managers could significantly improve local air quality and potentially reduce noise

1. The inefficiencies that exist in aircraft operations around the airport terminal mean that aircraft spend significantly longer on the ground with their engines running than is necessary. It is estimated that at Heathrow alone there could be a saving in fuel burn of 90,000 tonnes per annum through the introduction of A-SMGCS and related ground management systems, such as improved surface management. This saving is roughly equivalent to one day of fuel burn across the whole ECAC area. In addition to improvements in local air quality through better fuel efficiency there should also be a noise reduction associated with aircraft spending less time with their engines running, though this may not have a significant impact beyond the airport perimeter. Improvements in ground operations are being studied today, for example the Eurocontrol study into more flexible taxiing times at Heathrow which aims to reduce the total time spent taxiing to the runway. This and other studies provide a first step towards the eventual introduction of full surface management systems.

The introduction of Direct Routing in the en-route flight phase could reduce fuel burn significantly through enabling aircraft to fly optimal flight paths

2. Aircraft have to fly along a fixed route network when journeying from start to destination airports. The route network is an historic part of the infrastructure, resulting from the days when following a set of ground beacons was the only reliable source of navigation for aircraft. However, with the advent of GPS and modern FMS onboard the aircraft it is now possible to derive a set of way points which are not necessarily linked to physical locations on the ground. These new technologies enable the introduction of new concepts of operation, such as Direct Routing, whereby the aircraft determines an optimal flight path from start to destination airports without reference to fixed points on the ground.

3. Estimates of efficiency improvements presented in the previous section will translate directly into reductions in fuel consumption and hence reduced global environmental impact. For a typical short haul flight it is estimated that the reduction in flight time could be as much as 20 minutes (Arthur D. Little,1999a). An example given is a flight from the UK to a Southern European destination, this requires an aircraft to fly through the airspace of many European states and the routings provided by these states can result in a journey which is far from direct. Assuming a 12% improvement in efficiency on 80,000 tonnes of fuel for such a flight, this equates to nearly 10,000 tonnes less fuel consumption (Arthur D. Little, 1999a)

Air Traffic Operations procedures, including Advanced Continuous Descent Approaches offer significant noise reduction potential at airports

4. Air traffic operations procedures such as alternative approach and departure procedures e.g. Advanced Continuous Descent Approaches (ACDA) offer noise reduction at airports by supporting reduced thrust settings during landing. Research by NLR (Erkelens, 1998) shows a significant fall (approximately halving) in the 65 dBA footprint for a Boeing 747 versus a conventional approach, whilst NASA research predicts 2-3dB noise reduction. Clearly the actual in situ level of noise reduction achieved will depend on numerous factors, notably the aircraft type, and therefore the more conservative NASA forecast is likely to be more realistic of the noise improvement benefits of ACDA technology. ACDA also offers improved fuel consumption, reduced emissions and reduced overall approach time.

For current world-wide aircraft fleet operations, improvements in CNS/ATM could reduce fuel burn per trip by 6% to 12% on average

5. CNS/ATM aims to make maximum use of available capacity by improving the identification and predicted movement of aircraft and vehicles in the airport movement area. This incorporates technologies underlying Direct Routing and A-SMGCS discussed previously.

6. Fuel savings associated with introduction of CNS/ATM systems are estimated to range between 6-12% per trip on average (IPCC, 1999; *Eurocontrol, 1997; FAA, 1988; ICOA, 1998a).* Developments in Europe are being led by EUROCONTROL who have defined the future European ATM System (EATMS) and associated ATM strategy for 2000+ managed on a total system perspective from gate to gate. Harmonisation of these systems will in theory lead to a global integrated ATM system.

Improvements in aircraft utilisation, cruise speed optimisation, operational weight reduction and improved taxiing could lead to potential reduction in fuel burn per trip of 2-6%

7. Fuel savings can also be achieved through the operational optimisation of aircraft operations. These include improving aircraft capacity utilisation (a function of aircraft configuration and utilisation), reducing the operational weight of the aircraft, improved taxiing and optimising the aircraft speed.

8. Whilst economic pressures on the industry have dictated that many of these factors have already been optimised by operators, the IPCC (IPCC,1999) estimate that further optimisation of such operational measures can result in fuel savings of between 2-6% per trip.

Some ATC practices will reduce the potential environmental mitigation benefit of new technologies

9. There often exists a trade-off between operational procedures to maximise the throughput of aircraft within the highly constrained existing CNS/ATM infrastructure and the desire to minimise the global and local environmental impact of aircraft. For example, to maximise the capacity of runways at the busiest airports the operational procedure in the UK is to have stacks. Even with the introduction of new technologies for improved environmental mitigation this operational procedure will reduce the environmental benefit through more emissions due to greater fuel burn and more noise in the vicinity of the stacks.

10. The existing airspace structure also imposes constraints on aircraft entering into the approach phase of flight. The flight level to distinguish between lower and upper airspace was determined many years ago and since then the optimum performance envelope of aircraft has changed significantly. Nowadays, these flight level boundaries combined with national boundaries can result in aircraft having to descend to sub-optimal flight levels well in advance of starting their approach, or inhibit aircraft from following an optimal glide path into an airport.

11. In *en route* airspace many routes are so congested that often aircraft cannot gain clearance to the optimum flight level for their journey. Also, technology limitations mean that the existing route structure and its operation is very inflexible, ideally aircraft should increase their flight level as they burn fuel and reduce their payload. This dynamic approach to flight operations is just not possible today, again reducing the benefit that can be accrued from the introduction of environmental mitigation technologies.

4.6 Overall Environmental Mitigation Benefit

This sub-section summarises the benefits offered by new technologies in terms of where the benefit occurs, either global or local environmental mitigation, and over what time frame. All gains are cumulative and relative to current technology or international standards

Advances in airframe, engine and ATC/CNS technology and operational improvements are forecast to offer average fuel efficiency improvements of up to 2%/annum until 2030

1. Global warming emissions from aviation are predicted to grow at 5%/annum based on continued growth of the industry. Net cumulative benefits from mitigating technology are forecast at 2%/annum and this assumes continuous take-up of the technology (see Figure 4.4 and summary table below).

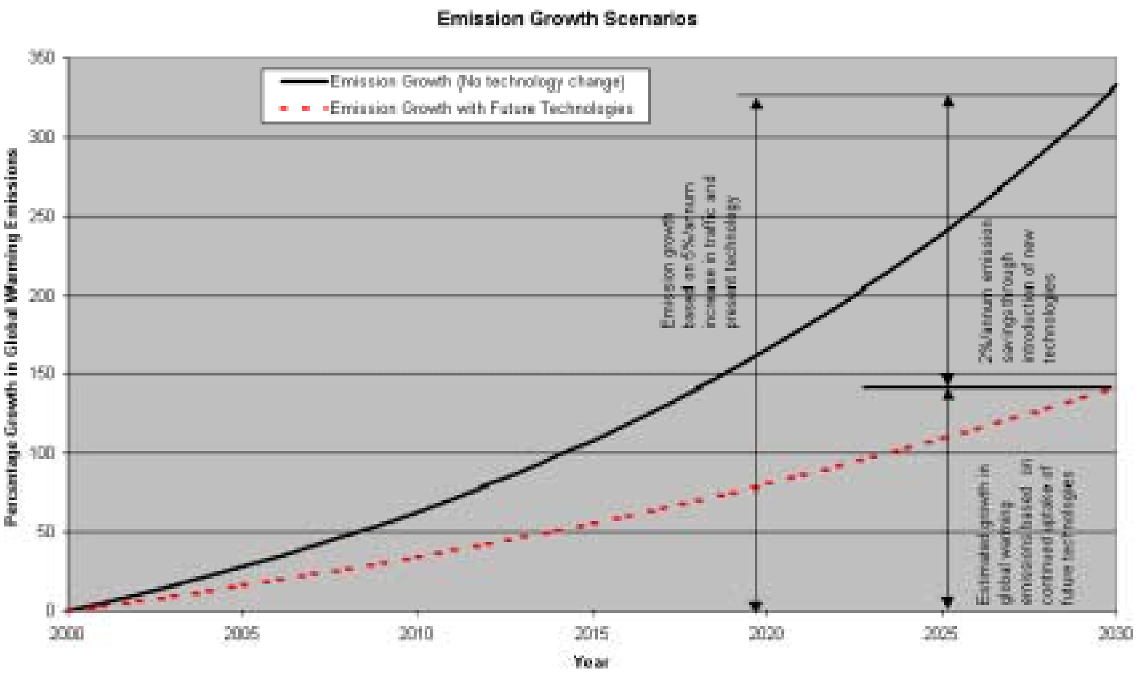

Figure 4-4: Emission Growth Scenarios to 2030 (Source: ADL Analysis)

High Altitude CO_2 and NO_x Emissions	**Technology Benefit Characterised by Fuel Saving**					
	<2005		2006-2015		2016-2030	
	Component[25]	**Gain**	**Component**	**Gain**	**Component**	**Gain**
	Engine:	10–15%	Engine:	15-20%	Engine:	20–30%
	Airframe:	5-10%	Airframe:	10-20%	Airframe:	30-40%
	ATC:	3-6%	ATC:	6-12%	ATC:	6-12%
	Operational	2-3%	Operational	3-6%	Operational	3-6%
	Total: [26]	**20-34%**	**Total:**	**34-58%**	**Total:**	**59-88%**
	Net gain until 2030 is equivalent to average 2%/annum improvement in fuel efficiency (ASK kg^{-1} fuel)					

2. These estimates compare favourably to alternative industry and research predictions of technology benefits, as follows:

   – Maximum 82%, and more practical 50% to 62% CO_2 reduction from engine and airframe technologies until 2027, estimated under the NASA Environmental Compatibility Research programme *(EcoA, 1998; Quinn, 1998).*

   – 20% fuel efficiency improvement from airframe and engine improvements until 2010, based on British Aerospace predictions *(Flight International, 2000a)*

Low NO_x technology developments are forecast to deliver 80% reduction in LTO emissions by 2030

3. Significant advancements in NO_x reduction technology are predicted. These estimates compare well with goals set under NASA's Ultra Efficient Engine Technology (UEET) programme, which aims to develop long-term technologies that deliver 70% less NO_x during the LTO cycle *(Flight International, 2000b).*

Local Air Quality	**Technology Benefit Characterised through NO_x Emission Reduction**					
	<2005		2006-2015		2016-2030	
	Component	**Gain**	**Component**	**Gain**	**Component**	**Gain**
	Engine:	20–30%	Engine:	30-50%	Engine:	50-80%
	Airframe:	unknown	Airframe:	unknown	Airframe:	unknown
	ATC:	unknown	ATC:	unknown	ATC:	unknown
	Operational	unknown	Operational	unknown	Operational	unknown
	Total:	**20-30%**	**Total:**	**30-50%**	**Total:**	**50-80%**

[25] For details on these benefits for Engines, Airframes and CNS/ATM see Section 4.3, 4.4 and 4.5 respectively.
[26] These totals are likely to be optimistic since particularly when looking at engine and airframe technologies, interactions are likely to reduce the overall benefit.

4. However, increased airport traffic and airport and surrounding traffic congestion may negate the potential NO_x reduction benefits of these technologies, especially at high volume airports within close proximity of major conurbations. For example, it has been shown that aircraft contribute between 16% and 35% of the ground level NO_x concentration at London Heathrow (Flight International, 2000b), and that 1996 NO_x air quality measurement at Heathrow are out of compliance with the Government's National Air Quality Strategy target for NO_x (BAA, 1998). Therefore, continued pressure to improve air quality as driven by European and UK regulations, in particular the UK National Air Quality Strategy, is expected.

Integrated noise reduction technology advancements covering engine, airframe and operational developments is forecast to reduce noise from future aircraft in the next 10 to 15 years by 10dB relative to Chapter 3

5. Technology advancements until 2030 are predicted to reduce the noise from future aircraft by 10dB relative to chapter 3, although the perceived effect when coupled with increased traffic and unknowns on the actual phase out of older technologies remains uncertain.

Local Noise	**Technology Benefit Characterised through Component Noise Reduction**					
	<2005		2006-2015		2016-2030	
	Component	**Gain**	**Component**	**Gain**	**Component**	**Gain**
	Aircraft	3-4dB	Aircraft	6-10dB	Aircraft	more than 10dB
	ATC:	2-3dB	ATC:	unknown	ATC:	unknown
	Operational	unknown	Operational	unknown	Operational	unknown
	Total:	unknown	Total:	unknown	Total:	unknown
	By 2030 aircraft noise is predicted to fall by 10dB relative to Chapter 3 standard					

Future aircraft designs until 2030 are considered most likely to be based around conventional airframe configurations, integrating best practice technology to address global and local emissions and noise

6. Futuristic concepts, such as the blended wing body, aim to bring together many of the latest engines, combustors and noise reduction technologies under a new and radically different airframe concept. Whilst the Blended Wing Body concept offers significant capacity and environmental benefits (see Annex B) the industry remains uncertain on the concepts viability within a 2030 timeframe.

7. Indeed given a predicted development and certification timeframe of decades, an unspecified market for the concept, additional infrastructure requirements, and uncertainties as to its performance and viability of supporting technologies, significant take-up of a Blended Wing Body design by airlines before 2030 is considered unlikely.

8. The trend, therefore, remains that future aircraft designs until 2030 are considered most likely to be based around conventional airframes (cigar shape as opposed to blended wing), with increasingly more emphasis placed on technology components that address fuel burn, emissions and noise in order to respond to airport and international pressures to minimise local and global impacts. Clearly this trend is a significant limiting factor to realising the potential environmental gains offered by "less conventional" aircraft designs.

5 Influences on the Take-up of Future Technologies

1. This section describes our analysis of the influences on the take-up of future technologies. When considering the take-up of new technologies for capacity enhancement, we have addressed the implications of commercial realities in the broad context rather than undertaking a detailed financial appraisal, to establish where commercial limitations of the technologies exist.

2. This analysis has been split into three parts. The first part (Section 5.2) describes generic technology take-up issues as they relate to the aviation industry. The second part (Sections 5.3 to 5.10) describes technology take-up issues as they relate to specific capacity enhancing and environmental mitigation technologies. The last part (Section 5.11) describes take-up issues that are not directly related to the take-up of future technologies for capacity enhancement or environmental mitigation at UK airports. Each part is described in more detail below.

3. **General take-up issues (Section 5.2)**: This section addresses general take-up issues that are not technology specific and apply across the industry. These are classified and described according to five categories, as follows:

   – **Return on Investment (ROI)**: Investment costs and the time horizon for a return on the investment for stakeholders;

   – **Technology Interdependencies**: Whether a technology has significant dependencies on other technologies or relies on enabling technologies being available;

   – **The need for Standards, Agreements and Certification**: The extent to which there is a need for certification and international agreements to be in place, and whether these exist already;

   – **Match between Stakeholder Needs and Technologies:** Whether a technology supports the business needs of the major stakeholders who would have to invest; and

   – **Match with Current Policy:** The extent to which the uptake of a technology is consistent with current policy, both in the UK and internationally

4. **Capacity and Environmental Technology Specific Take Up Issues (Sections 5.3 to 5.10):** These sections describe technology specific take-up issues. Whilst in most cases the broader general take-up issues will have an influence, the objective here is to contextualise more specific take-up issues by relating them to the main challenges and impacts identified earlier in this report. These are:

   – Take-off, landing and runway capacity;
   – Taxiways, Manoeuvring Areas and Gate Capacity;
   – ATC Infrastructure Capacity;
   – Terminal Utilisation;
   – Aircraft technologies and business models for capacity;

- – Global Climate Change;
- – Local Air Quality; and
- – Noise.

5. It also aims to identify mechanisms for accelerating the take up (see for example Box 5-1), and based on our review of the literature, interviews with stakeholders and the workshop exercise to interpret how stakeholders may respond.

Box 5-1. Government Initiatives to Accelerate Take-Up

- Consult widely on technology development and research needs;
- Support research and development of relevant promising technologies through either wholly funded research and Seedcorn programmes or collaborative schemes;
- Support trials, demonstration and validation projects and pilot implementation projects
- Oversee the dissemination of research results and promote good practice;
- Facilitate public-private partnerships with clearly defined roles; and
- Provide incentives to promote the use of cost-effective technology through fiscal and regulatory measures and promote discussions on the way forward.

6. **Other Technology Take-up Issues (Section 5.11):** This section addresses issues that are not directly related to take-up of future technologies explicitly within the scope of this study.

7. The overriding objective of this section is therefore to identify the major take-up issues, at a general and technology specific level, options for accelerating take-up, and an indication of the effectiveness of the accelerating mechanisms. The policy implications this analysis raises are discussed in Section 6.

5.1 Overview

Take-up issues for future technologies have been broadly categorised as either general, or relating to capacity and efficiency, or relating to environmental mitigation. The most significant general issues that create barriers to technology take-up are high costs, economic and performance uncertainties, and low technology turnover; interdependence between advanced technology development and enabling technologies; lengthy standard approvals and stringent certification; difficulties in matching differing investment timescales of its stakeholders; alternative ATC technical solutions for the same basic function; and development of harmonised ATC technical solutions dependent upon the effectiveness of Eurocontrol.

Our analysis also identified technology take-up issues as they relate to specific capacity enhancing and environmental mitigation technologies and more critically investigated mechanisms to accelerate take-up and the effectiveness of the mechanisms. Mechanisms that would accelerate take-up of the most promising capacity enhancing technologies are: finding agreement on new separation standards to accelerate wake vortex technology deployment; Eurocontrol to drive towards generic solutions for arrival, departure and runway management systems and NATS to prioritise their development; match implementation costs for A-SMGCS to the capacity benefits to stakeholders; finding early agreement at a European level on the future communications navigation and surveillance technologies to be used to enable future concepts of operation; linking operational improvements to performance targets to accelerate the take-up of new controller tools; adoption of ISO standards to enable interoperability of smart card technologies; and availability of airport infrastructures to accommodate VLAs.

Take-up of technologies that address global emissions is essentially driven by commercial pressures to minimise fuel costs. To accelerate this process and place greater emphasis on future technology development and take-up our analysis has identified a need for market based incentives. These can take numerous forms but our interpretation of responses from the industry indicate that a combined approach encompassing open emission trading, a recycled charging system and voluntary agreements offers an effective approach to tackle the challenge of lowering the future global climate change impact of the industry.

To drive take-up of technologies that focus on mitigating local impacts our analysis highlights the need to introduce ambitious noise and local air quality standards underpinned by financial incentives. This could involve a dual approach based on: tightening future NO_x and noise standards at an international level; and increasing the emphasis on local charging to reward best practice in terms of NO_x and noise performance.

Finally our analysis identified a number of issues not directly related to take-up of future technologies for capacity enhancement or environmental mitigation, but which nevertheless have an indirect effect on technology take-up. These include: future allocation of radio frequency spectra that could have a major impact on the air transport industry and its existing and new technologies; limitations due to land take at airports which could be a driver for the introduction of ADS-B for closely spaced parallel runway approaches; and operational practices that have developed that limit the maximum benefit that can be derived through the introduction of new technologies.

5.2 General Issues

This section addresses general take-up issues that are not technology specific and apply across the industry.

Investment Costs and Return on Investment

Aviation is characterised through high development, capital and maintenance costs, long payback periods and low production volumes, limiting new product entry and take-up

1. Development, capital and maintenance costs of aircraft are high. For example, the development of the A3XX is reported to have cost Airbus $12 billion to date (Flight International, 2000a), whilst for an engine component, such as a combustor, the cost can easily be as high as $100 million. Capital costs are also significant and to a large degree account for the long in service life cycles expected.

2. Feedback from industry stakeholders indicates that high costs within the industry provide a very strong business incentive to extend the lifetime of existing fleets. For example, by installing Hush-Kits to achieve Chapter 3 compliance and retrofitting NO_x combustor 'kits' to achieve lower NO_x limits.

3. The impact and significance of the high development costs are further multiplied due to the relatively low production volumes in the industry. For example, it is common to have a successful aircraft engine model that has a production cycle of less than 100 units per year. This can be compared to an automotive engine model that can have a production cycle well in excess of 100,000 units per year. The marginal development costs are therefore disproportionately higher than in most other industries and as a consequence discourage new developments and compound the uncertainties of the market place.

Uncertainties about economic and performance benefits of new technologies limit the opportunities for their implementation

4. For a new technology to have an impact, the airlines and ATC service providers must put it into service. In the case of a technology that does not provide immediate cost benefits (e.g. NO_x reduction technology on fleets) product acceptance can be difficult. This is due to uncertainties surrounding predicted performance, maintenance costs and limited operating experience to prove reliability, especially when alternative well proven products already exit. In the case of ATC related technologies (e.g. infrastructure technologies that enable new controller tools) the benefit to the airlines often cannot be quantified or cannot be realised until most fleets are equipped, making it difficult to justify investment.

5. These factors are particularly significant in an industry where investment costs are high and payback times long. Taken together these factors mean that operators will often demand significant performance improvements, certainly in the order of 20%, before considering upgrading or replacing current fleets.

Economic and customer requirements, coupled with long production and in-service lifetimes limit opportunities for implementation of new technologies

6. The economic pressures of the industry dictate that both production runs and in service lifetime of aircraft are long in order to offer operators and manufacturers a chance to payback their investments. For example, a production run of 20-30 years and an in-service aircraft lifetime of 25 to 35 years are fairly typical for the industry. Therefore although progress in airframe and engine technology has an important effect on the time scales over which aircraft mature, equally important are economic and customer requirements, which dictate long production runs and in-service lifetimes resulting in low implementation possibilities.

Technology Interdependencies

Technological developments within the aviation industry are often dependent on parallel advancement of numerous "enabling" technologies

7. The aviation industry is a significant user of the latest materials, processes and manufacturing developments and these can become absolute limiting factors to aviation specific developments. For example, realisation of engine development benefits through reduced NO_x, fuel demand and noise require substantial investments in a wide range of research and development fields that are not necessarily unique to the aviation industry. These include aerodynamics to improve engine airframe integration, cooling technology to deal with increasing temperatures associated with future increased pressure ratio engines, materials to withstand higher temperatures and stresses at lower weight, and systems for engine and noise control.

8. The industry is also dependent upon the availability of enabling technologies for the realisation of many new ATC concepts. For example, many ATC controller tools are predicated on the availability of an air-ground datalink for transmitting information about aircraft intent, future candidate communication technologies include VHF datalink Modes 3 and 4. Final decisions on the full implementation of these technologies have still be to be made, and there inherent respective limitations means other candidate solutions may emerge. These chains of dependency slow down and reduce the likelihood of technology take-up.

Often there exist alternative ATC infrastructure technologies to provide the same basic function, making it difficult to choose the best one

9. It is necessary to draw a distinction between the technologies that support the underlying ATC infrastructure and how that infrastructure is then used to provide more capacity. For example, a datalink to support air-ground communications is key to many future concepts but technologies that could provide such a datalink include Mode S, VDL Mode 3 and a satellite communication link. Another example is the need for area navigation by the direct routing concept, this can be supported by DMEs instead of GPS. Different technologies carry with them different risks and one has to weigh the risks against the costs when deciding which to implement.

10. The consequences of these alternatives are many and far-reaching. Where it is necessary to achieve European level agreement on investment in a new

infrastructure technology it is extremely difficult to get consensus since the different interested parties have very different views on the associated risks and costs. Where a technology can enable many future concepts it is difficult to decide the cost benefit of that technology since it depends intimately on which concepts are enabled and different stakeholders may not agree on which ones should been selected. Typically, when developing future concepts the performance limitations of the candidate enabling technologies are not taken fully into account. The risk is that the future concept is predicated on a technology that cannot deliver the necessary performance levels within reasonable cost margins.

11. This situation often leads to the criticism that the ATC industry is technology driven, always alighting upon the latest technology to support a new concept. In practice it leads to technology lag, the industry being unable to invest in a new technology fast enough for it not to be superseded, therefore the industry tends not to invest at all.

The need for Standards, Agreements and Certification

The aviation industry requires agreed standards to be in place and is subject to stringent certification processes, these impose additional costs and lengthy lead times

12. The aviation industry is characterised through an uncompromising focus on flight safety. All primary components must be proven by a rigorous series of factory and operational tests conducted by the manufacturer and overseen by the regulating agency (i.e. FAA or JAA). This process is both lengthy and costly.

13. In the automotive industry, for example, an automotive manufacturer can employ field tests with a statistically significant sample size to demonstrate engine reliability, since as a percentage of total volume this sample will be small (50 experimental engines form a yearly production of 100,000 is only 0.5%). By contrast, in the case of aero-engines a sample of 50 could represent 50% of yearly production and therefore the use of field trials which can both be cost and time efficient is not a viable option. Instead lengthy and costly test bed alternatives need to be employed to meet all certification safety requirements prior to use.

14. In the cases where new materials are proposed for primary structures an additional hurdle can be that a certification process does not yet exist. This will require a certification process to be developed and approved, which again imposes additional delays on the development and application of new technologies into aircraft.

15. For the CNS infrastructure technologies, such as VHF datalinks, the benefits of the new technologies cannot be exploited fully without a large geographical coverage and clarity of functionality and performance. Standards must therefore be agreed across many countries before implementation can begin, this can be particularly difficult when different interested parties support alternative technical solutions to the same problem (e.g. VHF Modes 3 and 4 for provision of air-ground datalinks). Where technologies require major re-fits of aircraft, with potentially many suppliers

of the same basic functionality equipment, there is the need for an agreed set of standards with which all equipment must comply.

Match between Stakeholder Needs and Technologies

Stakeholders' priorities and investment timescales differ, which raises uncertainties over technology benefits and limits opportunities for joint investment initiatives

16. The primary stakeholders typically share similar issues, however their priorities will often differ. For example, decisions by fleet operators are influenced primarily by aircraft mission, performance and operating costs, whilst decisions by airport operators, local neighbours and regulators typically place greater emphasis on aircraft noise and emissions performance.

17. Furthermore, the typical investment cycles for aircraft operators and aircraft manufacturers differ enormously. Whilst manufactures typically plan up to 20 years ahead, for aircraft operators this could be only a few years. The effect of this is to introduce significant uncertainties and barriers to manufacturers, and to a lesser extent airport authorities, to invest in new technologies since payback timescale requirements are long and projected demand (governed by operator demand for aircraft etc.) is significantly shorter.

18. Safety is without question a key driver for the industry. In addition, the major driver of ATC technology take-up is capacity whereas for the airline operators in Europe it is a trade-off between reduced delays, increased frequency of service and greater consistency of service. For short haul flights especially, some airline operators have indicated they would be prepared to accept increased journey times if they could guarantee greater consistency of service for their passengers. The airline business can change significantly over relatively short time horizons, as particular routes become popular or new business models come into place or there is a slump in the market. On the other hand, ATC investments in future technologies often have very long time horizons (e.g. the introduction of MLS has taken 15 to 20 years and is only just starting to be implemented at major UK airports). ATC service providers attempt to provide sufficient capacity to meet forecast requirements but this is inherently unpredictable and often subject to change. All this means it is very difficult for ATC service providers and airline operators to match their respective priorities for investment timescales in future technologies.

Future technologies may not fit within present day airport infrastructure, imposing financial and practical constraints on their take-up

19. Airport infrastructure is designed to fit aircraft complying with present day norms for aircraft design. In practice this means a footprint that is no larger than 80 by 80 meters. As technologies move into the future and stretch current thinking they introduce practical difficulties since these designs do not necessarily conform to present day airport infrastructures. For example, it is likely that future blended wing designs would require changes to taxiways and/or terminal design to accommodate a dramatically different airframe design to today's conventional cigar shaped aircraft. This introduces not only practical and logistical difficulties but also potentially huge

cost implications, which if unresolved could severely limit the range of destinations for such aircraft, at least in the shorter term. Even the less futuristic VLAs still require significant ground infrastructure changes at major UK airports before they can land, use the taxiways and access the gates.

20. Similar infrastructure requirements apply also to the take-up of alternative fuels to kerosene. Whilst aircraft powered on cryogenic hydrogen have been proved in practice (for example Tupolev TU 155) and would offer the possibility of cutting global warming emissions, practical constraints due to lack of infrastructure for manufacture, storage, handling and distribution of the fuel introduce significant barriers to take-up.

Public perceptions may limit take-up of future technologies

21. Over the past 40-50 years the public have become accustomed to the look and feel of what has remained a relatively unchanged basic configuration for jet aircraft. Future technologies such as unducted fan engines (which resemble large swept blades rather than the usual compact turbo fan engines we have today) and blended wing airframes provide radically different alternatives. Whilst these may offer substantial environmental benefits, manufacturers[27] remain uncertain whether public perceptions of what an aircraft should look like can be resolved, and consequently the market and take-up of such designs could be significantly reduced.

22. Many capacity enhancing technologies have an environmental burden associated with them. Even when a technology improves emissions or noise on a per passenger basis (e.g. VLAs), if the technology serves to increase the total number of passengers the overall environmental burden resulting from this growth will increase. Public perceptions about the overall environmental impact of capacity enhancing technologies, once the growth in total passengers they enable is taken into account, could limit their take-up.

Airport safety and noise contours potentially restrict future capacity enhancing technologies

23. With increasing awareness of, and public resistance to, the safety risks and noise impacts associated with living near busy airports, it is becoming increasingly common to define airport specific safety and noise contours. In future, it is anticipated these contours could be used to define safety risk and noise limits within which the airport must operate. As such, both safety and noise contours can potentially constrain the take-up of capacity enhancing technologies, since airports will need to ensure these limits have not been exceeded through introducing capacity enhancing measures.

Match with Current Policy

Eurocontrol plays a central role in the take-up of future ATC technologies and effectiveness in this role is becoming increasingly important

[27] Based on feedback during Technology Workshop (ADL, 2000a).

24. The ECAC transport ministers have tasked Eurocontrol, in co-operation with the European Community, to establish mechanisms for reinforcing the implementation of the Gate to Gate (GTG) ATM strategy by all parties involved in and affected by decisions made by Eurocontrol. In the future, the revised Eurocontrol convention provides for more effective working of the organisation through clarification of its objectives, transparent separation of regulatory and service provision functions where practicable, and the speeding up of decision-making processes.

25. The GTG strategy being promoted by Eurocontrol is a fairly recent enhancement of the original EATMS concept, where the focus was on *en route* and terminal air traffic control and how to harmonise operations, functions and systems across Europe to improve planning, reduce controller workload and increase the potential capacity of the ATM network. GTG has extended the concept to include airport functions and operations and provide capacity benefit at airports through better planning.

26. The reason for extending the original concept was a recognition that the whole process of air travel does not start and end the moment an aircraft takes off or lands at a runway. Managing traffic on the ground is also vitally important for optimising traffic throughput. Improved planning, better communications between the airport operators and airport ATC, *en route* ATC and ATFM stemming from enhanced information management and more integrated systems will help ensure that the resources at capacity constrained airports are used more efficiently.

27. It is a common and shared view that in the fields of safety, performance, airspace planning and design EU rules may play a fundamental role to ensure an appropriate implementation and enforcement of Eurocontrol rules. A possible future route for increasing the effectiveness of Eurocontrol is through the European Union (EU) becoming a member of Eurocontrol. This could pave the way for new mechanisms, such as majority voting, to come into effect, enabling Eurocontrol to take advantage of EU legal instruments when trying to ensure member states implement new technologies to agreed timescales. Whether the European Union becomes a member of Eurocontrol is unclear and recent communiqués (European Union, 2000) suggest this is less likely than previously thought. However, what is clear is that the EU recognises it has an increasing role to play in ensuring policy at a European level leads progress at a national level towards ATM harmonisation.

28. What is clear is that Eurocontrol will play a pivotal role with respect to the successful implementation of the GTG strategy, pushing through the take-up of new technologies by all parties in support of this strategy.

5.3 Take-off, Landing and Runway Utilisation

This sub-section addresses take-up issues for future technologies which enhance capacity during take-off, landing and runway usage. Of those technologies addressed by this study, the most promising future technologies for improving take-off, landing and runway capacity were found to be those which address wake vortex effects, arrival and departure managers, runway managers, satellite landing systems[28] and ADS-B[29] for closely spaced parallel runway operations.

Drivers and Barriers

The special operational environment for LHR is a big incentive for the application of technologies that address wake vortex effects to increase runway utilisation

1. Deployment of turbulence warning systems to provide knowledge of the dispersal of wake vortices produced by an aircraft are still at the research and prototype stage with some trials systems in use, such as at Frankfurt airport. The UK are probably second only to the USA in this area of research to understand wake vortex effects, largely the result of having an airport that operates an approach only runway (i.e. Heathrow) where vortex effects are an important issue.

2. The incentive for development of turbulence warning systems is that they may allow the spacing between aircraft to be reduced, thus enabling more movements per hour at a runway without the need to change the airport infrastructure. This applies to both arriving and departing traffic flows, but is more critical for arrivals since turbulence effects are greater. Improvement in hourly movements means the payback would be immediate. The same incentive exists for the development of Boeing's aerodynamic techniques to cause wake vortices from an aircraft to collide with each other a short distance behind the aircraft. There is the additional incentive for Boeing since their medium sized 757 has been classified as "heavy" since they can produce significant vortex effects.

3. The ideal is that wake vortex technologies allow separations to be defined for individual aircraft types, instead of the 5 categories in use in the UK today. The minimum spacing at Heathrow on approach is 2 ½ nm, with the next spacing being set at 4 nm. The ability to define spacings for individual aircraft types may not reduce the minimum separation very much but instead tailor the separation to the exact requirements of the aircraft, building up fractional gains of a nm each time. The cumulative effect of this, at face value, appears significant.

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[28] Take-up issues for satellite systems will be discussed in Section 5.5 under ATC Infrastructure technologies and take-up issues specific to SLS will be discussed in Section 5.11 under Other Factors.

[29] Take-up issues for ADS-B will be discussed in Section 5.5 under ATC Infrastructure technologies and land take issues relating to operating closely spaced parallel runways will be discussed in Section 5.11 under Other Factors.

If it becomes possible to define aircraft separations to better than ½ nm there will be additional technical issues to resolve, including improving the resolution of controllers' pseudo radar screens, providing sequencing tools to assist controllers in the much more complex task of spacing and ordering traffic flows optimally, and providing datalink for sufficiently accurate aircraft position information to be available to the controller.

4. A consideration raised by NATS for some of the UK's busiest airports, and in particular Heathrow, is that operations have already been extensively optimised to maximise runway capacity, therefore one cannot assume that implementation of, say, turbulence warning systems or new aerodynamic techniques will result in a dramatic increase in hourly movements. That said, year on year NATS have succeeded in increasing the hourly movements at LHR and there is every reason to believe that application of new technologies will increase runway capacity. A further consideration is that wake vortex effects are very complex and therefore an operational system whose performance can be relied upon will be difficult to realise. However, at airports whose operations have not been extensively optimised and whose traffic flows could require segregated modes of use, technologies that address wake vortex effects and allow closer separation of aircraft could enable many more movements per hour (reliable figures for how much improvement are not known).

For airlines the return on investment in arrival, departure and runway managers would be extremely short-term, the difficulty is introducing these tools into operational use

5. The potential benefits of introducing arrival, departure and runway managers is high for the airlines since there would be a commensurate reduction in fuel consumption through minimised delays and optimising aircraft flight paths (e.g. reduced use of holding patterns on arrival). Runway managers would also increase runway management efficiency and optimise capacity of the runway and airspace, being especially relevant at highly congested airports and airports with complex layouts such as multi line-up capabilities and rapid exit taxiways.

6. From the ATC perspective, the benefit of arrival, departure and runway managers would be realised from more effective distribution of workload among the controllers.

7. Building these managers into a new concept of operation and introducing such a system into controllers' workload is the major challenge. The role of controllers could be seen to be compromised through their introduction, which is a potential barrier to take-up. The hardware is usually standard off-the-shelf technology that can be easily integrated into existing systems.

8. A further barrier to the take-up of arrival and departure managers is that they could require the management of flights over other countries' sovereign airspace (e.g. an arrival manager at Heathrow could require the management of flights over French and Belgian airspace).

Mechanisms to Influence Technology Take-Up and their Effectiveness

For wake vortex technologies to achieve their full benefit there would be a need to be a re-assessment of existing aircraft separation standards to see whether they can be reduced

9. In parallel with research into wake vortex effects and the development of new systems to predict them or new aerodynamics to cause their early decay, there would need to be a reassessment of existing separation standards for aircraft and relating these new separations to aircraft performance and runway utilisation needs, as appropriate. Separation standards, defined by ICAO, are based on figures originated in the 1970's. In the UK the three categories defined by ICAO have been further divided into five categories which better represent wake vortex effects of aircraft. However, to get the maximum advantage from application of this technology, through optimising separations based on turbulence effects, there is a need to check whether aircraft should be categorised differently to how they are today and, if so, progress the re-categorisation. Progressing re-categorisation of aircraft separation standards would have to be done in close liaison with NATS and ICAO.

10. Boeing has announced a new aerodynamic technique to cause more rapid decay of wake vortices. If this proves to offer the benefits suggested by Boeing then one mechanism to accelerate its take-up would be to mandate the retrofitting of this technology to all medium and heavy aircraft that are prone to producing wake vortices. It is highly likely that the other major manufacturer of large aircraft, Airbus, would object strongly to such a mandate since it would require them to pay a licence for use of the technology.

The future evolution path for arrival, departure and runway managers is already integrated into the EATMS planning concept developed by Eurocontrol, active support of these activities where they match the needs of UK airports and airspace will influence take-up

11. The whole drive for the application of arrival and departure managers comes from Eurocontrol and its EATMS concept. Arrival managers will be integrated first into the EATMS planning concept, followed by departure managers and finally runway managers. In the longer term, the EATMS concept assumes the integration of AMS and DMS into a common modular planning systems architecture. As part of the GTG concept, the DMS would evolve into what is termed the "integrated slot" concept where an overarching management system embraces arrival and departure managers as well as surface and runway managers. Integration of AMS and DMS is long-term and further integration consistent with the GTG concept should be considered as very long-term.

12. Accelerating the process of take-up of arrival, departure and runway managers requires strong support for Eurocontrol lead activities to influence their progress and ensure a match with the needs of UK airports and airspace. Influence would also be

needed at a political level where sovereign boundaries could limit the optimum implementation of these managers.

13. There is also the need for a significant amount of research and development of operational concepts that enable such systems to be introduced into the controllers' workload. To date, Eurocontrol driven developments of new concepts have proved slow to yield implementable applications and NATS are becoming more cautious about where their resources should be focussed. Therefore, only where the benefits to NATS are clear are NATS likely to provide substantial support for future Eurocontrol lead developments such as arrival, departure and runway managers.

14. The issue then becomes one of whether the priorities placed by NATS on development of these technologies matches the priorities of the airline operators. Specifically, the airlines are likely to gain substantially more benefit in terms of reduced costs through increased fuel efficiency than NATS may gain in terms of increased airport capacity. In the short-term, NATS priorities are focussed on improving consistency from controller to controller in terms of productivity, and from aircraft to aircraft in terms of always exiting the runway at the optimum exit point.

15. In the longer term, a possible accelerator for the take up of these new technologies by NATS is through increased complexity of traffic flows to the extent that controllers are no longer able to optimise them without the need for sequencing tools to provide advisories. This very much mirrors the incentives for investment in *en-route* controller tools, where the need for conflict alerts is now accepted by controllers as a necessary part of their work environment.

5.4 Taxiways, Manoeuvring Areas and Gates

This sub-section addresses take-up issues for future technologies that enhance capacity around the taxiways, manoeuvring areas and gates at an airport. Of those technologies addressed by this study, the most promising future technologies for improving capacity around the airport surface were found to be surface managers, A-SMGCS and ADS-B[30]. For surface managers the same issues apply as for arrival, departure and runway managers discussed in the previous section.

Drivers and Barriers

Airlines could realise efficiency gains from improved manoeuvring around the airport through the application of surface management tools

1. From the airlines point of view, better management of aircraft manoeuvring around the airport infrastructure through the application of surface managers would reduce their costs because of reduced fuel consumption through minimised delays, optimised aircraft routing on the ground, and optimised lining up of aircraft for take-off.

2. Although surface manager technologies are long-term prospects there is likely to be increased pressure from the airlines for greater overall management of the airport infrastructure to improve efficiency. Airlines are very keen for the introduction of an all embracing airport manager that integrates the whole process from the gate to the runway because of the enormous potential to minimise delays, the premise being that much of today's functionality could be fully automated.

The implementation costs for A-SMGCS are potentially very large, however the implementation can evolve over time with benefit to stakeholders at each stage

3. The costs of an A-SMGCS installation will vary considerably depending upon the expected traffic density, low visibility conditions and airport complexity (e.g. where the buildings are and, hence, where radars must be placed and how many are needed). The costs of a system providing surveillance, guidance control and planning is very expensive but it is possible to split these elements and implement them piecemeal. A surveillance system is reasonably cheap and would provide benefit to users (for a medium sized airport, estimates are in the region of £350k). A guidance system is more expensive and the benefits are less clear. A planning system is probably somewhere in between the two.

4. A full A-SMGCS is dependent upon many enabling technologies, such as surface and runway managers, to provide surveillance, routing, guidance, control or planning functions. This high level of dependency is another barrier to take-up and another reason why a staged implementation is most appropriate.

[30] Take-up issues for ADS-B will be discussed in Section 5.5 under ATC Infrastructure technologies.

5. A staged approach to the implementation of A-SMGCS would seem to offer many advantages. It spreads the investment costs and allows all stakeholders to derive benefit from its implementation at each stage. Once an airport has better surveillance information this can be incorporated in future into planning tools, thus providing for better taxiway operations, especially in poor visibility.

Mechanisms to Influence Technology Take-Up and their Effectiveness

Demonstration of the cost benefit and development of a clear migration path are necessary if A-SMGCS is to be implemented at major airports

6. Essentially, the same comments apply to this technology as to surface managers, since A-SMGCS is dependent on the same enabling technologies. The performance aspects of A-SMGCS are under consideration through European lead studies, the aim being to produce results on the operational benefits and quantify the performance benefits of the technology.

7. The mechanism for introduction of A-SMGCS is to define an implementation path that matches costs against benefit for the major stakeholders at each stage, to ensure investment costs are spread and benefit can be derived at each point in the implementation.

5.5 ATC Infrastructure

This sub-section addresses take-up issues for future enabling technologies in CNS, *en route* ATC and airspace design. Of those technologies addressed by this study, the most promising future enablers of enhanced capacity were found to be VDL, ADS-B, satellite systems, free routing, airspace design and controller tools.

Barriers and Drivers

Decisions at a European and world-wide level are needed to specify future VHF datalink should be implemented

1. Realistically, future datalink technologies should be implemented on a pan-European and, preferably, world-wide basis. This reduces costs of installation and equipage and ensures commonality across systems. Different stakeholders have differing views over which future datalink technology best matches their business needs, the choice being between Mode 3 and Mode 4 (Mode 2 having been agreed already as the next implementation step). Many airline operators prefer VDL Mode 3 and this mode is being promoted by the FAA in the United States. In Europe, many ATS providers do not consider Mode 3 capable of coping with the technical demands that will be placed on it, also Mode 3 does not satisfy the requirement to keep voice and data applications separated. In the UK, NATS are not convinced of the benefits of VDL Mode 4 for use in high-density traffic areas such as UK airspace.

2. The lack of resolution could delay implementation of much needed datalink technologies, which are an important enabler for a large number of future services. It could also result in the inability of the industry to choose and implement a single standard, which increases costs, reduces commonality and potentially means airlines will have to install both types of equipment on their aircraft.

ADS-B has the potential to support a lot of future concepts but in many cases alternative technologies offer greater cost benefit

3. ADS-B provides improved situation awareness for controllers and/or pilots through provision of surveillance information. There are a lot of potential future concepts that could be supported by ADS-B, some to enhance capacity and others to improve safety. Examples include go around detection, surface movement control, medium-term conflict detection and short-term conflict alert. Therefore, implementation of this technology could enable many new concepts for enhanced capacity at airports and improved use of airspace.

4. However, there are some major drawbacks to ADS-B that need to be overcome if the technology is to be taken-up. First, introduction of ADS-B requires strong commitment from all stakeholders to invest and equip. It is estimated that 95% equipage of aircraft is needed before the benefits of ADS-B enabled applications can be realised. Second, detailed transition plans would be required to ensure the

rapid take-up of the technology and to ensure operations continue smoothly and effectively during the transition period.

Even with the rapid take-up of the technology the transition phase, where a mixed environment of aircraft conventional equipped and re-equipped, would last many years. This is a major obstacle to take-up.

5. Third, many applications enabled by ADS-B could be enabled by other technologies, there may be cheaper ways of achieving the same end (e.g. ground surveillance through use of Mode S or multi-lateration). Fourth, the different applications require different levels of operational capability (e.g. data acquisition rate, operational traffic density limit, horizontal position error, etc.) making it difficult to define a common implementation for ADS-B which is not over specified (and costly) for many applications. Fifth, ADS-B is itself dependent upon enabling technologies, for example there is a debate as to whether the VHF communication datalink should be Mode S or Mode 4. The same issues then arise as discussed above for VHF datalinks. Finally, not all stakeholders are convinced that ADS-B is a technology well suited to application in high-density traffic areas.

Sovereignty issues of having systems that are reliant on satellite constellations under the control of other states will inhibit the take-up of these systems

6. The use of systems that are under national control (United States for GPS and Russia for GLONASS) raises the potential for services to be discontinued or accuracy to be reduced. The risk of this happening is considered unlikely, mostly due to the high levels of usage of GPS receivers in the United States where political pressure from transport lobbyists is strong and well organised. For the GLONASS system there are concerns that economic difficulties may have an impact on the maintenance of the satellite constellation. These sovereignty issues may go away with the future introduction of Galileo, the European satellite system designed to be fully compliant with but independent from GPS. The operational date for Galileo is set for 2008.

Use of satellite systems to enable new future technologies raises the issue of how to resolve the potential introduction of a single point of failure

7. The use of satellite systems to enable new future technologies can introduce a single point of failure into the system, which has safety implications. For example, with ADS-B applications position information for surveillance and timing information for datalink communications can both be derived from a satellite source. A drop in availability, reliability or integrity could result in a degradation or loss of both position information and communication link. Another example is where an aircraft's FMS uses satellite systems to provide position information used for navigation purposes and also downlinks this information to ground systems which use the same information for surveillance purposes. Once again, a drop in availability, reliability or integrity of the satellite source could result in a degradation or loss of both navigation and surveillance. Where this is especially problematic is if the failure goes undetected, in which case both the navigation and surveillance systems are using the same erroneous information.

8. Many practical applications based on the use of satellite systems for communications, navigation and/or surveillance will require safety cases to be drawn up which take account of the potential for a single point of failure. Prior to the availability of satellite systems, communications, navigation and surveillance functions were provided by separate systems and issues of single points of failure across these different functions did not occur.

Direct/Free Routing would require substantial investment in new ATC infrastructure technologies for its take-up

9. The driver for airlines of direct/free routing would be the reduced fuel burn, with the associated cost reduction, through aircraft flying shorter distances. The driver for ATC service providers is increased efficiency and reduced delays, thereby offering a better quality of service to users.

10. The take-up of direct/free routing would require substantial investment in ATC infrastructure technologies, such as communications networks to allow for real time data exchange between ATC service providers (civil and military). However, the technologies required do not represent a significant change over what is available today, it is the operational concept which is a more significant change. There would also be a need for re-design of the airspace, better sharing of civil / military airspace and better sharing of airspace across national boundaries.

11. Direct/Free routing cannot be considered in isolation, it needs to be considered in the context of other technologies and improvements, such as RVSM and FUA. The reason is that these other improvements are needed for the maximum benefit of this technology to be realised. To date, there is no clear commitment from member states to introduce direct/free routing.

A major obstacle to producing more en route capacity is that optimisation of European airspace has not been achieved to date

12. The requirements of users (i.e. the airlines) and ATS providers are the main drivers for changes to the airspace design across Europe. Today, European airspace structures are complex and disparate which leads to enormous inefficiencies that have in part resulted in the continued growth in delays and limitations on capacity. Changes in airspace design cannot be developed in isolation at a national level, hence the development of the ECAC Airspace Strategy. This strategy is consistent with the over-arching ATM 2000+ strategy and is in line with the ICAO Global Air Navigation Plan for CNS/ATM systems.

13. A major barrier to optimisation of European airspace has been that national interests have impeded progress towards a more homogeneous airspace, where the expressed needs of the users and ATS providers are taken properly into account. In short, there has in the past been a lack of political will. However, as European ministers appreciate the gravity of the problem posed by increasing delays and an inability to meet forecast demand, there is reason to believe that these barriers are being removed.

The take-up of new controller tools is mainly an issue of how to introduce the tools into the controller workload to provide capacity commensurate with traffic demand

14. In the short to medium-term the approach by NATS is to introduce new controller tools into the existing concept of operation to incrementally improve *en route* capacity as an indirect result of improving controller efficiency. The main driving force for NATS is its aim to provide capacity to meet current forecast air traffic demand. The main route to achieving this aim in the short to medium-term will be through the elimination of paper flight strips and the introduction of future area control tools.

15. Controller tools would include a package of measure such as trajectory predictors and conflict probes to reduce the number of conflicts that rely upon tactical intervention by the controller, hence the controller workload per aircraft will go down. Capacity should increase from implementation of these controller tools, figures to quantify the benefit were not available. The main barriers to implementing future controller tools are the need for NERC to become operational and then achieving the introduction of tools into the existing concept of operation.

16. In the long-term there will be a need to do more than incremental changes to existing concepts of operation since it is not anticipated that this approach will be sufficient to cope with forecast capacity demand over the next 20 years. Current thinking is that a future operational concept may be based on the PHARE concept, NATS and other European partners have invested in PHARE through a Eurocontrol lead research project. The PHARE concept assumes 4D-flight management with datalink trajectory negotiation to provide conflict free trajectories over fairly long flight paths. It assumes 4D FMS onboard the aircraft, an airway structure (i.e. not a full free flight environment) and direct routing of some form (though not point-to-point, as is implied by the direct/free routing concept).

17. Work to date has demonstrated the PHARE concept to be feasible but there would need to be a considerable amount of development work on the part of NATS and other European ATC service providers before anything becomes operational. The barrier to continuing development work is that it would be very costly and there is a risk that the future operational concept never gets implemented because it is too difficult to realise an acceptable transition path.

18. Also, there would be a need for airlines to undertake a fairly significant re-equipage of new electronics. At present these future concepts assume appropriate 4D FMS and datalink systems will be available. Although this assumption is reasonable for an initial concept, before any implementation steps can be taken a link has to be made between the actual performance needs of future controller tools and the available performance of enabling technologies in the aircraft and on the ground. This is another barrier to take-up since it is not easy to quantify the benefit to airline operators of them investing in technologies that are aimed at improving ATC services.

Mechanisms to Influence Technology Take-Up and their Effectiveness

Accelerating the process of choosing a future VHF datalink technology requires continued pressure at a European and international level to define the precise ATC requirements of such systems

19. The choice between VDL Mode 3 and Mode 4 is difficult to resolve in the short-term since there are many interested parties at an industry and political level who lobby extensively for their preferred solution. The two alternatives each offer specific benefits and both have some key drawbacks. A problem is that there does not exist a precise definition of which ATC services will be implemented in the future and hence it is not possible to define the requirements these services impose on VHF datalink technology. Without these requirements it is not possible to categorically state that one VHF datalink is better than another or, potentially, that neither is satisfactory.

20. At a European level, the EATCHIP communications strategy developed by Eurocontrol recognises the need for further studies to be undertaken in order to identify and select candidate solutions beyond 2005 for air ground datalinks. Possible options include VDL Mode 3, VDL Mode 4, new satellite generation, other future VHF links, gate link and HF datalink. Continued pressure must, therefore, be applied at a European and international level to define ATC services enabled by datalink and to select a future solution beyond 2005.

Accelerating the take-up of ADS-B requires continued strong involvement of Eurocontrol in co-ordinating European policy on ADS and ensuring all stakeholders to invest in the technology

21. There is already substantial involvement on the part of Eurocontrol in development of policy on ADS, with the service providers of each country being required to investigate the range of possible applications supported by ADS and their time frames for implementation. Performance requirements to support the wide range of possible applications have also been drawn up. Many stakeholders are, to date, unconvinced about the benefits to them of introduction of this technology, especially when cheaper alternatives exist and the benefits would not accrue until almost all airlines were properly equipped. As well as the airlines, NATS also have doubts about how much benefit this technology will bring, particularly given that many applications require significant changes to existing concepts of operation.

22. The take-up of this technology would broadly require two distinct steps. First, an assessment of the cost-benefit for a chosen range of applications, a specified performance, and a selected datalink technology. If the cost-benefit is good the second step is to promote the rapid introduction of the technology so that the benefit can be realised by all stakeholders as quickly as possible. The first of these steps is ongoing both at Eurocontrol and by NATS, though it is proving difficult to determine the true cost benefit of ADS-B – there are still too many uncertainties. The second step is dependent upon the outcome of the first and could include incentives or penalties to encourage technology take-up.

One mechanism for accelerating take-up of ADS-B is to give Eurocontrol greater powers to ensure agreements at a European level are reached and member states follow through implementation plans to agreed timescales.

The increased use of satellite systems for communications, navigation and surveillance is consistent with the European ATM 2000+ strategy

23. The take-up of satellite based systems for civil aviation is in part dependent upon the fact that the use of satellite technologies is an integral part of future European level strategies for improving the CNS infrastructure, within the framework of the ATM 2000+ strategy. The use of satellites is not mandated but it is anticipated that satellite technology will be used increasingly to enable a wide variety of new future concepts. Each application will be judged on its own merits when compared with alternative enabling technologies (e.g. whether to use GPS in preference to ILS or MLS for category I landings).

Direct/Free Routing and other evolutionary changes to en-route operations would require best practice to be propagated across Europe and greater powers for Eurocontrol to ensure timely take-up

24. Across Europe there are wide performance variations in *en route* ATC and removal of these variations is essential for incremental improvements in capacity and delays and essential to providing the necessary basis from which more advanced technologies and future concepts can be implemented to maximum benefit. Therefore there exist policy issues for those states whose equipage levels are low (the UK is not one of these states) and it is incumbent on the other member states to continue to apply pressure through Eurocontrol and the European Union for these states to improve. One mechanism is for Eurocontrol to propagate best practice throughout Europe by raising the standards of poor performing states to those of best performing ones. Another mechanism is to give Eurocontrol greater powers to ensure implementation plans are followed through to agreed timescales.

25. To further accelerate the take-up of direct/free routing, in the context of the future EATMP being promoted by Eurocontrol, would require substantial investment in infrastructure technologies, resources would need to be found to cover these investments. Also, political will would be needed to share airspace across sovereign boundaries. This, and the need for greater civil / military sharing of airspace, is less of an issue in the UK when compared with those countries in core Europe.

The roadmap for progressing the ECAC airspace strategy will need active support by all ECAC member states to become a reality in the current stated timescale of 2015

26. The ECAC airspace strategy addresses flight planning, ATC sector organisation, terminal airspace optimisation, route network optimisation, utilisation of user preferred trajectories, airspace management and airspace organisation.

27. If this strategy follows the time scales currently in place then in the short-term there will be the development of new or adapted airspace structures and the establishment of an ECAC airspace charter, including an airspace change process. In the medium to long-term there will be uniform application of airspace structures and classification throughout the ECAC region eventually leading to the fully flexible use of airspace, not constrained by national boundaries, by 2015. Free flight operations are considered to be a long-term prospect with no date attached.

28. For the airspace strategy to become a reality it requires enormous political will on the part of all ECAC member states. The continued active support by the UK through, amongst other channels, the CAA is an important element.

Fundamental changes in the provision of en route control is already considered a long-term prospect, short-term steps at national and European levels can help such changes to become a reality

29. Development programmes aimed at fundamentally changing the way *en route* ATC services are provided are likely to take at least 10 years before implementation, some suggest it could be as much as 15 to 20 years. Limited resources are focussed on addressing gains that can be derived from efficiency improvements to existing concepts of operation since there exist short-term capacity and delay problems to tackle. Longer term, more risky options tend not to get priority.

30. To some extent, the continued active support of European sponsored research projects is one way to accelerate the take-up of new controller tools supporting new concepts of operation. The consideration that must be made is whether this provides good value for money. European funded projects have a tendency to suffer from poor management and a lack of alignment of objectives for the respective stakeholders. They also tend to progress on the basis of consensus that is not always conducive to progressing the most effective way forward. That said, an undertaking to change the fundamental concept of operation for *en route* ATC service provision is beyond the ability of a single state. There is a need for collaboration and for agreements to be reached at regional and international levels.

31. To accelerate the take-up of new controller tools supporting new concepts of operation a balance has to be struck between actively supporting European funded programmes which drive the collaborative process, ensuring the carrying out of development work at a national level to ascertain what exactly the end system might look like, and issuing clear directives at a European ministerial level to ensure the timely introduction of new enabling technologies.

32. In addition to the above, the airline operators would need to be persuaded to take-up new technologies, such as 4D FMS and datalink, that enable the use of new controller tools. The most effective way to achieve this is to demonstrate a genuine benefit to the airline operators in a form that relates to their business needs, such as guaranteed quality of service improvements over fixed timescales. This can then be backed up by regulation to introduce a clear timeframe over which new equipment must be installed.

5.6 Terminal Utilisation

This sub-section addresses take-up issues for future technologies to increase passenger throughput inside airport terminals. Of those technologies addressed by this study, the most promising future technologies include e-ticketing, smart cards and RF tags and advanced biometrics for passenger identification.

Barriers and Drivers

The implementation costs of basic smart card systems are not huge but there is a strong element of conservatism amongst airlines which will delay their take-up

1. It is very difficult to count the cost of a delayed flight in money terms, but an estimate is £300-500 per minute for a B747 waiting on the tarmac. Ensuring there are no late passengers is an essential element of minimising delays and hence costs. This is especially important for airlines that operate complex hub operations that are heavily dependent upon aircraft achieving their timetabled slot, the knock-on effect of a delay can be substantial. As it is, those hub airports that have switched to using a wave system (this does not include Heathrow) have found the need to invest heavily in ground infrastructure to facilitate the processing of greater numbers of passengers and baggage within a short space of time. As the growth in passengers continues there will be an increased need to process them quickly and efficiently to match the operational needs of the business. Meeting this need is likely to require the introduction of more smart check-in technologies.

2. One caveat, the introduction of technologies that speed up the processing of passengers through the airport could have the negative effect of modifying the behaviour of some passengers. Knowing that it takes less time to go through the various checking processes of an airport, some passengers may choose to start their journeys later and give themselves less "slack" to accommodate any hold ups. If an unforeseen problem arises one is back to the situation of the late passenger holding up gate departure and risking losing the runway slot.

3. For a single airline the cost of installing basic smart card systems at a medium to large sized airport will probably be in the region of a few tens of millions of pounds. There is the hardware for check-in points, trackers, baggage handling and the costs of the smart cards themselves. There is also the software and its integration with existing departure control systems as well as any licence fees that will probably be levied by suppliers.

4. Airlines are very conservative when it comes to significant investments in new technologies such as smart cards. Many airlines face the dilemma of recognising the need for a fundamental change in the way passengers are handled if they are to cope with the forecast increase in numbers and retain cost efficient operations. Yet airlines cannot afford the cost of investing in systems where passenger reaction to them is uncertain, application areas for the technologies could be very niche, and the subsequent take-up of these new technologies could be disappointing. Basically, all airlines want to be fast followers, no one especially wants to lead.

5. In the UK both the airport and airline operators would have to invest in new technologies for RF tracking of passengers and baggage. In the USA, many airport terminals are also owned by the airlines, making it much easier to decide upon future investment plans.

Mechanisms to Influence Technology Take-Up and their Effectiveness

Adoption of ISO standards to enable interoperability for some smart card technologies will accelerate their introduction

6. There is a need for common standards to enable interoperability, especially if airports as well as airlines are involved in the implementation of new technologies. ISO standards for the chips inside smart cards are nearly agreed and IATA have come out in favour of a particular RF frequency for baggage tags. All technologies will require type approval and the use of smart cards in the UK would certainly require ETSI and WHO guidelines to be met.

7. The history of air transport is one of setting standards to reasonable timescales but very slow conformance to these standards. In the ticketing arena this is why even now one can still receive air tickets without even a magnetic strip and baggage tags without a bar code. The slow adoption of standards could easily result in significant delays in the introduction of smart check-in technologies, the take-up being patchy and resulting in the passenger having a wide variety of travel experiences.

8. Technologies for passenger identification and tracking, with their advanced biometrics and remote identification capability rely on the positive attitudes of passengers towards them for their successful take-up. People may not feel comfortable with having, say, fingerprints taken, also they may not feel that security has been properly applied if all they, and others, have to do to clear a security check is walk passed a remote sensor some metres away. There are also institutional obstacles to the implementation of many of these “smarter” technologies which need to be overcome, gaining their acceptance as providing an adequate level of security will take time.

5.7 Future Aircraft Enabling New Forms of Air Travel

This sub-section addresses take-up issues for future aircraft and alternative modes of air travel to those commonly used today that increase capacity. Of the technologies addressed by this study, the most promising future technologies are VLAs and small turboprop aircraft especially designed for use at small regional airfields.

Barriers and Drivers

Future demand for VLAs is only expected at the major European hubs on long haul routes

1. Both Boeing and Airbus expect there to be a market for VLAs but their forecasts for absolute aircraft size and total numbers of aircraft vary enormously. Boeing see the market expanding more in the medium to large sized aircraft whereas Airbus see a much bigger market for very large aircraft, eventually with capacities of up to 1000 passengers.

2. The development of the concept of VLAs is already well advanced, for example the Airbus A3XX is nearing launch. The main driver for introduction of this category of aircraft is demand to serve the Asia-Pacific region, 8 of the top 10 VLA routes are expected to serve this region. Decisions to place orders for these aircraft will depend mainly upon whether the airline operators believe the market is strong enough to ensure high load factors for these aircraft, which is needed for the routes they fly to be profitable.

3. Looking to Europe and the UK, VLAs are only expected to be utilised at the major hub airports on a limited number of long haul routes. The main reason is that load factor constraints mean the aircraft must be used on high capacity routes to make them viable.

4. From an ATC perspective, such large aircraft could result in reduced runway utilisation, especially since today’s regulatory approach broadly assumes that wake vortex effects increase with aircraft size and weight. The designers of the A3XX have done a great deal of design work both to improve understanding of the mechanism of the vortex and to reduce its intensity so as to avoid the imposition of regulations based on take-off weight. The aim is to ensure that aircraft separations need be no greater than when behind a B747 aircraft. Manufacturers state that the overall passenger throughput goes up irrespective of whether there is a reduction in runway movements because there are many more passengers per aircraft.

5. A further constraint on their introduction is the need for potentially expensive airport and terminal infrastructure changes to accommodate their extra width when manoeuvring along taxiways, and to enable them to access the terminal so that passengers can leave the aircraft quickly and efficiently. Collaboration, between VLA manufacturers, and airport authorities (as demonstrated by Airbus liaison with 50 airports world-wide) will help to minimise such costs. Assuming it is only major connecting hubs that will see the introduction of VLAs, in the UK this means

Heathrow and BAA's planning application for T5 includes the necessary infrastructure changes to accommodate VLAs.

6. Finally, there are concerns that present airport terminals will experience difficulties in managing sudden influxes of up to 1000 passengers at a time disembarking from an aircraft to then use the airport's facilities. This could create significant bottlenecks at passport control points and baggage handling points.

There could be growth in the medium to long-term in travel from small regional airports, supported by new low cost, small regional aircraft

7. An important driver for travel from small regional airports will be the congestion and delays experienced by passengers using major hub and spoke airports, people will seek alternative modes of travel to avoid the congestion such as the use of small regional aircraft from small regional airports. However, it is still the case that markets from small regional airports will be to large centres, creating a problem of acceptability of these very small aircraft in the traffic mix at hubs.

8. Whether there is a significant change in travel patterns is outside the scope of this study. However the introduction of new low cost, small regional aircraft could make short distance point-to-point travel viable for many passengers as long as these aircraft offer a sufficiently inexpensive, quick, more convenient and more flexible alternative. The Farnborough F1 (and similar proposals by Boeing) are examples of small regional aircraft which are under development.

Mechanisms to Influence Technology Take-Up and their Effectiveness

Assuming airline operators intend to use VLAs, their take-up can be accelerated through ensuring the airport infrastructure is in place

9. Assuming VLAs are developed, their smooth introduction can be enhanced by ensuring the necessary airport infrastructure is in place to accommodate them. In the case of Heathrow this either means the development of Heathrow T5 would need to go ahead on a timescale consistent with the introduction of VLAs or alternative infrastructure changes to the existing terminals and ground manoeuvring areas would be required on the same timescale.

The growth of travel from small regional airports, supported by new turboprop aircraft, will depend on whether commercial organisations can create a viable business

10. This form of travel is not available to large numbers of passengers today, it is too expensive. Hence, it is difficult to predict whether the advent of new low cost, low noise small turboprop aircraft will result in significant growth in this form of travel.

11. The growth in this form of air travel is most likely to be stimulated by a lack of alternatives. As hub and spoke operations become more congested, with point-to-point travel by regional jets limited to routes with high demand, there may exist a potential future market for small inexpensive regional aircraft flying point-to-point.

5.8 Global Climate Change

This section describes take-up issues relevant to engine, airframe and operational technology developments that improve fuel efficiency and therefore provide global environmental benefits[31] in terms of reduced high altitude CO_2 and NO_x emissions per passenger km.

Current Situation and Drivers and Barriers to Take-up

Investments into technologies to improve fuel efficiency are driven by commercial drivers to minimise costs and not through initiatives to reduce CO_2

1. **Driver:** Fuel costs are a significant expense. Delta Airlines estimate that fuel costs amount to over 12% of direct expenses (Brown, 1998). This ensures that fuel conservation has a significant business leverage by affecting competitiveness and ultimately profitability.

2. **Barrier:** Highly competitive industry and requirement for reduced cost for flying ensures that only win-win projects are progressed. There is no direct mechanism for regulating CO_2 emissions.

3. The industry faces high costs fuelled primarily by increasingly complex technologies. Taken together with a highly cost conscious passenger and freight market the emphasis remains that operators must focus on technology development and take-up that are aligned with the need to reduce operating costs. For the freight market margins are extremely small because yields are so low. This means investments tend to happen first in the passenger market, with the freight market waiting for technologies to be proven or regulated. Consequently, investment decisions and funds for research and development tend to focus on technology advances that produce short paybacks (e.g. significant and immediate fuel savings) and effectively can be viewed by the operators as a win-win proposition. Without any direct regulation of high altitude emissions, mechanisms to influence aviation's contribution to global warming potential are mainly linked to fuel efficiency and are market driven.

Mechanisms to influence take-up

Supply side measures to "multiply" competitive gains from fuel efficiency driven technologies and support R&D costs are required to accelerate technology take-up

4. To accelerate the take up of fuel efficiency technologies, and shift the emphasis away from short-term win-win projects there is a need to "multiply" the commercial incentives for take-up and help share the high R&D costs faced by the industry. This would help address technologies at the margin which may require a longer-term view and investment in research and development.

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[31] See Section 4.2 and Annex C for more details on and basis for the study's definition of global environmental benefits.

Indeed, signals from the industry[32] indicate that technologies at the margin, e.g. not offering more than a 20% fuel efficiency gain, or for which there are technical uncertainties will not be introduced unless there are greater incentives for take up.

5. In this respect there are numerous market based options to influence supply side market behaviour and mechanisms to support R&D. For example, tradable permits multiply fuel gain effects and introduce incentives for fleet replacement. The multiplier effect is introduced since the commercial value of the fuel efficiency gain is not simply the fuel saving cost but also the market value of the marginal permit saving. This also acts to deflate the value of the present fleet, promote take-up and thereby accelerate fleet replacement.

6. Similarly, shared Government (at a national or European level) or industry funding of research and development would help to address the issues of high R&D costs, and technology interdependencies faced by the industry (See Section 5.2). Such a scheme could, for example, be wholly or partly funded through a recycled charge.

7. Examples of technologies identified through this study that offer fuel efficiency benefits but face commercial (and technical) challenges to take-up include[33]:

   – **ATM/CNS technologies**: Uncertainties on whether arrival, departure, runway and surface managers provide sufficient capacity benefit for ATC service providers to invest the significant R&D required to establish operational implementations for these technologies.

   ATC has the potential to mitigate the production of contrails, which are localised transient effects. More flexible ATC capability combined with an ability to detect the onset of contrails could, in theory, lead to future technologies to avoid their formation. There are no known commercial benefits and no known R&D activities.

   – **Un-Ducted Fan Engines:** Uncertain demand from operators due to incompatibility with current fleet and possible noise impacts and significant R&D costs challenge commercialisation.

   – **Laminar Flow:** Uncertainties on technical performance and maintenance and capital costs affect commercial viability and challenge take-up

   – **Composite Wings:** Uncertainties on new material certification timescales, and relative price movements in alternative materials affect commercial viability and take-up

Effectiveness of take-up mechanisms

Views from the industry indicate that an open emission trading system offers the lowest compliance cost to reduce the industry's global impact and would encourage

[32] See for example output from issues workshop (ADL, 1999b).
[33] See Annex A and B for more details on technologies assessed.
[34] See Annex A and B for more details on technologies assessed.

supply side take up of cost effective (inside or outside of the industry) fuel saving technologies

8. The aviation sector does not currently face any controls on CO_2 emissions. Therefore the prominent drivers that influence total CO_2 emissions (and other high altitude global emissions) are the commercial incentive to minimise fuel cost (supply side) and demand for air travel. Analysis in Section 4 has shown that based on current forecasts for demand growth and technology development, total global emissions from aviation are set to continue increasing. This trend is not disputed by the industry and it is widely acknowledged that pressures enforced through the Kyoto protocol will eventually result in international action to limit or offset future growth in high altitude emissions.

9. Referring to the two drivers identified above, demand and supply side, feedback from the industry indicates that airlines, airport operators and manufactures[35]:

- Are opposed to measures that effect the demand side. They argue that command and control initiatives or overly high taxation of the industry that would restrict demand, imposes social costs (e.g. loss of passenger welfare if prices rise, loss of jobs, etc.) and equity issues that are disproportionately higher than the gains;
- Favour supply side measures that encourage flexible technology take-up and innovation, and are not closed to the aviation industry (i.e. the industry prefers Government measures that aim to control the supply side of the industry rather than the demand side);
- Favour market based mechanisms that provide the lowest cost for compliance; and
- Are reticent about environmental taxes. This reinforces the view published through ICAO[36] that industry discriminates strongly in favour of environmental charges as opposed to taxes. The industry perceives that charges would be recycled and kept within the industry to offset the costs of compliance, whilst taxation revenues would not be ring-fenced in the same way and consequently taken outside of the industry.

10. The implication of the above is that the industry favours mechanisms that would not undermine the industry's profitability but would provide flexible and cost efficient mechanisms to encourage CO_2 reduction through technology implementation within or outside of the industry.

11. Set against this, research based studies (for example as referenced in CAEP, 1999) indicate that:

- a closed trading regime would result in similar costs to industry as a fuel or en-route emissions levy.

[35] Based on output from issues workshop. See Annex E and Arthur D. Little, 1999b.
[36] See for example ICAO, 1998b.

- an open trading regime whereby trading between aviation and other sectors was allowed would be a more cost effective way of achieving a given level of emissions reduction.

12. Given the industry's preference for flexibility, unwillingness to depress demand through price rises and desire to minimise costs of compliance, the evidence suggests that from an industry supply side perspective these requirements are best met though an open emission trading system.

13. While an open emission trading system is attractive, there remain uncertainties as to whether other industries would be willing to sell their "share". An area for consideration could therefore include to opportunity for aviation to buy into other modes of transport or other industrial sectors in order to secure emission rights.

A recycled charging system would help fund and encourage technology innovation

14. Not withstanding the economic and environmental efficiency of an open emission trading system to encourage take-up, there is also a role for environmental based charges to fund technology innovation and R&D. Whilst an open emission trading system offers additional incentives for take-up of future technologies to improve fuel efficiency, there is also a need for funding at the R&D level to catalyse the process of innovation and launching of new technologies.

15. This is particularly relevant given the high development costs faced by the industry and its reliance on critical "feeder" technologies, for example development of CFD technology or new materials, whose development may require partnerships or joint initiatives. In this respect an environmental charge based system that recycled the revenues back into the industry would offer a mechanism to catalyse and accelerate new technology developments. Indeed, the industry has suggested that it would be efficient to set up a new central body (ideally at a world-wide level but otherwise on a European level) to collect the charges and that these could then be subsequently funnelled back into the industry based on funding applications made to the body by individual or joint stakeholders from the industry.

It is important to recycle revenues from market based instruments back into the industry, especially to offset the disproportionate impacts on 3rd World fleet residual values

16. Set against the emission saving potential of such initiatives it is important to recognise the disproportionate effect market based options or voluntary agreements could have on lowering the residual value of 3rd World airline fleets. These airlines tend to operate older, less fuel-efficient aircraft and are estimated by IATA to own and operate close to 50% of all aircraft in operation.

17. To ensure buy in and to support supply side take-up of new technologies from this large sub-sector is important therefore to promote a scheme that sponsors the retirement of older aircraft through a mechanism that recycles and directs revenues within the industry.

The industry is receptive to voluntary agreements, especially if these help to offset the need for fuel taxes

18. Voluntary agreements are similar to emission trading in that they are based on an overall cap on CO_2 emissions. In principal signals from the industry indicate it is willing to sign up to voluntary agreements in exchange for avoidance of fuel taxes. This leaves the question of finding agreement between industry and regulatory actors on a mutually acceptable voluntary limit, and early indications imply this may be prove to be problematic.

19. For example, recent communications by the European Commission and from industry indicate a significant gap between suggested targets for voluntary fuel efficiency improvements (4-5% per annum) and the industry's view on what is achievable. (ENDS, 1999; Commission of the European Communities, 1999).

20. Nevertheless, this study reconfirms that broadly speaking the industry is receptive and that responses by airlines to a voluntary agreement targets will closely match those identified by the CAEP working group (CAEP, 1999) and include to various degrees elements from the following:

- Accelerated fleet renewal and retirement
- Increased emphasis on fuel efficiency in aircraft purchasing
- Additional pressures by airlines to accelerate infrastructure improvements (e.g. CNS/ATM)
- Eliminating marginally profitable services
- Higher loading per aircraft through tighter seat configurations or yield management

21. Clearly, with no opportunities for airlines that exceed the voluntary targets to sell these gains, a voluntary agreement system by itself is unlikely to offer the same improvements in fuel efficiency and emissions arising from an emission-trading scheme. Furthermore, industry is likely to argue that any voluntary agreements include substantial growth targets together with some level of Government commitment to actions (e.g. R&D funding) to support the industry towards long-term improvements.

5.9 Local Air Quality

This section describes take-up issues relevant to combustor technologies that minimise NO_x emissions and therefore provide local environmental benefits[37] by reduced low altitude NO_x emissions over the LTO cycle.

Current Situation and Drivers and Barriers to Take-up

There are limited financial incentives for take up of NO_x reduction technologies other than the opportunity cost of capacity constraints

1. **Drivers:** The principle driver is compliance with international ICAO standards set by CAEP, but also local restrictions such as charges at certain airports e.g. Zurich Airport

2. **Barriers**: There are limited market drivers to incentivise take-up, whilst the technology development and capital costs are significant. Indeed, physical constraints dictate that a trade-off will always exist between the aims of NO_x reduction and improved fuel efficiency and therefore operational cost reduction.

3. NO_x reduction technologies centre on improvements to the combustor, and unlike fuel efficiency improvements which are largely driven and incentivised through fuel cost savings, are driven by ICAO's CAEP NO_x certification standards.

4. This creates practical difficulties for technology developers wishing to market low NO_x technologies and to operators wishing to justify investments that reduce NO_x emissions, especially if one factors in the possible loss of ETOPS for aircraft using new low NO_x technology. Consequently, take-up in the short-term remains largely regulatory rather than market led.

Mechanisms to influence take-up

Increasing incidence of locally based charges and evolving international regulations to reduce NO_x provide incentives for low NO_x technology take-up

5. There is longer term evidence emerging suggesting that incentives for low NO_x technology will increase. These incentives come from two sources. Firstly there are signs that local emission surcharges to the landing fees based on engine certification information, and therefore NO_x performance are increasing. For example, Zurich airport imposes "emission related" landing charges:

   "Primarily, the emission-related charge is there to create incentives: The specific emissions from air traffic are to be reduced by promoting and accelerating the introduction of the best available engine technology" (Zurich Airport, 1998)

[37] See Section 4.2 and Annex C for more details on and basis for the study's definition of global environmental benefits.

6. Following from Zurich, a similar emission-related charge has been applied to 10 Swedish airports beginning in 1 January 1998. These charges as would be expected, do not aim to restrict demand and are therefore revenue neutral. They do however provide a commercial incentive to airlines to purchase and operate aircraft with lower NO_x emissions.

7. Secondly, there is evidence to suggest that regulations of increasing stringency are expected, and furthermore that their scope may be extended to include NO_x produced during cruise and apply to in-service and not only new engines. For example, the European Commission has indicated that it will participate actively in the CAEP/5 work programme on gaseous emissions, with a view to reaching an agreement on new and complementary methodologies and standards by 2001. It has also indicated that it attaches high priority on initiatives to tackle regional and local impacts of NO_x (Commission of the European Communities, 1999).

Availability of low cost low NO_x combustor retrofitting options allow airlines to meet evolving targets with current fleets

8. The costs of retrofitting an older engine model with advanced combustors vary considerably. The IPCC report that retrofitting of a Dual Annular Combustor, is technically feasible but very costly since it could involve not only replacement of the combustor but also replacement of almost all other elements of the engine core (IPCC, 1999). Indeed, estimates by ICCAIA suggest that a retrofit may cost up to one third of the price of a new engine, even it were to be carried out as part of a standard hot section overhaul.

9. Less costly options are offered through the retrofitting of “NO_x reduction Kits”, which typically involve replacement of and or additions of specific combustor components to improve NO_x emissions of in service engines. Examples of these kits include the Pratt and Whitney "E-Kit combustor system"[38] (Pratt and Whitney, 1999) and upgrade options offered by Rolls Royce[39]. Both aim to maintain fleet values by extending the life of current engines by exceeding ICAO standards for new production engines (CAEP/2) and also to ensure the engine qualifies for the Swiss Class 5 emission category, amongst the strictest in the world (Zurich Airport, 1998).

Effectiveness of take-up mechanisms

The industry prefers an internationally ICAO led approach for setting future NO_x standards rather than uncoordinated introduction of emission charges at the local level

10. Whilst local introduction of emission charges by airports provides an incentive for low NO_x technology take-up concern has been raised within the industry,

[38] See Annex B.

[39] For example, the RB211-535E4/E4B upgrade, where the Phase 2 combustor and injector is replaced with a Phase 5 combustor and Trent style fuel injector.

[40] See Annex B.

particularly by manufactures and airlines that a continued uncoordinated approach may create unnecessary barriers. Firstly, manufactures will face difficulty in producing combustor designs that can meet different and evolving standards and this could hinder research and development, particularly for longer-term initiatives. Secondly, airlines may argue that the standards are discriminatory to certain aircraft given that they already comply with internationally recognised standards. The view is therefore that given NO_x standards will become more stringent, a co-ordinated approach, led by ICAO is in the longer term more likely to be effective in ensuring longer term air quality concerns and to gain buy in from the airlines and manufacturers.

Local stakeholders would be receptive of NO_x charges and regulations if they result in an improvement in local air quality

11. Local stakeholders such as local residents, businesses and local representatives (e.g. councillors and planners) are unsurprisingly likely to be receptive to proposals that aim to improve local air quality. Given that a business as usual scenario is unlikely to result in improved local air quality, especially if future growth is realised, proposals that provide incentives for operators to take-up best available technologies are likely to be encouraged. For example, studies at Zurich Airport have shown that if all aircraft operating to Zurich were equipped with low emission engines, emission levels could at least be stabilised, even if air traffic increases (Zurich Airport, 1998). This is an important consideration given that the air quality objective for NO_X as set out in the UK AQS and prescribed in the Air Quality Regulations 2000, has to be achieved by 2005.

A recycled air quality charge is preferred by business stakeholders since it provides incentives for take-up of best available low NO_x technology

12. From a business perceptive a charging system is preferred to a local air quality tax. Again the view is that charging allows revenues to be recycled within the industry to fund technology take-up. From an airlines perspective the charge offers a financial incentive to take-up best available NO_x technology, whilst for airport operators it provides funds for air quality improvement investments. For example at Zurich, revenues form the air quality charge are to be used to fund air improvement projects based on a sliding scale that reflect the project's air quality improvement contribution (Zurich Airport, 1998).

The Zurich emission charging model is in compliance with local legislation and ICAO guidelines and therefore may set a future precedent

13. The classification based model of emission charges in force at Zurich airport is in compliance with Swiss legislation and conforms to the CARFM report (Conference on Airport and Route facility management, June 1991) as well as to the principle guidelines of ICAO for charges or taxes. Indeed the charge was challenged unsuccessfully in the Swiss court in 1998 by IATA and continues to be paid by airlines using the airport. As such it is likely to set a precedent and continue to encourage take-up in other airports.

5.10 Noise

This section describes take-up issues relevant to operational, engine and airframe technologies to minimise aircraft noise during approach, departure and *en-route* and which provide local environmental benefits[41] by reduced community noise at airports and *en-route*.

Current Situation and Drivers and Barriers to Take-up

Take-up of noise reduction technology is driven by ICAO noise standards and more recently by local constraints with little incentive to go beyond compliance

1. **Driver:** The principle driver is compliance with Chapter 3 noise standards and with maximum noise levels set at the perimeter of airports. Noise caps at airports such as Schiphol, and as set down in the Manchester Airport Second Runway S106 agreement provide an additional driver to cut aircraft noise.

2. **Barrier:** There are limited market drivers to induce take-up, whilst the technology development and capital costs are significant. Noise abatement technologies can also result in increased fuel consumption, e.g. hush-kits introduce additional weight and fuel costs.

3. Technologies to minimise noise from the aircraft focus on the engines, airframe and operational environment. Unlike fuel efficiency technologies that are encouraged through fuel cost savings, noise reduction technology take-up is largely driven by ICAO's noise certification standards and increased local airport noise restrictions.

4. As with low NO_x technology this creates practical difficulties for technology developers wishing to market low noise technologies and to operators wishing to justify investments that reduce noise. Consequently take-up in the short-term remains largely regulatory (Chapter 3 noise standards are arguably the single most important recent driver to improve noise performance of aircraft) rather than market led.

Mechanisms to influence take-up

International noise certification standards and local charges and quotas encourage take up

5. Mechanisms to influence take-up of noise reduction technologies are historically and continue to be largely regulatory led. The principle driver being ICAO noise certification standards as set out under Chapter 2 and Chapter 3. The current timetable in Europe sets out a total ban of Chapter 2 aircraft on April 1 2002.

6. Alongside the regulatory requirement noise related charges are levied at several European airports as an incentive to use quieter aircraft and to finance noise insulation programs. The noise charges can take the form of an extra landing charge

[41] See Section 4.2 and Annex C for more details on and basis for the study's definition of global environmental benefits.

or a specific noise charge or tax. For example in the UK, BAA imposes a 70% differential charge on noisier Chapter 2 aircraft such as the B747-100 and also offers a 10% discount for the quietest Chapter 3 aircraft such as the B757 (BAA, 1999a).

7. Examples of technologies identified through this study that offer noise reduction benefits but face commercial (and technical) challenges to take-up include[42]:

– **Continuous Descent Approaches**: High level of research work comprising flight and ATC simulations, and in-flight demonstrations required to prove operational feasibility. Also, international co-operation between aircraft, engine and avionics manufacturers, civil aviation authorities and research institutions is needed to progress world-wide implementation.

– **Airframe Developments**: High research and development costs, together with certification environment that focuses on engine noise limits, and lack of commercial and regulatory incentives for take up of airframe technologies for reduced noise.

– **Active Noise Control**: Uncertainties on technical performance and maintenance and capital costs affect commercial viability and challenge take-up. Furthermore ANC technology is likely to introduce additional weight and therefore additional fuel costs which needs to be offset against the noise reduction benefits.

Effectiveness of take-up mechanisms

Further developments of international noise certification standards and transition rules are likely to encourage take-up of new noise reduction technologies

8. Chapter 3 noise stringency rules date back to 1977 and in that respect it does not represent state of the art engine and aircraft design technology. This has prompted action to evolve new standards at an international and European level. The current work programme of CAEP, as endorsed by the 32nd Assembly of ICAO, is looking at the introduction of a new noise certification standard and transition rules for phasing out the noisiest of the current Chapter 3 aircraft. The proposals call for the new standard to be significantly more stringent than the current Chapter 3 standard and would therefore encourage operators to comply through take-up of noise reduction operations and technologies.

A common noise classification scheme to determine slot allocations will encourage airlines to take-up noise reduction technologies, help airports to expand capacity and regulators to manage community noise at marginal airports

9. In addition to developments of new noise certification standards, the European Commission is planning to prepare policy measures aimed at advancing, on the basis of objective and non-discretionary conditions, the introduction of more stringent measures at a regional level, with particular emphasis on noise sensitive airports. The vehicle for these measures is likely to be a common noise classification scheme for aircraft, whereby the classification should reflect the

[42] See Annex A and B for more details on technologies assessed.

contribution to noise exposure of people living near airports. This could be achieved either through certification values or input data from the computation of noise exposure due to air traffic.

10. These proposals should provide the basis for development of environmental criteria into slot allocations at airports based on noise. If this system is combined with a quota system it provides incentives for airlines to take-up noise reduction technologies, on the basis that these will translate into greater slot allocation. This approach matches well with feedback from the industry which indicates that it is supportive of noise regulations that reward the best operators (in this case through additional slots) and therefore provides a system to justify the technology take-up (ADL, 1999b).

11. From a UK Government perspective, these proposals will help identify and therefore support the development of airport specific measures to address priority airports in the UK. Whilst from an airport operator view point, incentives and take-up of noise reduction technology would improve the overall capacity of airports instead of accepting the current tendency to "solve" environmental problems by means of capping the overall number of movements.

5.11 Other Factors

This sub-section addresses issues that are not directly related to future technologies for capacity enhancement or environmental mitigation at UK airports and their take-up. They are not explicitly within the scope of this study, but are important issues that have been raised by stakeholders during the course of work and could have an indirect effect on technology take-up, hence they are mentioned here.

The future allocation of radio frequency spectrum could have a major impact on the air transport industry and its existing and new technologies

1. In May this year the World Radio Conference of the International Telecommunications Union (WRC 2000) will meet to discuss, amongst other things, radio frequency allocations between users. The concern is that civil aviation could lose out in this process, it does not own the frequencies it uses and there is enormous pressure from the telecomms industry for re-allocation of many of the frequencies currently used by civil aviation.

2. Frequencies need to be set aside for radio navigation systems and for future GNSS (e.g. Galileo). For example if ILS frequencies, which are not protected, come under threat this could mean such systems are no longer usable for Cat III landings. If such changes are to happen they must do so in a planned way to enable the air transport industry to take appropriate steps. In the case of ILS, especially in the South East where frequencies are already limited for ILS operations, one way forward could be to mandate GPS for Cat I landings and MLS for anything below Cat I. However, this would need Government decisions on what is going to happen, the timeframe for transition and proper consultation with representative organisations (e.g. ICAO and NATS).

3. In the future, aviation will rely even more on satellite frequencies for a variety of applications, such as take-offs and landings in all types of weather and establishment of *en route* positions, to enhance safety or improve cost efficiency. However, a number of aviation's critical radio frequencies are under threat, including those exclusively reserved for GNSS, and if aviation loses its protected frequencies at WRC 2000, the decision will be irrevocable, potentially safety and operational efficiency would be compromised.

Limitations due to land take at airports could be a driver for the introduction of ADS-B for closely spaced parallel runway approaches

4. Although land take is not a technology for enhancing capacity at UK airports, clearly the availability of more land to build more runways would overcome many of the capacity problems at our busiest airports. However, this is not feasible in many cases and therefore technology is often used to overcome many of the limitations placed on an airport and ensure continued capacity growth.

5. A future technology that could overcome land take limitations on capacity growth at some airports is ADS-B for closely spaced parallel runway approaches. There already exists a trial system, NASA Langley's AILS, which may offer a development route for building a new runway where the spacing between the runways is too close for parallel operations using existing technologies.

There exist a number of operational practices that have developed over time which limit the maximum benefit that can be derived through the introduction of new technologies

6. The operational practices presented here represent what has been raised during workshops and interviews. In each case, these practices have been indicated to potentially reduce the maximum benefit that would otherwise be derived through the future application of new technologies. Given the pressures that exist for increased capacity and improved environmental mitigation, there may be a case for examining the basis for some of these operational practices.

7. The continued presence of "grandfather" slots (i.e. slots which for historic reasons remain allocated to specific airline operators) is cited as an example of an out of date practice. Its continued existence is one example of a number of factors that mean it is not possible to optimise slot allocation and aircraft scheduling. This will impact the benefit that can be derived from the take-up of technologies such as A-SMGCS and surface managers.

8. The use of stacks is an integral part of the concept of operation at the London TMA. This practice has developed because it is the most efficient way to feed aircraft onto the runway and maximise runway utilisation. However, it is not efficient in terms of noise and emissions, also it is not consistent with the Eurocontrol lead GTG strategy. Another practice is the holding of aircraft at the end of the runway awaiting departure. This is excellent for optimal sequencing of aircraft for departure but again is not efficient in terms of reducing emissions. It must be noted that some element of queuing is an essential pre-requisite of raising declarable capacity closer to runway service rate. Reductions in queuing to reduce the environmental burden would need to be mitigated by other tools, such as surface managers, to deliver aircraft to the runways in an optimum sequence at predictable intervals.

6 Implications for Prospective Government Policy

This section describes the implications for future prospective Government policy of the findings described in Sections 3 to 5 and the output from the issues focus workshop. It is essential that this section is interpreted in the context of these findings.

1. The section is broken down into four sub-sections. The first three sub-sections address implications for prospective Government policy that relate to encouraging the take-up of technologies to address:

   i) Capacity and efficiency issues;

   ii) Global environmental issues; and

   iii) Local noise and air quality issues.

   The last, and fourth, sub-section deals with non-technological issues related to capacity and environmental constraints.

2. Each sub-section starts by defining the pressure for change (the broader context and pressure for change, i.e. why the potential need for Government policy) and finishes with the implications for Government Policy as they relate to technology take-up to tackle the issue. These implications are presented in the context of mechanisms the Government could consider introducing to encourage the take-up of future technologies for capacity enhancement and environmental mitigation. As such, it should be stressed that they are not intended as statements of future Government policy.

3. The last sub-section deals specifically with non-technological issues associated with airport expansion, intermodal transport, and more general trade-off decisions between global, local and performance criteria. This sub-section sets out these issues to the extent that they can have an impact on technology take-up, and hence implications for prospective Government policy.

6.1 Overview

Implications for future Government policy can be categorised as those promoting technology development and take-up, and those addressing non-technological issues. The technology driven policy implications (not withstanding ongoing efforts) are firstly to address continued concern regarding capacity and efficiency of airports and airspace and secondly to address continued concerns regarding global climate change effects and local noise and air quality impacts.

In this respect, for enhanced capacity and efficiency Government working together with appropriate actors should consider to: improve ATC harmonisation, promoting robust benchmarking and greater transparency within the ATC community; introduce mechanisms that promote medium- and long-term investment in ATC systems; agree future datalink technologies; encourage the take-up of technologies whose primary benefit is improved efficiency because capacity and environmental mitigation benefits will follow; link proposed changes to existing operational practices with improved efficiency and environmental performance; and define for security checks at airports what constitutes positive identification and proves intent to travel.

Our analysis of views from the industry indicates that to help tackle the industry's global and local impacts Government working together with the appropriate actors should consider to: agree medium and long-term Kyoto objectives for the sector and to contribute to developing market based approaches that encourage fuel efficiency; step-up pressure for tighter international standards for aircraft noise and engine emissions, and if sufficiently ambitious international agreements are not reached, adopt noise and emission measures at a UK or European level; and support noise and emission based charges (as for example at Zurich airport) at UK airports which encourage performance beyond the latest ICAO/CAEP noise and NO_x standards.

Our analysis has also identified non-technological issues that result in capacity and environmental constraints at UK airports and which therefore have implications for future Government policy in a wider context. These include: difficulties associated with airport expansion; lack of intermodal connections with UK airports; and a need for greater clarity on the trade-offs between local, global and more general performance criteria.

The non-technologically driven policy implications (not withstanding ongoing efforts) are: improve the local decision process and provide guidance on future local priorities with respect to airport operations; introduce national planning processes and standards which reduce the long lead times experienced for planning applications; use Airport Transport Forums as an effective conduit to encourage stakeholder investment in and passenger take up of intermodal transport at UK airports; and communicate future policy direction on priorities between local and global environmental impacts to help support longer term technology development and take-up strategies within the industry.

6.2 Capacity and Efficiency Issues

This sub-section presents implications for prospective Government policy relating to capacity and efficiency, for both the airport and airspace, on the application of new technologies for capacity enhancement and environmental mitigation.

Pressures for Change and Implications for Prospective Government Policy

For each major finding the pressures for change are discussed along with the technologies they impact. In the shaded boxes, the implications for prospective Government policy are given, based on the desire to introduce mechanisms most likely to encourage their take-up.

ATC service provision across Europe is fragmented and this makes the industry slow to respond to pressures for increased capacity

1. ATC provision across Europe is inefficient because the system is fragmented along national boundaries, making it difficult to manage and optimise for efficiency. The operational efficiencies of European ATC centres differ greatly because of differences in airspace design and traffic flows. No robust mechanisms for benchmarking the performance of ATC centres exists. Therefore, it is difficult to identify and focus on ATC centres with low productivity in order to improve the efficiency of the system as a whole. This situation is beginning to change with the advent of CANSO, but there is still much to be done before a widely accepted benchmark for the ATC industry exists.

2. At an international level Eurocontrol attempts to harmonise the ATC infrastructure but lacks the authority to force member states to implement change within a given timeframe. There is also often a lack of political will to push through changes that are agreed at ministerial level. Predominantly, ATC services across Europe are provided on a national basis by monopolies with an institutional status. National interests can obstruct change. These factors result in an industry that is slow to respond to the pressure of increased capacity demand, and that inhibits the take-up of new technologies.

3. There is a lack of commonality and transparency in the way in which costs, determined by Eurocontrol, are allocated by ATC service providers to the airlines. Therefore, it is not possible to ascertain which ATC service providers give poor value for money, and then to apply pressure for improvement. However, Eurocontrol’s Performance Review Council (PRC) is investigating the transparency of costs through its “information disclosure” process. This study is well advanced and the PRC is likely to publish the first report of its findings in late 2001.

4. With respect to the take-up of future technologies for enhancing capacity, the future technologies affected by fragmented ATC services across Europe are those embraced and progressed by Eurocontrol within the context of the ATM 2000+ strategy. This is because these technologies require solutions that embrace the ATM system as a whole if they are to be effective in providing increased capacity and efficiency. Eurocontrol's role is to provide generic solutions and an overarching framework within which individual member states can progress technologies to

implementation, taking into account national requirements. Technologies affected include arrival and departure managers, surface managers and runway managers, along with technologies embraced by future ECAC strategies for CNS and for airspace design.

I[43]1 – In line with Government's ongoing efforts to improve ATC harmonisation, promoting robust benchmarking and greater transparency within the ATC community will increase technology take-up

5. For the UK the impact of a fragmented European ATC infrastructure with its variable performance is reduced efficiency, reduced airspace capacity, increased delays and unnecessary fuel use and emissions. It is not possible to consider UK airspace in isolation – an under-performing ATC centre in one part of Europe will have a knock-on effect on the UK.

6. A potential remedy exists under the Revised Eurocontrol Convention (signed by Governments in 1997) giving the European Union membership of Eurocontrol. This would pave the way for Eurocontrol to ensure regulation is applied more actively by member states. For example, the introduction of majority voting would enable Eurocontrol to apply pressure on member states to implement changes to agreed deadlines.

7. From a UK perspective, lobbying for improved efficiency of ATC service provision across Europe will increase the likelihood of many technologies being taken up in the future and maximum benefit from the application of these technologies being delivered. Areas where the Government can continue to apply pressure for greater harmonisation of ATC service provision across Europe include:

- Promoting the setting up of robust benchmarking to identify less efficient ATC centres;
- Promoting greater transparency of costs, business plans and investment plans for ATC service providers;
- Promoting the sharing of best practice across ATC providers to raise the standards of less efficient ATC centres to match those of the "best in class";
- Pioneering the introduction of Key Performance Indicators to provide metrics for comparing ATC service provision;
- Clarification of the role and institutional status of Eurocontrol, including its powers to enforce change;
- Influencing discussions on the total number of ATC centres across Europe; and
- Influencing decision making at European ministerial level (e.g. through ensuring decisions made at European ministerial level, such as at the recent MATSE VI meeting, embrace UK airspace and airport requirements).

[43] Implication (I) for prospective Government policy.

Evolutionary change in ATC operations is difficult to realise, the technical challenges are enormous, leading to a focus on incremental change

8. Incremental improvements to the current operational concept will enhance capacity. For example, once NERC becomes operational it will offer many opportunities to enhance capacity through incremental changes. However, it is not possible to predict whether incremental changes to NERC will provide substantial enhanced capacity. On the contrary, it is likely that this approach will not be sufficient to satisfy forecast capacity demand in the medium- to long-term.

9. In past years there have been many new concepts of operation, supported by future technologies, for improving airspace design, airspace usage, flight profiles, and traffic flow. In practice, many European programmes aimed at evolutionary improvements to ATC service provision have failed to deliver on the timescales originally planned. This inability to bring about significant change has a negative impact on the take-up of future new technologies. One example is the PHARE programme, a European research study aimed at providing 4D trajectory negotiation and requiring changes to the airspace structure, the implementation of air-ground datalinks, and the application of new controller tools. After much effort and cost it now seems likely that such a concept is, at best, a long-term prospect.

10. As a consequence, it is much more likely that small incremental changes to existing concepts of operation remain the norm. At a national level this is so, the capacity benefits being realised more easily and changes being less reliant on the introduction of new technologies. However, since this approach only addresses short-term capacity and efficiency shortfalls this means capacity constraints and delays will remain for the foreseeable future.

The monopolistic status of providers and limits on how much can be charged for the provision of ATC services removes the incentive to improve and invest in ATC related technologies

11. The monopolistic status of ATC service providers acts to remove incentives to invest in new technology to improve performance since there is no direct competition for service provision. A truly competitive ATC environment is not feasible since there can only be one provider for a given piece of airspace, it is also probably not desirable. Without true competition other mechanisms which introduce some of the positive aspects of competition can be employed to force down costs, improve performance and, particular to this study, promote long-term investment in new technologies.

12. Charges for providing ATC services are set at a European level, revenues are collected by Eurocontrol and then distributed to member states. This process acts to remove incentives to invest in new technologies to improve ATC services since the amount levied does not relate to the sophistication of the ATC system for a member state.

I2 – Consistent with Government activities to progress PPP of NATS, introducing mechanisms that promote medium- and long-term investment in ATC systems will accelerate the take-up of new technologies

13. With respect to the users of ATC services, the need is to encourage actions that enable better long-term prediction of future requirements for ATC services to enable better take-up of new technologies. Possible mechanisms include:

- Ensuring any future regulatory framework for NATS addresses the long-term viability of the ATC system through future R&D activities that focus on long-term capacity needs as well as short-term ones;
- Providing a regulatory framework whereby NATS must achieve a comprehensive set of quality of service targets for its users, including both capacity and efficiency elements;
- Allocating a greater proportion of route charges and landing fees into R&D of long-term future technologies;
- Modifying the ATC charging structures to secure greater efficiency of airspace use;
- Introducing penalties to airlines[44] when they exceed their forecasted capacity requirements; and
- Encouraging airline operators to maximise aircraft utilisation through the introduction of an element within route charges that take account of aircraft utilisation.

Many CNS infrastructure technologies require international standards to be agreed before their implementation and regulation to encourage their take-up

14. Many technologies for communication, navigation and surveillance rely upon standards being in place before they can be developed and implemented, and regulation to be in place to ensure their timely take-up by users and providers. Getting agreement on standards is typically a very long process, because there are many stakeholder interests to take into account and many vested interests to consider. Of the technologies addressed by this study, this is especially true for VHF datalinks and the use of satellite systems. This affects all the future concepts that are dependent upon these enabling technologies.

15. Potential disincentives for airline operators investing in ATC infrastructure technologies include:

- Often a very high take-up rate must be achieved before any benefit can be derived;
- It can take many years for all airline operators to become equipped;
- Equipment often only supports ATC applications with no opportunity for airline applications to be enabled by the technology; and

[44] In practice, airlines can seldom give accurate predictions of traffic growth beyond 1 year, such mechanisms could result in over-bidding with consequential over-investment in long-term ATC-related technologies.

– Sometimes airlines are forced to invest in more than one technology to provide the same basic functionality.

16. The above explains why regulation is required to stimulate the rapid take-up of infrastructure technologies, though this must be introduced in close co-operation with users.

17. Finally, the forthcoming reallocation of frequency spectrum this summer at the WRC conference could have a detrimental effect if frequencies currently allocated for use by civil aviation are re-assigned to different users. In the context of this study, future concepts reliant upon satellite communications for their operation could be in jeopardy if frequencies exclusively reserved for GNSS are reallocated. A balance must be achieved between meeting demands for spectrum from a rapidly growing telecommunications industry and protecting spectrum for civil aviation use to ensure a high quality communications and navigation infrastructure is maintained for aviation. This is a known issue and, for example, at MATSE VI in January 2000 a decision was reached whereby transport ministers in co-operation with ICAO will seek to ensure that decisions taken at the WRC conference will take account of the needs of the aviation community.

I3 – As part of the Government's continued involvement at an international level in setting standards, focussing on agreeing future datalink technologies will promote the take-up of technologies enabled by datalink

18. Government is already actively involved in the development and agreement of standards and regulations at an international level. For example, the DETR, the DTI and the CAA all have representation at European fora. The Government also works closely with industry and with NATS when developing new proposals to take to European fora.

19. Recognising the importance that the UK Government already places on new ATC infrastructure standards and regulation, a focus on the following issues will help accelerate technology uptake in areas enabled by ATC infrastructure technologies:

– Which future air-ground and air-air datalink technology is to become the standard for ATC service provision; and
– Which frequency spectrum allocations are to be protected for civil aviation use and for GNSS based applications.

The main driver for the implementation of future ATC technologies is to satisfy forecast capacity demand

20. To date, ATC service providers have focussed technological advances on satisfying the growth in forecast air traffic demand, whilst maintaining or improving safety. This demand-based perspective is starting to shift, recognising the environmental cost of the industry, and this change will need to continue as can be seen in the following extract from the final communiqué from MATSE VI:

"*…in addition to short-term measures which are needed to solve the most urgent congestion problems, it would be necessary to assess quickly economic incentives which would allow management of the future growth of air traffic by including environmental costs which are not currently taken into account in air transport.*"

21. Many future technologies can improve efficiency but do not necessarily increase capacity. For example, a technology which optimises the time taken for aircraft to taxi from the stand to the runway will not, on its own, improve capacity at Heathrow. Even so, investing in technologies to improve efficiency will help release some of the many bottlenecks that exist, which is beneficial given how over-constrained air transport operations are today. Also, for some technologies, efficiency gains will translate into environmental benefits through greater fuel economy.

22. There is limited incentive today for ATC service providers to invest in management systems whose main benefit is improved efficiency for environmental benefit. For example, reducing the need for holding patterns in the air and on the ground would have a positive environmental benefit, but would also require substantial investments in sophisticated management systems to ensure airport capacity was still optimised. In the future, the incentive to invest could exist if traffic patterns and flows became so complex that sophisticated management systems are required to assist controllers in optimising capacity. This is a long-term prospect.

23. For airline operators the incentives are much greater, improved fuel efficiency and reduced operating costs would make the payback from management systems very short-term. However, given how over-constrained air transport operations are today, there is a risk that introducing new management systems to, say, reduce holding aircraft at the runway prior to take-off would simply mean aircraft have to wait longer at the stand (and these are also often a major bottleneck).

24. In the future a better balance between technology take-up for enhanced capacity and improved efficiency for environmental benefit will be required, especially given concerns about the environmental impact of the industry. Of the technologies addressed by this study, those that improve efficiency at UK airports are arrival and departure managers, surface and runway managers, and A-SMGCS.

I4 – Encourage the take-up of technologies whose primary benefit is improved efficiency because capacity and environmental mitigation benefits will follow

25. There is a case for the introduction of incentives, or regulatory frameworks, to encourage the take-up of technologies whose primary benefit is improved efficiency. Such investments would not also support future capacity enhancement through relieving some of the bottlenecks, but by tackling inefficiencies in the system would also provide environmental benefits. These incentives, or regulatory frameworks, can take many forms, including:

– Encouraging NATS to invest in development programmes for technologies to improve efficiency for environmental benefit, for example through the terms of any future regulatory framework for NATS if PPP proceeds;
– Better, more efficient, routings for airlines which invest in new technologies to improve efficiency for environmental benefit; and
– Route charging and landing fee structures that benefit airlines that invest in new technologies to improve efficiency for environmental benefit.

I5 – Link changes in existing operational practices with improved efficiency (where there is an environmental benefit) to encourage technology take-up

26. Government should consider linking changes to existing operational practices that have an environmental cost (e.g. stacking, holding aircraft at the runway, etc.) with the take-up of future technologies to improve efficiency where there is an environmental benefit and to ensure airport capacity is not compromised.

27. Possible approaches include:

– Introducing a component into landing fees that is used directly for investment in future airport management systems aimed at improving efficiency;
– Linking slot allocations to future aircraft equipage levels necessary for the introduction of airport management systems (though not currently compatible with EU law and could prove difficult to implement in practice across existing slots with indefinite grandfather rights); and
– Defining quality of service parameters that NATS must achieve which, over time, include an ever more important environmental mitigation component through airport efficiency measures.

There is the prospect of new technologies changing the form in which security checks at UK airports are conducted

28. Advances in future technologies (e.g. smart cards and e-ticketing) will improve the throughput efficiency of passengers at busy airports. With the possible introduction of VLAs with 600 or more passengers embarking and disembarking at a time, there may come a point where security checks such as passport controls become the major bottleneck, especially if technology advances have already penetrated all other aspects of a journey. Technological advances point to the use of smart cards complemented by biometric measures for personal recognition at security check-points to speed up the security process.

29. Today, from the UK one must demonstrate intent to travel in order to pass through a security check. With full smart card technology there is no absolute need for a piece of paper to show a valid seat reservation on an aircraft, an electronic booking is sufficient. In many respects retaining some form of paper ticket would remove much of the benefit of investing in smart card technology.

30. At present, a valid passport with the name that matches the boarding pass and a photograph that looks like the passenger is required. In future, it could involve fingerprint recognition, retinal measures, etc. for which there are no legal definitions of what would constitute positive identification and reconciliation.

I6 – Consider the need for Government policy to define what constitutes positive identification and what proves intent to travel to enable the take-up of new technologies for security checks at airports

31. To dispense with currently used paper based boarding passes there will need to be a re-definition of what is legally required to be shown by a passenger to confirm intent to travel.

32. The introduction of biometrics for passenger identification will require changes in the definition of what constitutes positive identification of a passenger and then what constitutes reconciliation with intent to travel information, particularly if this is smart card based. Improved passenger and baggage screening techniques will be needed if security controls are not to be a major bottleneck in the future. However, when doing so, a clearer relationship is needed between the level of security risk that can be tolerated with the introduction of new technologies and the extent of the screening required.

6.3 Global Environmental Issues

This sub-section presents the implications for prospective Government policy relating to the development and take-up of future technologies to address the global environmental impacts (e.g. its contribution to global climate change) of the industry.

Pressures for change

The pressures for change with respect to global environmental issues are as follows:

There is growing pressure from stakeholders to include the international impacts of the aviation sector within the Kyoto Protocol provisions, but as yet no agreed view on how this should be done

1. The global nature of the industry poses special and complex problems to its regulation. For example, under the Kyoto protocol to the UNFCCC, Annex 1 (industrialised) countries have committed to reduce their collective emissions of greenhouse gasses by approximately 5% by 2008-2012 compared to 1990 levels. However, recognised and agreed methods for allocation of aviation's international emissions do not exist (see Box 6-1), hence these currently remain outside national inventories. As a consequence, the implications of the Kyoto protocol for aviation remain uncertain both in timing and extent.

Box 6-1 UNFCCC Kyoto Protocol – International Aviation

"The Parties included in Annex 1 shall pursue the limitation reduction of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organisation and the International Maritime Organisation" (UNFCCC, 1998, Article 2, paragraph 2).

Options for the allocation of global emissions from aviation currently being investigated by the UNFCCC Subsidiary Body for Scientific and Technical Advice (SBSTA) include:

Option 1 – No allocation.
Option 2 – Allocation of global bunkers sales and associated emissions to parties in proportion to their national emissions.
Option 3 – Allocation according to the country where the bunker fuel is sold.
Option 4 – Allocation according to the nationality of the transporting company, or to the country where an aircraft or ship is registered, or to the country of the operator.
Option 5 – Allocation according to the country of departure or destination of an aircraft or vessel; alternatively, emissions related to the journey of an aircraft or vessel shared by the country of departure and the country of arrival.
Option 6 – Allocation according to the country of departure or destination of passengers or cargo; alternatively, emissions related to the journey of passengers or cargo shared by the country of departure and the country of arrival.
Option 7 – Allocation according to the country of origin of passengers or owner of cargo.
Option 8 – Allocation to a party of all emissions generated in its national space.

Scientific uncertainties exist in qualifying the global emission impacts of aviation and this further complicates its inclusion within the Kyoto protocol.

2. In terms of impact potential, the global warming impact of aviation's emissions (measured through a combined index termed radiative forcing by IPCC) is complicated through multiplicity of emission effects[45]. This results in the overall impact being estimated at 2 to 4 times the effect of aviation related CO_2 emissions alone.

3. Of the non-CO_2 emissions, water vapour effects (contrails and cirrus clouds) represent the largest uncertainty. Furthermore, the combined effects of NO_x at altitude remain uncertain since NO_x emitted from subsonic aircraft acts to increase atmospheric ozone, which leads to increased global warming potential but it also destroys methane, leading to reduced global warming potential. The combined effect is complex and not fully understood, and may give rise to localised effects.

Compliance costs to achieve CO_2 reductions in line with Kyoto are potentially significant and could suppress demand if passed on through higher fares

4. Assuming demand for passenger and freight services continues to increase as forecast, predicted development and take-up of future technological advances based on a "business as usual" scenario in the short, medium and long-term will not offset the environmental requirements implied by rigorous interpretation and enforcement of the Kyoto protocol. Given relative high emission abatement costs compared to other industries, such as road and rail and many non-transportation sectors, the cost of compliance for the aviation industry is potentially very high and could, if passed on through significantly higher fares, result in suppressed demand. The industry claims this would eventually result in passenger welfare losses and other socio-economic dis-benefits, such as job losses.

5. It remains to be seen how significant abatement costs will be on travel demand. For example, alternative research suggests that the introduction of an aviation fuel tax equivalent to a fuel price increase of 10% per annum (where this cost is passed on through an equivalent fare increase) would reduce the forecast annual passenger growth rate over a 10 year period to 3.8%. This is at the low-end of current growth rate predictions. (The Department, 2000).

There is a significant mismatch between what the industry says it can voluntarily agree to and what policy makers require for compliance with Kyoto targets

6. Recent communications by the European Commission and from industry indicate a significant gap between suggested targets for voluntary fuel efficiency improvements (4%-5% per annum) and the industry's view on what is achievable (ENDS, 1999; Commission of the European Communities, 1999). Indeed, industry sources claim it will be more than a decade before the sector can exceed annual 1.1% reductions. In a joint statement, the European Airline Association (AEA) and the aerospace industry association stated that major emission reductions through

[45] The global warming potential of aviation is not determined solely through CO_2 emissions but is also contributed to through NOx, water vapour, contrails, cirrus clouds, sulphate and soot emissions.

new technology developments will only be possible after 2012. This is the end of the 2008-2012 "first commitment period" under the Kyoto climate protocol, by when the EU is committed to cutting domestic greenhouse gas emissions by 8% relative to 1990 levels.

Mechanisms to influence take-up and their effectiveness

7. Section 5.8 details the drivers and barriers for take-up of technology to address CO_2 and NO_x emissions. Given this context it proposes different mechanisms to accelerate take-up and analyses their effectiveness. In this respect effectiveness is used to describe our understanding of how the industry's stakeholders would respond based on published material, interviews with industry stakeholders and the output from the technology and issues workshops. The main headlines from this analysis are:

- Investments into technologies to improve fuel efficiency are driven by commercial drivers to minimise costs and not through initiatives to reduce CO_2;
- Supply side measures to "multiply" competitive gains from fuel efficiency driven technologies and support R&D costs are required to accelerate technology take-up;
- An open emission trading system offers the lowest compliance cost to reduce the industry's global impacts and would encourage supply side take-up of fuel saving technologies;
- A recycled charging system would help fund and encourage technology innovation;
- It is important to recycle revenues from market based instruments back into the industry, especially to offset the disproportionate impacts on 3rd World fleet residual values; and
- The industry is receptive to voluntary agreements[46], especially if these help to offset the need for fuel taxes.

Implications for Prospective Government Policy

8. The implications for prospective Government policy with respect to introducing mechanisms most likely to encourage the take-up of new technologies to address global environmental issues are as follows:

I7 – Continue to work with industry and ICAO/CAEP to develop and communicate a clear set of medium and long-term Kyoto objectives for the sector

9. Significant progress has and continues to be made against this objective through international ICAO/CAEP working group initiatives to which the DETR and

[46] It is worth noting that while voluntary agreements can be an effective mechanism for reducing an industry’s global emissions they can give rise to monitoring and enforcement problems

industry (airlines, manufacturers and airports) contribute (see Box 6.2).

10. Nevertheless no firm consensus exists yet on how aviation's global emissions may be brought within the Kyoto protocol. Decisions on compliance with the Kyoto Protocol will help the industry address some of its current uncertainties and to plan for the future.

Box 6.2: Status of CAEP Developments

ICAO's Committee on Aviation Environmental Protection (CAEP) is developing policy options for reducing aviation emissions. CAEP have focused on three possibilities:

Working Group 3: Further increasing the technological efficiency of aircraft so that aircraft become less polluting in terms of emissions per passenger

Working Group 4: Improving air traffic management and other operating procedures to minimise fuel use

Working Group 5: Introducing market based options to provide economic incentives to airlines to limit emissions. The options include fuel levies, emissions trading and voluntary agreements.

These initiatives are drawn together through the CAEP focal point liaison and interface with the UNFCCC. The UK makes a substantial contribution to this work, particularly with regard to emissions standards and economic incentives. Key endpoints arising from this work include successful pressing for the evaluation of a range of scenarios that could lead to substantial reductions in total emissions – if agreement can be reached to link international aviation to the Kyoto flexible mechanisms. However, the concepts are novel and complex and it will be essential to get agreement from developing countries and industry if they are to be accepted within ICAO at its 33rd Assembly in the autumn of 2001.

I8 – Consider support of a combined market based approach based on environmental charges, open emission trading and voluntary agreements to promote take-up and development of technologies to minimise aviation's global emissions

11. Our analysis of views from the industry indicates a need for Government to conclude its current investigations of mechanisms for reducing CO_2 emissions from domestic aviation so that the industry can develop its responses. Through its liaison with ICAO and the UNFCCC Subsidiary Body for Scientific and Technological Advice it is already involved in setting the international response. The industry has indicated that it would be receptive to a combined approach, encompassing environmental charges, emission trading and voluntary approaches, to tackle specific technology take-up and development barriers faced by the industry. Such a combined approach would therefore help to overcome the theoretical and practical criticisms levelled at individual mechanisms.

Working within this combined approach Government should:

I8.1 – Consider support of open and flexible emission trading permits systems to encourage fuel efficiency technology take-up

12. Government continues to be involved in the ICAO/CAEP Working Group 5 initiative to investigate market-based options for capping future CO_2 emissions.

Published studies and reports[47] indicate that open and flexible emissions trading systems are both environmentally and economically efficient. These criteria fit well with industry's need to minimise costs of compliance by offering a flexible system that offers the lowest cost of compliance and provides incentives for technology take-up and innovation that exploit cost savings amounting from marginal fuel efficiency and emission permit gains.

13. In practice an open emission trading system offers the industry the opportunity to exploit global emission savings at a lower marginal cost in other industries. For example, fuel cell technology or cryogenic hydrogen fuels offer significant potential to cut global CO_2 and NO_x emissions, and our analysis has concluded that these technologies are neither a practical nor commercially viable for aviation before 2030. However, other industries that do not face the same physical, safety and high investment cost constraints as aviation, e.g. car transport, can viably implement such technologies, provide marginal global emission gains and at a lower cost than the equivalent gains made in aviation.

I8.2 – Consider support of environmental charges that are recycled within the industry to fund technology innovation, research and development

14. There is broad industry consensus that charges as opposed to taxes are preferable, since the perception is that income from taxes as opposed to charges would not be recycled within the industry. The recycling of these charges is seen as fundamental to the funding and catalysing of a process that supports innovation and research and development of future technologies.

15. In this respect, industry believes it would be efficient to set up an independent central body (ideally at a world-wide level but otherwise on a European level) to administer the collection and subsequent allocation of R&D funding to stakeholders of the industry. Such as system would need to be reconciled within the context of Government policy and treasury constraints.

I8.3 – Work with industry to agree voluntary agreements that are "over and above business as usual" for future fuel efficiency improvements

16. Current evidence suggests a significant mismatch between policy maker's expectations for voluntary agreements on future fuel efficiency improvement and industry's view on what is achievable. This suggests that there is a need for continued dialogue to negotiate a level that is both demanding but commercially and technically feasible, especially since the industry is generally supportive of voluntary agreements. Clearly the emphasis should be on achieving voluntary agreement that go beyond "business as us usual".

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[47] Summarised within CAEP (1999), and IPCC(1999).

I8.4 – Support initiatives to promote better scientific understanding of the contrail and cirrus cloud radiative forcing (contribution to global warming) impacts of air travel and consider how these impacts may be incorporated or combined with Kyoto CO_2 targets and minimised through market based and other approaches

17. The recently published IPCC report on aviation and the global atmosphere (IPCC, 1999) has highlighted the significant contribution that aviation induced contrail and cirrus cloud formation has on aviation's total radiative forcing potential (contribution to global warming). Based on current projections the relative contribution of contrail and cirrus cloud effects from air travel to aviation's radiative forcing is forecast to increase to over 50% by 2050.

18. At the same time, the focus of international and national efforts to mitigate global warming impacts from aviation is on measures to control aviation's CO_2 and NO_x emissions. In part, this focus is explained by the relatively recent formal recognition and quantification of the contrail and cirrus cloud global warming impacts from aviation but also due to the level of scientific uncertainty associated with these effects, especially with the global warming impacts of cirrus cloud formation.

19. Taken together these factors indicate a need for Government to continue to promote efforts that help gain better scientific understanding of these effects. This would include acting on the recommendations of an recent scoping study let by the DETR Global Atmosphere Division to investigate the effects of contrails and cirrus cloud formation[48].

20. Furthermore, there is a need for Government to consider how these impacts could be incorporated or combined with Kyoto CO_2 targets and the role Government can play (e.g. through market based and other approaches) to promote technological developments and take-up that mitigate aviation's global warming effect from all sources.

[48] Ongoing research led by Dr McFadyen

6.4 Local Noise and Air Quality Issues

This sub-section presents the implications for prospective Government policy relating to the development and take-up of future technologies to address the local environmental impacts (e.g. NO_x emissions and Noise) of the industry.

Pressures for change

The pressures for change with respect to local issues are as follows:

Local concerns about noise will continue to influence and restrict future airport growth

1. The local environmental impacts of airports are varied, but historically local opposition has centred on aircraft noise. The industry has made significant progress in reducing both absolute noise levels from aircraft and improved operating procedures, both of which are evidenced through the shrinking of the 57 leq contour (considered to define the boundary for the onset of noise disturbance). Nevertheless, noise continues to remain high in the agendas of local residents and decision-makers. For example, Boeing research[49] on world-wide noise control measures indicates that curfews, noise budgets and limits and slot restrictions have grown in step with passenger figures, with the number of airports world-wide experiencing noise-related restrictions growing from 140 in 1980 to 350 in 1998.

Increased emphasis on controlling local air quality is likely to restrict airport expansion

2. With increased air traffic and the associated growth in ground traffic, congestion and pollution, noise concerns are being increasingly supplemented by growing concerns about local air quality, particularly ozone formation from NO_x emissions. Research has linked ozone to serious human health effects such as decreased lung function, increased respiratory symptoms and lung inflammations, but also effects have been linked to forest damage and crop yield losses.

3. In the UK, as part of their local air quality management duties, local authorities are currently reviewing and assessing air quality in their areas. Where a local authority considers that one or more of the air quality objectives is unlikely to be met by the relevant deadline, it must declare an air quality management area (AQMA). It must then draw up an action plan setting out measures it intends to take to meet the objectives and including a timetable for their implementation. Within this review and assessment process, those relevant local authorities must consider the current and future impact of airports in their area.

[49] Based on 591 airports in Boeing database, www.boeing.com/assocprodcuts/noise/summary.htm

4. It is therefore likely that international regulatory controls by ICAO (e.g. CAEP/2 and CAEP/4) will continue to be enforced and tightened, whilst at a local level measures will continue to be developed, gain credence and set precedents. For example, Zurich airport introduced emission-based charges in 1998. These charges were challenged by IATA in the Swiss Federal Court but this challenge proved unsuccessful and charges continue to be paid by all airlines.

Mechanisms to influence take-up and their effectiveness

5. Sections 5.9 and 5.10 detail the drivers and barriers for take-up of technology to address local concerns relating to noise and air quality. They also propose different mechanisms to accelerate take-up together with an analysis of their effectiveness. In this respect effectiveness is used to describe our understanding of how the industry's stakeholders would respond based on published material, interviews and the output from the technology and issues workshops. The main headlines from this analysis are:

- There are limited financial incentives for take up of NO_x and Noise reduction technologies other than the opportunity cost of capacity constraints;
- Increasing incidence of locally based charges and evolving international regulations to reduce NO_x and noise provide incentives for technology take-up;
- The industry prefers an internationally ICAO led approach for setting future NO_x and noise standards rather than uncoordinated introduction of emission and noise charges at the local level;
- Local stakeholders would be receptive of NO_x and noise charges and regulations if they result in an improvement in local air quality and community noise;
- The Zurich emission charging model is in compliance with local legislation and ICAO guidelines and therefore may set a future precedent; and
- A common noise classification scheme to determine slot allocations will encourage airlines to take-up of noise reduction technologies, help airports to expand capacity and regulators to manage community noise at marginal airports.

Implications for prospective Government policy

6. The implications for prospective Government policy with respect to introducing mechanisms most likely to encourage the take-up of new technologies to address local issues are as follows:

I9 – Continue pressing for tighter international standards for aircraft noise and engine emissions to accelerate take-up of best available NO_x and noise mitigation technologies identified by this study

7. Government, working with ICAO should continue to influence and press for tighter world-wide standards for aircraft noise and engine emissions. This would fit with industry's preference for international standards. Future noise and emission standards should look to reflect what is achievable using the latest technology but also consider the cost implications.

8. To further expedite take-up of best available technology, and given that Chapter 3 noise stringency rules date back to 1977, there is a role for Government to find agreement to prevent the use of aircraft which barely meet existing noise standards. To some extent this is already being aided by airport operators imposing additional airport charges to reflect noise performance.

I10 – If sufficiently ambitious international agreements are not reached, Government should consider use of noise and emission measures at a UK or European level to influence take-up of better performing technologies in the global fleet

9. The Government has set air quality objectives to be achieved by relevant deadlines (as prescribed by the *Air Quality Regulations 2000* and set out by the UK AQS) and has committed itself to minimising airport-induced noise. Therefore if sufficiently ambitions world-wide measures can not be agreed then the UK Government should look to develop and introduce emission and noise measures at a European or UK level. These would require careful consideration to ensure they did not contravene international trade agreements, ICAO agreements or bilaterals or introduce market distortions.

I11 – Consider support of noise and emission based charges and/or quotas at UK airports which encourage performance beyond the latest ICAO/CAEP noise and NO_x standards, to provide a financial incentive for new technology take-up, and funds for noise and air quality improvement projects

10. The Government's New Deal for Transport White Paper indicates a commitment that industry should pay its external costs. However, there is limited financial incentive for operators to go beyond current ICAO/CAEP noise and NO_x certification standards, especially for aircraft that are already in service. A system that rewards the best and punishes the worst should with time accelerate technology take-up of noise and NO_x reduction technology and help minimise the local effects of capacity growth at UK airports.

11. For example, airport emission charges at Zurich and more recently in Sweden suggests that a local charging system has legal precedent (IATA were unsuccessful in challenging Zurich), offers a mechanism to financially encourage operators to take up low NOx technology and/or to alter their fleet operations to preferentially utilise aircraft operating out of the airport.

12. In the short-term, local charging is likely to accelerate low cost retrofit options to cut NO_x emissions. These offer economically viable options to maintain fleet values by extending the life of current engines by exceeding ICAO standards for new production engines (CAEP/2) and by qualifying for the Swiss Class 5 emission category. In the longer term airport charging is likely to encourage take-up of advanced single annular or double annular combustors which offer even greater NO_x reductions.

13. Additionally, supporting fixed noise contour limits, as applied at a number of European airports (e.g. Schiphol), offers an approach which permits air capacity growth but sets limits to the noise impacts of growth. Such an approach, which can be controlled through the existing planning system (as in the Manchester Airport Second Runway S106 agreement) has the advantage that it encourages stakeholders (e.g. airlines, airports, community) to work in a co-ordinated and strategic manner to achieve common goals and targets and encourages greater investment in improved technologies and practices.

14. The implications of any airport charging approach would need to be considered within the context of "Single Till" principle currently in operation in the UK.

6.5 Other Non-Technological Issues

This sub-section presents the implications for prospective Government policy with respect to non-technological issues as they relate to the capacity and environmental constraints faced by the industry to the extent that they can have a bearing on the take-up of future technologies. The areas covered are:

- **Airport expansion**: For example, local concerns relating to local air quality, noise and land take associated with new a new runway or airport terminal.
- **Overriding Priorities**: For example, general priorities on future trade-offs between local, global and capacity performance.

Airport Expansion Issues

1. Airport expansion projects are generally driven by the desire to add to runway capacity, add terminal capacity and / or additional car parking. Such plans generally introduce a number of issues at the local level, including land take, implications of congestion, additional noise and impacts on air quality. Section 6.4 deals with the technology take-up implications for Government policy to deal with the noise and air quality issues, whilst the next sub-section deals with intermodal issues to address local congestion. This section therefore looks at the more general local and political factors such expansion raises and their implications for Government policy.

Pressures for change

The pressures for change with respect to airport expansion issues are as follows:

Long time horizons for airport planning applications mean the decision-making processes often bear little relationship to the business needs of airports, thereby creating a barrier to technology take-up

2. Multiple long-term planning inquiries, where the goal posts shift over the very long time horizons, often mean that the planning inquiry process and subsequent decision exceeds any timescales commensurate with the business needs of airport and airline operators. This can make the final ruling somewhat meaningless and hence undermine the whole process and its stated intentions. Furthermore this uncertainty is a barrier to forward planning and therefore is not supportive to technology take-up.

This situation is underpinned and reinforced by:

Local stakeholder influence is high, and the procedures for dealing with their concerns are often ineffective, resulting in long delays in critical airport expansion decisions

3. Local stakeholders are voicing their airport concerns in more vocal, structured and effective ways, creating barriers to airport expansions. Rising awareness of quality of life, safety and health issues from airport activities is encouraging local stakeholders to become more proactive and organised in their response to proposals for airport expansion. Furthermore local concern and actions are increasingly being accentuated through widespread media coverage and support from pressure groups. For example, most of the issues surrounding the Heathrow Terminal 5 inquiry were in essence local, nevertheless media coverage and concerted local action assisted through pressure groups quickly resulted in the planning process becoming a national agenda item. Evidence suggest that the processes to deal with stakeholder concerns are not particularly effective and the planning process as a consequence becomes protracted and costly and the outcome uncertain.[50]

Lack of mechanisms to quantify, articulate and communicate the costs and benefits of aviation provide credibility to NIMBY behaviour

4. Tools and mechanisms to capture and quantify the costs and benefits of airport activity remain largely undeveloped. Therefore, whilst the financial benefits from increasing airport capacity are clear, the external cost to society are not. Furthermore, there is a perception that many of the benefits are regional and national, for example through employment opportunities, whilst the external costs, such as additional noise and congestion, are borne locally. This brings into play a number of interrelated problems.

5. Firstly, since cost benefit arguments may fail to recognise and represent fully local concerns and priorities, which may be exacerbated by the lack of an effective two-way dialogue process, there is a loss of trust on the part of local residents towards potential airport projects. Secondly and closely related to the first point, issues of equity and perceived balance between the "pain and gain" for local stakeholders tend to support NIMBY behaviour (Not In My Back Yard). Finally, at many airports today there are comprehensive measurements taken of noise and local air quality. In future, these may form a basis for regulation and, against this backdrop of mistrust, local environmental groups, airlines operators and airports could all use this information to suit their own needs rather than for the benefit of all.

<u>Implications for prospective Government policy</u>

6. The implications for prospective Government policy with respect to airport expansion issues and introducing mechanisms most likely to encourage the take-up of new technologies are as follows:

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[50] The approach used by Manchester Airport in consulting with and formulating strategies and agreements to address local community concerns during the application for its second runway offers a recent example of a more open and flexible approach.

I12 – In line with ongoing Government policy there is a need to improve the local decision process and provide guidance on future local priorities with respect to airport operations

7. At a local level restrictions are often truly "local" and not to be found in place at other airports. As public awareness increases there is a need for local communities to understand the full range of issues regarding the operation of an airport, its possible future expansion and potential new investment programmes. There are noise and pollution effects and how these compare with other transport mechanisms, and there are the socio-economic benefits of an airport as a major economic driver, providing jobs for the local community.

8. There are a number of possible measures that could be taken to raise awareness of the full range of issues and improve the consistency of approach at the local level towards future plans for airports. These include:

- Supporting local initiatives to educate the public;
- Providing more Government funding to agencies researching local issues;
- Providing strong leadership to local Government through setting environmental targets and developing a framework for industry to comply;
- Promoting transfer of best practice on local noise and air quality; and
- Providing some means for limiting unhelpful local Government restrictions.

9. On another level, a lack of mechanisms to measure costs and benefits of airport activity means it is difficult to make comparisons between alternative solutions to the many issues facing airports and their stakeholders.

10. This leads to the need for improved information flow and transparency of decision making to support insights into environmental, health and safety trade-offs as well as economic ones. It also highlights the need for greater consistency between local, national and international requirements and how they are resolved. To achieve these important elements would require clear guidelines from the Government on what constitutes sustainable trade-offs between emissions, noise and performance at airports in the UK.

11. There may be merit in reviewing national and local standards to create a framework within which consensus can develop, one which puts the local and national impacts and issues into perspective and allows industry to plan accordingly. This framework would enable airport operators to commit earlier to longer term investment programmes, at present problems at airports are solved through incremental (add-on) improvements over what is done today. This would in turn enable better planning by ATC service providers and airline operators.

Overriding Priorities

12. Physical constraints mean that technology developments are restricted by trade-offs between improving one area of performance at the expanse of another. In determining future technology development and take-up strategies clearly it is important for industry to be aware of the Government's view on the importance placed on different performance areas. This section therefore addresses the Government policy implications of these intrinsic trade-offs.

Pressures for change

The pressures for change with respect to trade-offs between local, global and performance criteria are as follows:

There are intrinsic trade-offs between global and local environmental impacts imposed by alternative technology take-up strategies

13. There are intrinsic trade-offs imposed by current technologies between impacts on the local and global scale. For example measures to improve fuel efficiency and reduce aircraft noise have in general resulted in a higher engine operating pressures and temperatures and increased production of NO_x for a given type of combustor technology. However, combustor design developments are working towards minimising such trade-offs.

14. There are also trade-offs between environmental impacts for different transport modes. For example, high-speed rail can offer significant emission savings over air transport, although the net effect is sensitive to numerous factors, including the type of aircraft, type of train and the type of service. However, rail networks require significant infrastructure investment and the potential noise footprint is not limited, as with aviation, to the airport but extends along the entire track length.

Implications for prospective Government policy

15. The implications for prospective Government policy with respect to trade-offs between local, global and performance criteria and introducing mechanisms most likely to encourage the take-up of new technologies are as follows:

I13 – Communicate future policy direction on priorities between local and global environmental impacts to help support longer term technology development and take-up strategies within the industry

16. Performance trade-offs between the environmental mitigation of different technologies (e.g. noise versus fuel burn, H_2O versus CO_2, or NO_x versus fuel burn) mean that technology decisions will often favour one impact over another.

17. Given such trade-offs exist between future technologies and their potential environmental impact or mitigation, there is a requirement for clear guidance from the Government and or ICAO on the importance they place between local and

global environmental impacts.

7 Conclusions for Prospective Government Policy

This section concludes the main body of the report by providing an overview of the potential for new technologies to contribute to aviation capacity growth, concomitant with environmental impact mitigation. The study findings are also placed in a context wider than the actual scope of the study, by looking at both supply and demand for aviation services, and by extending our view beyond the mid-term (to 2030) focus of the study.

7.1 Overview

The process of selecting technologies with significant potential for capacity enhancement or environmental mitigation benefit resulted in almost thirty future technologies being selected for further assessment during the course of this study.

Technologies to enhance capacity and mitigate environmental impact were identified at all stages of the journey process, including passengers moving through the terminal, aircraft manoeuvring around the airport, during landing and take-off and when aircraft use the airspace.

On a purely qualitative basis the "most promising" future technologies for increased aircraft capacity enhancement were thought to be technologies addressing wake vortex effects and A-SMGCS. VHF datalink is also believed to be very promising and this is because it is an important enabler of future concepts such as new controller tools, direct/free routing and ADS-B. Arrival, departure, runway and surface management systems were thought to be promising for capacity enhancement at and around the airport as well as promising for environmental mitigation through efficiency improvements. Smart cards and biometrics for passenger identification were believed to be important technologies for increasing passenger throughput.

The most promising future technologies for global emissions mitigation are composite material primary structures incorporating latest aerodynamic concepts, very high BPR engines and blended wing body aircraft. For noise mitigation they are the use of nacelle treatment, reduction of engine source noise and reduction of airframe and installation noise effects at the component level. For local air quality mitigation, in the longer term they are LPP combustion technology, and in the shorter term developments of basic combuster designs to minimise NO_x emissions.

Most of the promising future technologies have barriers to take-up which either reduces the likelihood of take-up or delays when take-up occurs. Removing or reducing these barriers is a matter for Government, the EC and a range of International Aviation Fora.

Even with deployment of the most promising future technologies, if demand is unconstrained by capacity then, in absolute terms, the net global effect of the aviation industry on the environment is set to increase. The implications are that one must either manage growth to what technology can deliver or accept that aviation is a high added value component of the UK's transport system and that reduction in global emissions can be more easily achieved in other transport or industry sectors.

7.2 Overview of Promising Technologies

1. This study has as its main task the identification of the most promising future technologies capable of contributing to enhanced aviation capacity, and to the mitigation of environmental impacts arising from aviation. This sub-section summarises the candidate most promising technologies and categorises them by where in the journey process they provide benefit. Further, a qualitative assessment of the benefit offered and the difficulty of technology take-up is provided. Finally, where there exist potential opportunities for Government policy to accelerate take-up for the "most influential" technologies this is highlighted. These summaries are presented in a diagrammatic form at the end of this sub-section.

2. At the outset more than sixty technologies were considered and an initial screen was applied to select those most able to provide significant benefit. Figure 7-1 summarises the future new technologies that passed the initial screen, the criteria used for the final screen and the resulting list of candidate most influential technologies. Annex A and B describe these technologies.

3. The technologies in Figure 7-1 have been categorised by stage of journey - at the airport, during landing and take-off or in the airspace. The steps of a journey that comprise each journey stage are presented in the table below:

	Journey Stage	**Steps in the Journey**	
		From	**To**
1	Airport (outbound)	Passengers arrive at the airport terminal	Passengers board the aircraft
		Aircraft leaves the gate	Aircraft arrives at the runway
	Airport (inbound)	Aircraft leaves the runway	Aircraft arrives at the gate
		Passengers disembark the aircraft	Passengers leave the airport terminal
2	Take-off	Aircraft joins the runway and takes-off	Aircraft leaves the airspace in airport vicinity
	Landing	Aircraft arrives in the airspace in airport vicinity	Aircraft lands and exits the runway
3	Airspace	Aircraft enters *en route* airspace of departure airport	Aircraft about to leave *en route* airspace of arrival airport

4. For the candidate most promising technologies, further assessment established in qualitative terms only the extent to which each contributes capacity and environmental benefit and the likelihood of their take-up by the air transport industry. Figure 7-2 summarises the results of this assessment and classifies the influential technologies into "promising" and "very promising" and by journey stage and their "difficulty" for take-up. Section 5 defines the criteria used to assess technology take-up potential, whereby difficulty of take-up shown in Figure 7.2 is a measure used to describe the compound effect of all the assessed take-up criteria.

5. Many future technologies, or new concepts reliant upon future technologies, are dependent upon enabling technologies that have to be implemented before the future technology can be deployed. The table below presents these dependencies for the technologies addressed by this study:

Future Technologies / New Concepts	**Enabling Technologies**[51]
Direct/Free Routing	GNSS, VHF Datalink, controller tools
Controller tools	VHF Datalink
RMS	AMS, DMS
ADS-B	VHF Datalink, GNSS
SMS	AMS, DMS
A-SMGCS	AMS, DMS, RMS, SMS[52]
Active Laminar Flow (Control) Systems	New materials and system technologies, boundary layer stability techniques, Computational Fluid Dynamics
Staged Conventional Combustors	New Materials Technology
LPP Combustion Technology	New Materials Technology

6. For the "promising" and "very promising" technologies only, Figure 7-3 indicates their likely take-up time horizon and whether the technologies offer capacity or environmental benefit, or both. The technologies are presented by the stage of the journey where they apply.

7. To summarise, those technologies which offer greatest future capacity or environmental benefit (termed here as promising or very promising) yet have long take-up time horizons or are difficult to take-up (for example due to high R&D requirements) are the ones where future prospective Government policy could have an important role to play. Needless to say this approach should not adversely preclude or disadvantage take-up of technologies not matching these criteria.

[51] There often exist alternative enabling technologies, only technologies addressed by this study are cited.
[52] More sophisticated A-SMGCS including control and planning functions is dependent upon RMS and SMS.

8. The “very promising future” technologies which are difficult to take-up and which have medium to long time horizons for their deployment include; very high BPR engines, Blended Wing Body aircraft, composite material primary structures incorporating latest aerodynamic concepts, nacelle treatment for aircraft noise reduction, technologies addressing wake vortex effects, turbulence warning systems providing an initial technological step towards their effective control, A-SMGCS, LPP combustion technology and biometrics for passenger identification.

9. Similarly, promising technologies include active laminar flow (control) systems, geared fan engines, direct / free routing, active noise control, departure, runway and surface management systems, satellite landing systems, staged conventional combustors and staged combustors with lean burning.

10. The technologies that fall into these categories and their corresponding implications for Government policy are detailed in Figure 7-4. Clearly this can not claim to be an exhaustive list of potential technologies, nevertheless it does provide a generic list of technology types and a qualitative prioritisation based on environmental and capacity benefits to help guide prospective Government policy.

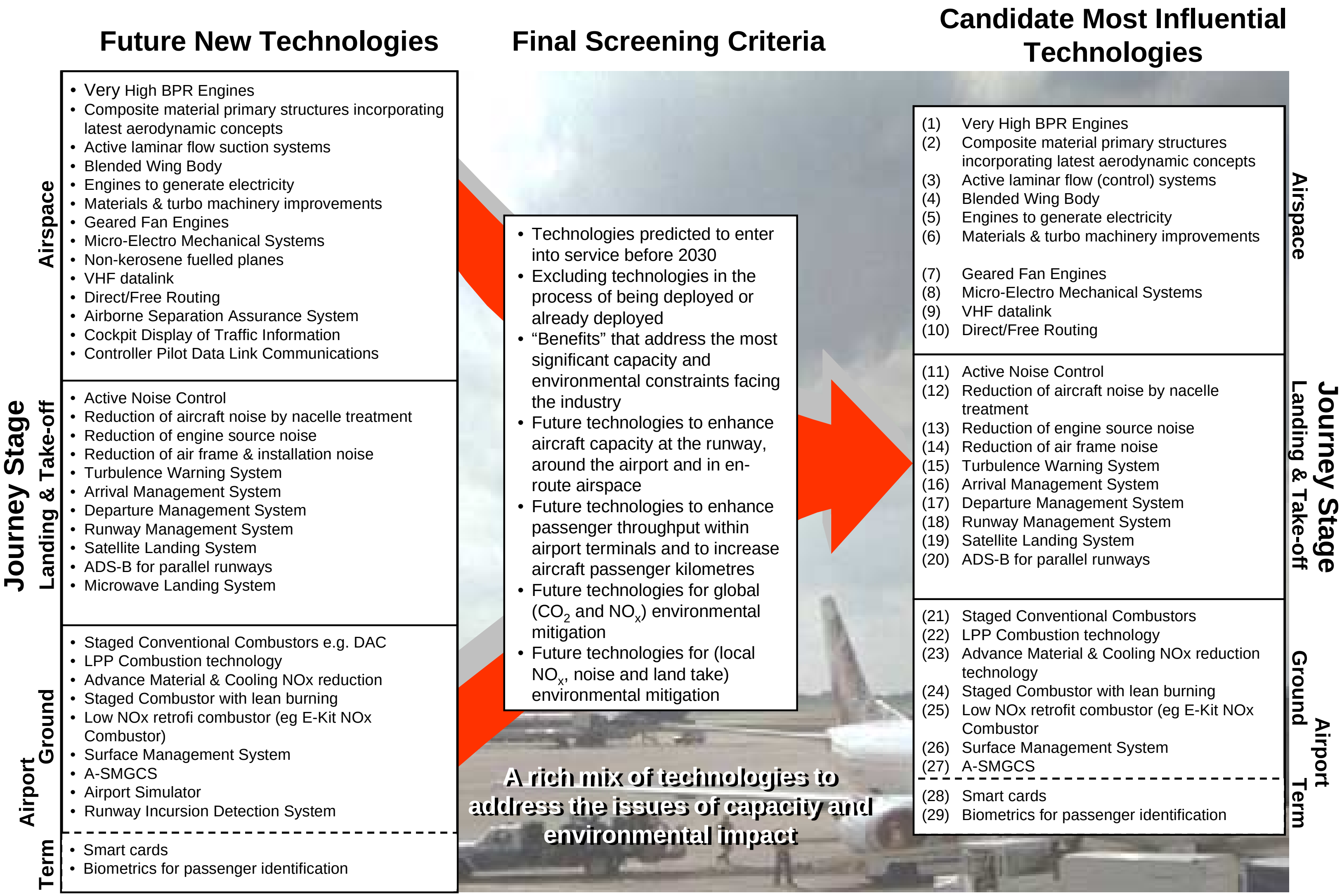
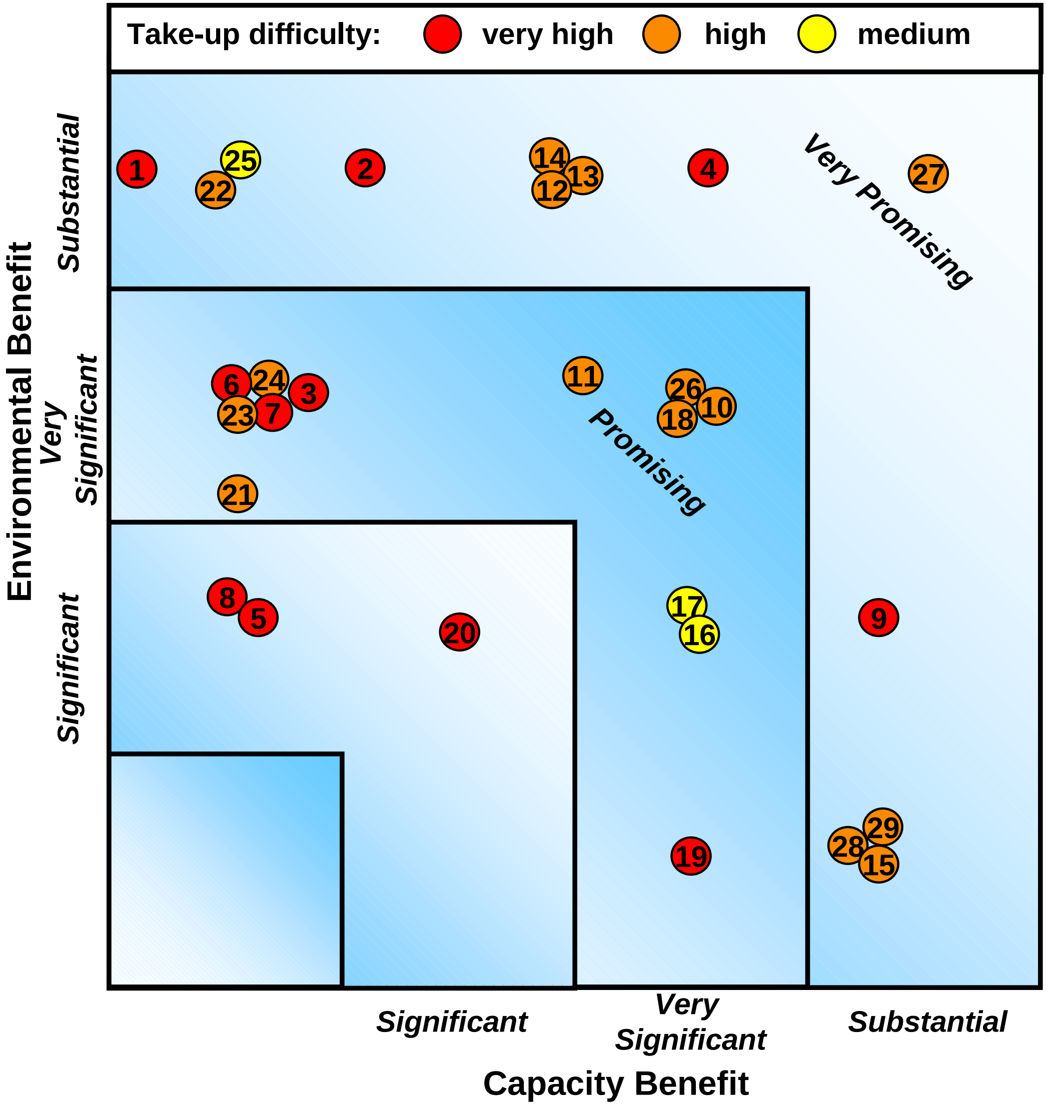


Figure 7-1: List of Screened Candidate Most Influential Technologies



Candidate Most Influential Technologies

Journey Stage

Airspace

(1) Very High BPR Engines
(2) Composite material primary structures incorporating latest aerodynamic concepts
(3) Active laminar flow (control) systems
(4) Blended Wing Body
(5) Engines to generate electricity
(6) Materials and turbo machinery improvements
(7) Geared Fan Engines
(8) Micro-Electro Mechanical Systems
(9) VHF datalink
(10) Direct/Free Routing

Landing & Take-off

(11) Active Noise Control
(12) Reduction of aircraft noise by nacelle treatment
(13) Reduction of engine source noise
(14) Reduction of air frame and installation noise
(15) Turbulence Warning System
(16) Arrival Management System
(17) Departure Management System
(18) Runway Management System
(19) Satellite Landing System
(20) ADS-B for parallel runways

Ground

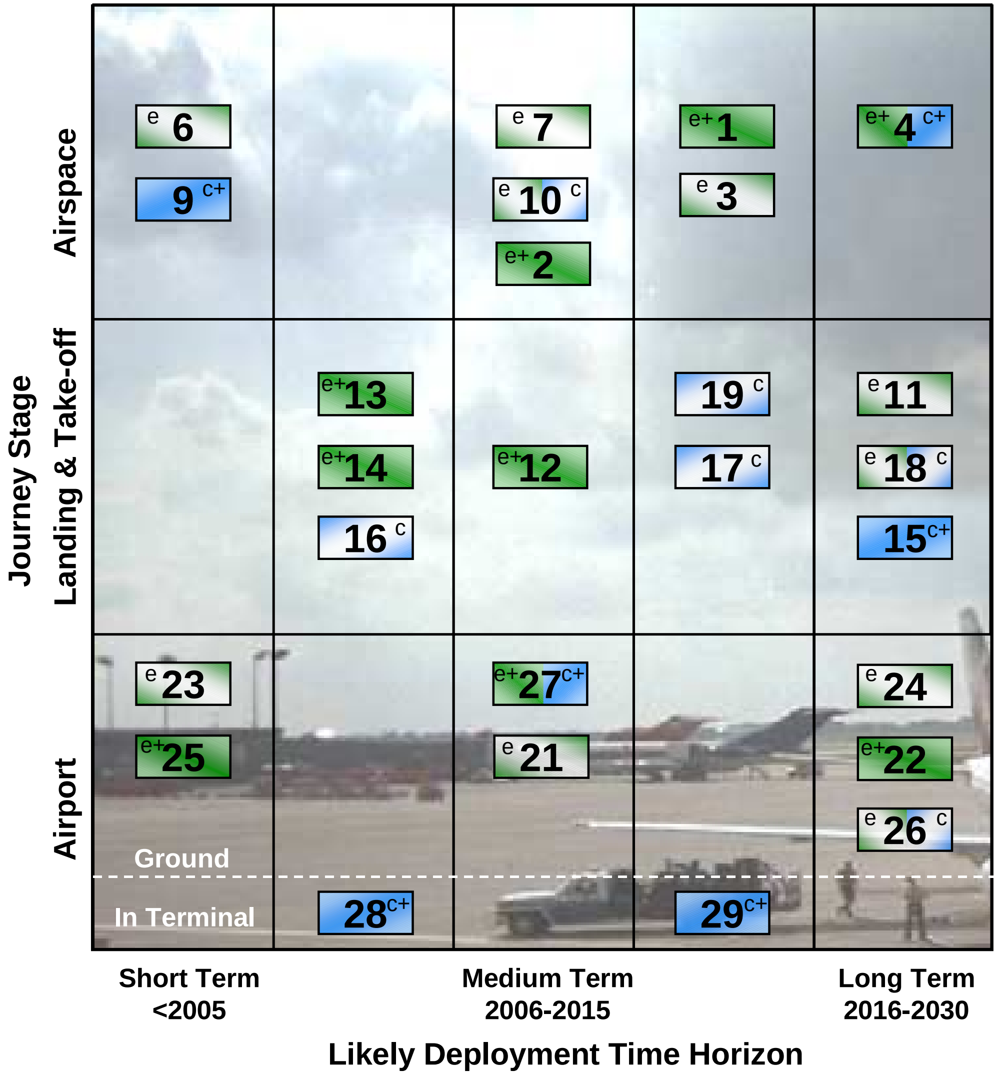
(21) Staged Conventional Combustors
(22) LPP Combustion technology
(23) Advance Material & Cooling NOx reduction technology
(24) Staged Combustor with lean burning
(25) Low NOx retrofit combustor (eg E-Kit NOx Combustor)
(26) Surface Management System
(27) A-SMGCS

Airport Term

(28) Smart cards
(29) Biometrics for passenger identification

Figure 7-2: Qualitative Measure of Technology Benefit and Associated Take-up Difficulty

Very Promising and Promising Technologies



Very Promising and Promising Technologies

(1) Very High BPR Engines
(2) Composite material primary structures incorporating latest aerodynamic concepts
(3) Active laminar flow (control) systems
(4) Blended Wing Body
(6) Materials and turbo machinery improvements
(7) Geared Fan Engines
(9) VHF datalink
(10) Direct/Free Routing

(11) Active Noise Control
(12) Reduction of aircraft noise by nacelle treatment
(13) Reduction of engine source noise
(14) Reduction of air frame and installation noise
(15) Turbulence Warning System
(16) Arrival Management System
(17) Departure Management System
(18) Runway Management System
(19) Satellite Landing System

(21) Staged Conventional Combustors
(22) LPP Combustion technology
(23) Advance Material & Cooling NOx reduction technology
(24) Staged Combustor with lean burning
(25) Low NOx retrofit (eg E-Kit NOx Combustor)
(26) Surface Management System
(27) A-SMGCS

(28) Smart cards
(29) Biometrics for passenger identification

e+	Substantial environmental benefit
e	Very significant environmental benefit
c+	Substantial capacity benefit
c	Very significant capacity benefit

Figure 7-3: Most promising technologies categorised by journey stage and take-up time horizon

Deployment Time Horizon	Very Promising Future New Technologies	Journey Stage	Implications for Policy
Short	(9) VHF Datalink	Airspace	I1, I3
	(25) Low NOx retrofit combustor (eg E-Kit NO_x Combustor)	Airport	I9 to I11
Short / Medium	(13) Reduction of engine source noise	Landing & Take-off	I9 to I11
	(14) Reduction of air frame and installation noise	Landing & Take-off	I9 to I11
	(28) Smart Cards	Airport	I6
Medium	(2) Composite material primary structures incorporating latest aerodynamic concepts	Airspace	I7, I8
	(12) Reduction of aircraft noise by nacelle treatment	Landing & Take-off	I9 to I11
	(27) A-SMGCS	Airport	I1, I2
Medium / Long	(1) Very High BPR Engines	Airspace	I7, I8
	(29) Biometrics for passenger identification	Airport	I6
Long	(4) Blended Wing Body	Airspace	I7 to I11
	(15) Turbulence Warning System	Landing & Take-off	I2
	(22) LPP Combustion technology	Airport	I9 to I11

Deployment Time Horizon	Promising Future New Technologies	Journey Stage	Implications for Policy
Short	(6) Materials & turbo machinery improvements	Airspace	I7, I8
	(23) Advanced Material & Cooling NO_x Reduction Technology	Airport	I9 to I11
Short / Medium	(16) Arrival Management System	Landing & Take-off	I1, I4, I5
Medium	(10) Direct / Free Routing	Airspace	I1, I2
	(21) Staged Conventional Combustors	Airport	I9 to I11
	(7) Geared Fan Engines	Airspace	I7, I8
Medium / Long	(3) Active laminar flow (control) systems	Airspace	I7, I8
	(17) Departure Management System	Landing & Take-off	I1, I2, I4, I5
	(19) Satellite Landing System	Landing & Take-off	I1, I3
Long	(11) Active Noise Control	Landing & Take-off	I9 to I11
	(18) Runway Management System	Landing & Take-off	I1, I2, I4, I5
	(24) Staged Combustor with lean burning	Airport	I9 to I11
	(26) Surface Management System	Airport	I1, I2, I4, I5

Directly Relevant Implications for Government Policy*

I1	**In line with Government's ongoing efforts to improve ATC harmonisation, promoting robust benchmarking and greater transparency within the ATC community will increase technology take up**
I2	**Consistent with Government activities to progress PPP of NATS, introducing mechanisms that promote medium and long term investment in ATC systems will accelerate the take up of new technologies**
I3	**As part of the Government's continued involvement at an international level in setting standards, focussing on agreeing future datalink technologies will promote the take up of technologies enabled by datalink**
I4	**Encourage the take up of technologies whose primary benefit is improved efficiency because capacity and environmental mitigation benefits will follow**
I5	**Link changes in existing operational practices with improved efficiency (where there is an environmental benefit) to encourage technology take up**
I6	**Consider the need for Government policy to define what constitutes positive identification and what proves intent to travel to enable the take up of new technologies for security checks at airports**
I7	**Continue to work with industry and ICAO/CAEP to develop and communicate a clear set of medium and long term Kyoto objectives for the sector**
I8	**Consider support of a combined market based approach based on environmental charges, open emission trading and voluntary agreements to promote take up and development of technologies to minimise aviation's global emissions**
I9	**Continue pressing for tighter international standards for aircraft noise and engine emissions to accelerate take up of best available NOx and noise mitigation technologies identified by this study**
I10	**If sufficiently ambitious international agreements are not reached, Government should consider use of noise and emission measures at a UK or European level to influence take up of better performing technologies in the global fleet**
I11	**Consider support of noise and emission based charges and/or quotas at UK airports which encourage performance beyond the latest ICAO/CAEP noise and NOx standards, to provide a financial incentive for new technology take up, and funds for noise and air quality improvement projects**

* Implications I12 and I13 address non-technological issues and are, as such, broadly applicable to most technologies.

Figure 7-4: Where prospective future Government policy may influence technology take-up

7.3 Overarching Conclusions from the Study

1. This study uses UK Government and industry forecasts for growth in demand for aviation services as the basis to explore the capacity enhancement potential of new technologies. When we apply to these forecasts the impact of the most promising new capacity enhancing technologies and environmental mitigation technologies identified in this study, the following conclusions have been drawn:

2. Whilst there are a number of very promising technologies to increase capacity, it is land-use planning for increased runway capacity that has the greatest potential to contribute to capacity enhancement. In fact, without further runway development, the combined contribution of new technologies is very unlikely to be able to accommodate future forecasts of demand.

3. Many of the capacity enhancing technologies need a clear statement of aviation priorities, and a set of aviation standards – without which the industry will not have a coherent long-term framework within which to take decisions, many of which will involve substantial outlay.

4. We have identified a number of very promising technologies to mitigate environmental impacts from global emissions, noise, and local emissions, and together these could contribute to a significant incremental decrease in the normalised environmental impacts from the sector. However, if demand is unconstrained by capacity, then in absolute terms, the net effect on the environment is set to increase even if the new technologies are introduced and deployed. The physical limits to operational efficiency of the current generation of aircraft mean that it is unlikely that cost-effective solutions will be found to resolve this issue through technologies relevant to the time-horizon of this study.

5. The implications of this demand on technology imbalance are that either you manage growth to what technology will deliver in order to mitigate any deterioration in impact, or you accept that aviation is a high added value component of the UK's transport system. Open emission trading offers a pathway for counter balancing the forecast growth of global emissions from aviation and this remains an important choice facing the UK and other industrialised countries with strong aviation sectors.

6. Again, as for capacity enhancing technologies, the commercial uptake of the most promising technologies will not happen without a framework (including partnership with Government) within which the industry can plan its investments in the variety of, and sometimes conflicting, technology solutions to environmental impact mitigation.

7. Although outside the scope of this study, it is evident that demand-side management could be key to reducing the absolute environmental impact from the sector. Where demand-side management includes instruments that internalise environmental externalities and that reward performance beyond established standards, then this approach may also spur new technology uptake. This would be consistent with the Government's White Paper – *A New Deal for Transport*, which states that:

"The policies we bring forward for civil aviation, as for other forms of transport, will reflect our strategy for sustainable development. This means aviation should meet the external costs, including environmental costs, which it imposes."

8. If we look beyond the scope of this study (i.e. beyond 2030), it is probable that a new generation of air-traffic management, airframes, energy sources, power-trains, and mobility solutions may provide a breakthrough to the capacity / environment barrier. Figure 7-5 provides a scenario of how the aviation sector may evolve to a new generation of air-travel (Arthur D Little, 1999c).

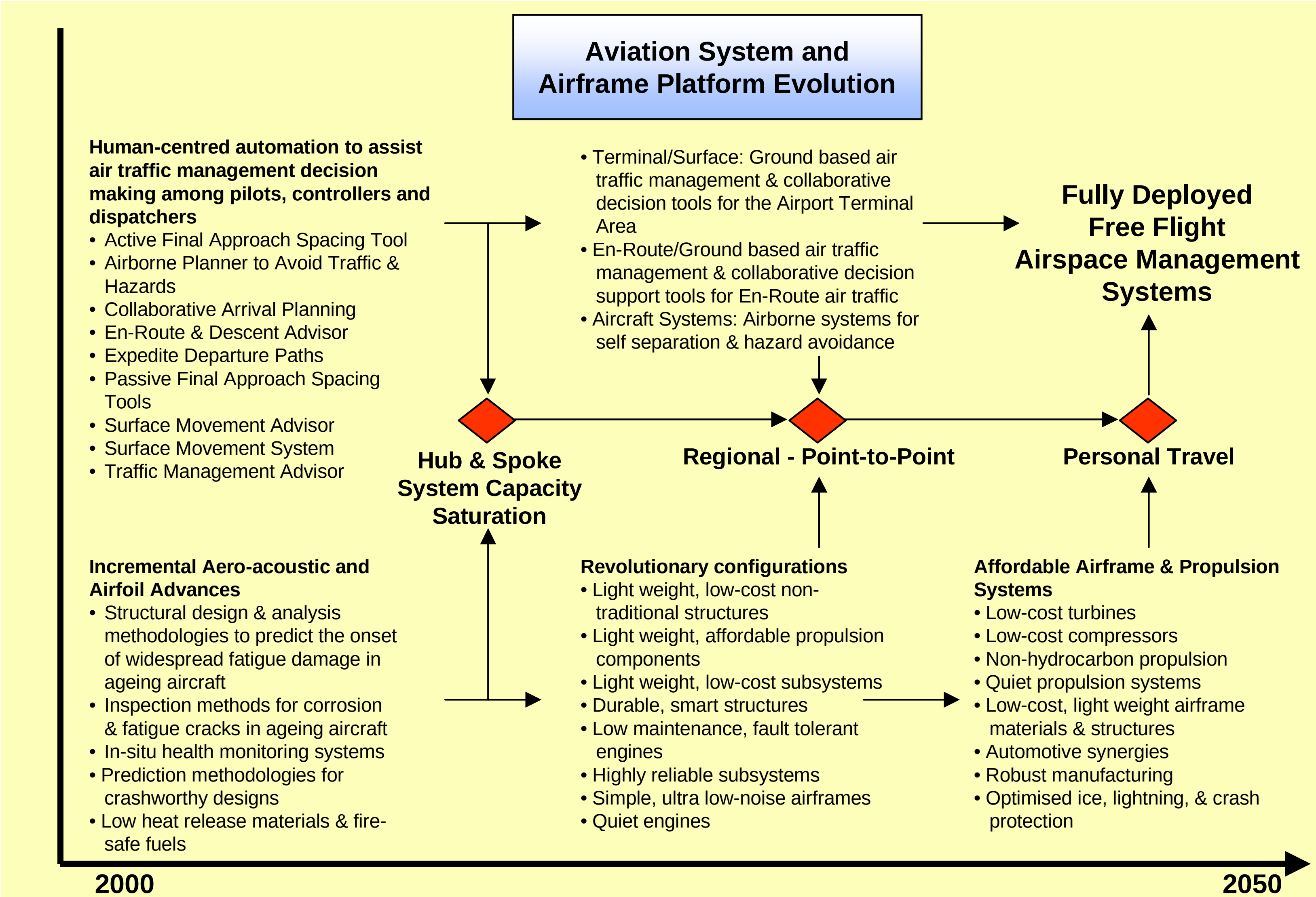


Figure 7-6: Future Aviation System and Platform Evolution

7.4 Summary of Implications for Government Policy

I1	**In line with Government's ongoing efforts to improve ATC harmonisation, promoting robust benchmarking and greater transparency within the ATC community will increase technology take up**
I2	**Consistent with Government activities to progress PPP of NATS, introducing mechanisms that promote medium and long-term investment in ATC systems will accelerate the take up of new technologies**
I3	**As part of the Government's continued involvement at an international level in setting standards, focussing on agreeing future datalink technologies will promote the take up of technologies enabled by datalink**
I4	**Encourage the take up of technologies whose primary benefit is improved efficiency because capacity and environmental mitigation benefits will follow**
I5	**Link changes in existing operational practices with improved efficiency (where there is an environmental benefit) to encourage technology take up**
I6	**Consider the need for Government policy to define what constitutes positive identification and what proves intent to travel to enable the take up of new technologies for security checks at airports**
I7	**Continue to work with industry and ICAO/CAEP to develop and communicate a clear set of medium and long-term Kyoto objectives for the sector**
I8	**Consider support of a combined market based approach based on environmental charges, open emission trading and voluntary agreements to promote take up and development of technologies to minimise aviation's global emissions**
I8.1	**Consider support of open and flexible emission trading permits systems to encourage fuel efficiency technology take up**
I8.2	**Consider support of environmental charges that are recycled within the industry to fund technology innovation, research and development**
I8.3	**Work with industry to agree voluntary agreements that are "over and above business as usual" for future fuel efficiency improvements**
I8.4	**Support initiatives to promote better scientific understanding of the contrail and cirrus cloud radiative forcing (contribution to global warming) impacts of air travel and consider how these impacts may be incorporated or combined with Kyoto CO_2 targets and minimised through market based and other approaches**

I9	**Continue pressing for tighter international standards for aircraft noise and engine emissions to accelerate take up of best available NOx and noise mitigation technologies identified by this study**
I10	**If sufficiently ambitious international agreements are not reached, Government should consider use of noise and emission measures at a UK or European level to influence take up of better performing technologies in the global fleet**
I11	**Consider support of noise and emission based charges and/or quotas at UK airports which encourage performance beyond the latest ICAO/CAEP noise and NOx standards, to provide a financial incentive for new technology take up, and funds for noise and air quality improvement projects**
I12	**In line with ongoing Government policy there is a need to improve the local decision process and provide guidance on future local priorities with respect to airport operations**
I13	**Communicate future policy direction on priorities between local and global environmental impacts to help support longer term technology development and take up strategies within the industry**

Annex A Capacity Benefit Technologies

This annex summarises the airport infrastructure, airspace design and ATC technologies assessed through the desktop exercise and technology workshops. It includes the following sections:

Desktop review and screening: The first part of the annex includes a list of the technologies that were reviewed and provides a summary of the technologies that were screened for taking to the workshop.

Technologies taken to Workshop: The second part of the annex provides detailed descriptions of the technologies taken to the workshop.

Other significant technologies: The third contains detailed description of technologies that were screened as significant but were not taken to the workshop.

Desktop Review and Screening

The desktop review and screening process was used to limit and prioritise technologies to take to the technology workshop. This process included a literature survey and interviews and visits to key stakeholders, (e.g. NATS, Eurocontrol, CAA, BA, BAA, DERA, CSC).

The output of this process is summarised in Table 1 below and includes a list of the technologies reviewed together with brief description and prioritisation.

Technology	Entry Into Service	Brief Description	Screening Status
A-SMGCS (Core System)	Medium-term	The A-SMGCS is a system providing routing, guidance, surveillance and control to aircraft and associated vehicles in order to maintain movement rate under all local weather conditions	ααα
Aeronautical Telecommunication Network (ATN)	Medium-term	The ATN is a data communications inter-network that provides a common communications service for all Air Traffic Services Communications (ATSC) and Aeronautical Industry Service Communications (AINSC)	α
Airborne Radar	Short-term	The airborne radar is used primarily for weather detection, ranging and analysis. Its secondary role is to provide navigation information by ground mapping of significant land contours.	α
Airborne Separation Assurance System (ASAS)	Long-term	The term ASAS is used to cover a range of concepts where the responsibility for separation from other aircraft is either partially or wholly delegated to the pilot.	αα
Airport Simulator	Medium-term	Airport simulations are available to model many aspects of airport activities.	αα
Arrival Management System (AMS)	Short/Medium-Term	The Arrival Management Systems are ground-based air traffic management automation tools used by Area Control Centre (ACC), Approach (APP) and Tower (TWR), designed to optimise traffic flow in and around the Terminal Manoeuvring Area (TMA).	ααα
Automatic Dependent Surveillance Broadcast (ADS-B)	Medium-term	ADS-B is a function on an aircraft or a surface vehicle that periodically broadcasts its state vector and other information.	ααα
Autonomous Precision Approach and Landing (APALS)	Long-term	The APALS is an autonomous precision guidance system, which uses standard avionics to determine the aircraft position. Originally developed by Westinghouse, further development is not expected in the foreseeable future by them or others.	α
Co-operative Vehicle Tracking System	Short-term	This system is dedicated to the management of vehicles moving on the airport surface.	α
Cockpit Display of Traffic Information	Long-term	CDTI is the function of presenting surveillance information about the surrounding traffic to the flight crew.	αα
Controller Pilot Data Link Communication (CPDLC)	Short-term	Controller Pilot Data Link Communications (CPDLC) is a means of communication between Controller and Aircrew, using data link for ATC communication.	αα
Controller Safety Net in TMA (STCA, MSAW)	Short-term	Air conflict detection implemented in ground systems and applicable in terminal area are the following: Short Term Conflict Alert (STCA) for air segments of flight and Minimum Safe Altitude Warning (MSAW) for final approach segment.	α
Data Link Flight Information Service (D-FIS)	Short-term	D-FIS (Data Link Flight Information Service) is a means of providing flight information to Aircrew using air/ground data communications.	α

Technology	Entry Into Service	Brief Description	Screening Status
Departure Management System (DMS)	Long-term	DMS is a ground-based air traffic management automation tool used by Area Control Centre (ACC), Approach (APP) and Tower (TWR), designed to optimise traffic flow in and around the Terminal Manoeuvring Area (TMA).	ααα
Direct Routing	Medium-term	A system for enabling routing as near directly as possible between departure and destination point based on a pre-determined route rather than one which is constrained to sit along pre-defined airways.	ααα
Docking Guidance System (DGS)	Short-term	The Docking Guidance System is a system dedicated to the aircraft parking phase, to facilitate precision positioning of the aircraft in close co-ordination with the passenger boarding bridges when entering parking stand.	α
Enhanced Vision System (EVS)	Medium-term	Infra Red (FLIR) and millimetric Wave (mmW) Radar with the images fused and displayed on a pilot's Head Up Display (HUD) to provide an equivalent visual image of the view in front of the aircraft.	α
Gatelink	Short-term	Gatelink provides the communications connectivity for a parked aircraft located at the airport terminal, maintenance bay, or remote parking area.	α
Microwave Landing System (MLS)	Short-term	MLS is a precision approach and instrument landing guidance system operating in the microwave spectrum (5 GHz)	αα
Mode S Gate	Medium-term	A Mode S Gate is a simple Mode S interrogator station to be installed near parking exits or runway access.	α
Mode S Multilateration	Medium-term	The Mode S Multilateration is a system dedicated to the localisation and identification of mobiles equipped with Mode S transponders.	α
Multi Mode Receiver (MMR)	Short-term	The MMR provides the airborne segment of the precision guidance systems based on the following three systems: Instrument Landing Systems (ILS), Satellite Landing System (SLS) and Microwave Landing Systems (MLS).	α
Multi-Sensor Data Fusion System	Medium-term	The sensor fusion builds a traffic situation picture either by combining the data coming from different sources from one mobile into a single track when sensors coverage overlap or by building one continuous track for one mobile using data from succession sensors.	α
Runway Incursion Detection System	Short/Medium-term	A runway incursion detection system is a DPS component which analyses the surveillance data coming from different sensors (in general the main sensor is a primary surface movement radar) and issues alarms to the controller when a potential conflict is detected inside the runway sensitive area.	αα
Runway Management System (RMS)	Long-term	RMS is a decision assistance tool in which the tuning of the aircraft sequence for take off integrating accurate position of arrival will be the main function.	αα
Satellite Datalink	Short-term	The aim of satellite datalinks is to provide a communication media between the aircraft and ground during periods when the aircraft is out of coverage of other terrain based systems.	α

Technology	Entry Into Service	Brief Description	Screening Status
Satellite Landing System (GBAS, SBAS)	Medium/Long-Term	The SLS is a precision guidance system, which uses information transmitted by either Global Positioning System (GPS) or GLObal NAvigation Satellite System (GLONASS) or both.	ααα
Secondary Surveillance Radar (SSR) & Mode S	Short-term	Secondary Surveillance Radar (SSR) interrogates co-operative targets, whose transponders reply to another frequency with coded information.	α
Surface Management System (SMS)	Long-term	The Surface Management System (SMS) is the planning/routing tool for ground movements.	αα
Taxi Route Conflict Detection System	Long-term	A Taxi Route Conflict Detection System is a module which analyses the surveillance data coming from different sensors.	α
Taxiway Guidance System	Medium-term	The aim of the Taxiway Guidance System is to provide surface visual information to pilots during aircraft taxiing phase.	α
Turbulence Warning System	Long-term	The primary method used to track and analyse wake vortices is based on Light Detection And Ranging (LIDAR).	ααα
VHF Datalink (VDL)	Short-term	Datalink over VHF has been used in the aeronautical domain since the 1980s with the use of ACARS (Aircraft Communication Addressing and Report System), developed initially for AOC (Aeronautical Operational Communications) purposes.	ααα

Table 1: Summary of technology screening: ααα = Assessed to workshop αα = Not taken to workshop but significant α = Not taken further

Technologies Taken to Workshop

This section details the capacity benefit technologies that were discussed and assessed at the technology focused workshop (see Section 1 of the main report for details on the study approach).

Advanced Surface Movement, Guidance and Control System (A-SMGCS)

All airports have some form of Surface Movement Guidance and Control System (SMGCS). They provide guidance to an aircraft from a landing runway to the parking position on the apron and back again to the take off runway. In the simplest form, this may consist of painted guide lines and in the more advanced systems employ switched taxiway centrelines and stop bars. The present SMGCS system relies heavily on the "see and be seen" principle to maintain separation between aircraft and/or vehicles on the movement area. Problems have occurred with the increase in traffic, difficulties in navigating on taxiways on more complex airport layouts and in lower visibility operation. An advanced system is required to resolve these problems and maintain operating capacity in all weather conditions. The term Advanced Surface Movement, Guidance and Control System (A-SMGCS) has been defined to cover these future systems. The A-SMGCS is a system providing routing, guidance, surveillance and control to aircraft and associated vehicles in order to maintain movement rate under all local weather conditions within the Airports Visibility Operational Level (AVOL) whilst maintaining the required level of safety. In addition, planning is considered as an additional supporting function.

The significant difference between the functions of the current SMGCS and A-SMGCS is that the latter must not merely provide more precise guidance for all aircraft and vehicles on the movement area, between the runway(s) and the stands, but it must also be able to ensure separation between all moving aircraft and vehicles in conditions when their speeds prevent such separation being maintained visually. It is impossible for a controller to meet this task even when using a conventional labelled Surface Movement Radar (SMR). Therefore, A-SMGCS provides situation awareness not only to the controller but also to those aircraft and vehicles that are liable to come into proximity with each other.

The complex traffic flows may require A-SMGCS to function as a surface management system, which is responsible for the planning and management of all aircraft and authorised vehicles on the movement area.

Arrival Management System (AMS)

With the growing traffic there were increasing needs for the on-line advisories to solve the traffic flow problems, especially in the terminal area, which is the ultimate constraint on the airspace capacity. The first studies to develop this kind of system date back to the end of 1970s. As there are no standards and definitions of such a tool, the systems vary both in terms of functions and names, for example: Terminal Air Traffic Management System (TATM), Traffic Metering and Sequencing System, Approach Sequencing Advisory System, Automatic Slot Assignment etc.

However, all of them provide advice on how to optimise traffic flow of arriving aircraft, and thus the term Arrival Management System (AMS) seems to be most appropriate.

The Arrival Management Systems are ground-based air traffic management automation tools used by Area Control Centre (ACC), Approach (APP) and Tower (TWR), designed to optimise traffic flow in and around the Terminal Manoeuvring Area (TMA).

The Arrival Management generates advisories for the controller in order to meet the planned arrival sequence. The main capabilities are metering and sequencing of the traffic of inbound aircraft. The system calculates aircraft's optimum scheduled time of arrival (STA) at the TMA's entry point and runway threshold, along with the delay to be absorbed. It might enable controllers to test various sequencing options but the controller still remains fully in charge of all actions as the system provides only the advisories.

Automatic Dependent Surveillance Broadcast (ADS-B)

ADS-B is a function on an aircraft or a surface vehicle that periodically broadcasts its state vector (horizontal and vertical position, horizontal and vertical velocity) and other information. ADS-B is automatic because no external stimulus is required to elicit a transmission; it is dependent because it relies on on-board navigation sources and on-board broadcast transmission systems to provide surveillance information to other users. The aircraft or vehicle originating the broadcast may or may not have knowledge of which users are receiving its broadcast. Any user, either aircraft or ground-based, within range of this broadcast, may choose to receive and process ADS-B surveillance information. ADS-B supports improved use of airspace, reduced ceiling/visibility restrictions, improved surface surveillance, and enhanced safety such as conflict management.

Although there are several methods of broadcasting aircraft information, the following two types of communications media are prime candidates for sole or shared usage.

1090 MHz Long Squitter

The 1090 MHz ADS-B is based on the 1090 MHz Extended Squitter that shares the frequency band with SSR, SSR Mode S and ACAS.

The system operates by transmitting extended length messages (112 bit compared with 56 bit for normal messages) containing position and intent information. The broadcast information can be received by other aircraft, vehicles and ground stations.

The extended squitter transmitter would be implemented within the aircraft's Mode S transponder. The receiver would probably be implemented within the aircraft's ACAS although separate units may be used.

The precision of the data has been defined in the Manual of Mode S Specific Services as being compatible with the requirements of the encoding capabilities of the 1090 MHz medium.

Self-organised Time Division Multiple Access (STDMA) - VDL Mode 4

The STDMA, proposed by the Swedish CAA as a candidate for the future VHF system, for CNS applications, is defined as a multiple access scheme based on time-shared use of an RF channel employing:

- Discrete contiguous time slots as the fundamental shared resource; and
- A set of operating protocols that allows users to mediate access to these time slots without reliance on a master control station.

The STDMA concept of operations is based on the following elements:

- A GNSS receiver for the determination of user position and accurate system time. (The STDMA airborne system will function in a degraded mode if the GNSS receiver is unavailable or inoperative);

- A self organising protocol for slot reservations that provides high system throughput and efficiency without reliance on external or master control stations;

- A computer, that maintains position/track data for all users detected, as well as their current and planned slot assignments, for use in supporting user requirements as well as controlling/mediating access to the channel; and
- Optional use of ground controllers/monitors to provide a feed to ground-based operations, as well as to control channel access more precisely and efficiently than is possible with the self-organising protocol. When a ground station assigns users to specific slots, the affected users switch to position reports with message types that indicate they are under ground control.

An STDMA station can enter an established network on a particular channel in two ways:

Autonomous mode

In this mode, an STDMA station "listens" to a pre-defined channel for a period of time, for example 1-2 minutes, to determine channel activity, other participating member IDs, current slot assignments and reported positions of other users, and possible existence of STDMA ground stations. During this time period, a "dynamic directory" of all members operating in the system is established. After building a frame map that includes activity status for all slots and reported positions for all users, the transponder selects for its own use a slot that is unused and unreserved. It begins broadcasting position reports in this slot. If all slots are already in use or reserved, it selects a slot associated with the most distant user and broadcasts in that. The rationale behind this decision making is that the most distant user is not relevant in the local domain. Nearby users detect the new transmissions and add the user information to their slot maps and position data bases. All data transmitted over the data link will be continuously stored in each STDMA transponder operating within radio range.

Controlled mode

In this mode, an STDMA station that has been operating in a controlled mode on one channel can be auto tuned to a different channel and slot assignment by the controlling STDMA station. This allows for rapid contention-free network entry as an STDMA-equipped aircraft transitions from one airspace to another (e.g., high density terminal area airspace with STDMA operations on a special channel, to *en route* airspace with STDMA operations on the common signalling channel).

Departure Manager System (DMS)

With the growing traffic there were increasing needs for the on-line advisories to solve the traffic flow problems, especially in the terminal area, which is the first constraint for departure on the airspace capacity.

The first thinking to develop this kind of system date back to the beginning of 1990s. As there are no standards and definitions of such a tool, the studied systems vary both in terms of functions and names, for example Traffic Metering and Sequencing System, Departure Manager, Departure Management system, Automatic Slot Assignment etc...

However, all of them has the objective to provide advice on how to optimise traffic flow of departing aircraft, and thus the term Departure Management System (DMS) seems to be most appropriate.

DMS is a ground-based air traffic management automation tool used by Area Control Centre (ACC), Approach (APP) and Tower (TWR), designed to optimise traffic flow in and around the Terminal Manoeuvring Area (TMA).

DMS should generate advisories for the controller in order to meet the planned departure sequence. The main capabilities are metering and sequencing of the traffic of outbound aircraft. The system calculates aircraft's optimum scheduled time of departure: Calculated Take-Off Time (CTOT) at the departure runway taking into account:

- CFMU Slot if any,
- constraints on the TMA's exit point,
- runway rate of departure
- ground operations (engine start-up, push-back, taxiing, line-up ...) fixed time parameter
- along with the delay to be absorbed.

It might enable controllers to test various sequencing options but the controller still remains fully in charge of all actions as the system provides only the advisories.

Direct Routing

A system for enabling routing as near directly as possible between departure and destination point based on a pre-determined route rather than one which is constrained to sit along pre-defined airways. Requires GPS on the aircraft and an air ground datalink. Requires additional tools for the controller, such as conflict probes and conflict detection.

Satellite Landing System (GBAS, SBAS)

The SLS is a precision guidance system, which uses information transmitted by either Global Positioning System (GPS) or GLObal NAvigation Satellite System (GLONASS) or both. The term Global Navigation Satellite System (GNSS) is a term used to encompass both systems.

The typical accuracy, availability and integrity of the stand-alone GNSS is not sufficient for use as a precision guidance aid. Although by itself the GNSS is not suitable for precision guidance, the performance is suitable for non-precision approaches. To improve the GNSS accuracy, errors in the system have to be reduced. These errors are as follows:

- Satellite Position Error;
- Clock Stability;
- Ionospheric delays;
- Tropospheric delays;
- Receiver noise; and
- Multipath.

In addition to these errors (shown above), the accuracy of the signal is further degraded to civilian users of GPS by deliberately introducing additional errors using a technique known as selective availability (S/A).

By knowing the precise co-ordinates of a fixed receiver site, corrections for the majority of errors, including S/A can be established. This information may be transmitted direct to the aircraft or combined with other solutions from a network of fixed sites to increase the integrity and availability of the correction. This technique is known as differential GNSS or DGNSS. Typically the corrections are sent by ground based datalink systems using VHF, C-Band or Mode-S, which due to the limited range or the transmissions are known as Ground Based Augmentation Systems (GBAS) or Local Area Augmentation Systems (LAAS). Future options for a space borne transmitters capable of providing corrections to a much greater area are known as Space Based Augmentation Systems (SBAS). Two SBAS systems are currently under development. These are the Wide Area Augmentation Systems (WAAS) under development by the USA and the European Geostationary Navigation Overlay System (EGNOS).

The guidance solution is calculated on board the aircraft and is based on the aircraft's current position and the co-ordinates of the runway. The co-ordinates may be derived from signals transmitted along with the local area corrections or by setting the appropriate runway through the Flight Management System (FMS).

Technical details

GPS

GPS is a satellite-based radio-navigation, positioning and time transfer system operated by the United States Department of Defence (DoD). The GPS system consists of three discrete areas, which are called the space segment, control segment and user segment. The space segment consists of 24 operational satellites placed in 20,200km orbits orbiting approximately every 12 hours. The satellites are designed to form a constellation such that a minimum of five satellites will be in view at any time. The satellites transmit data on two frequencies named L1 and L2. The L1 signal contains the Coarse Acquisition (C/A) code and the Precision (P) code. GPS provides two levels of service for stand alone or uncorrected users. These services are named the Standard Positioning Service (SPS) and the Precise Positioning Service (PPS). All users have access to the C/A code for SPS, however, the use of PPS is restricted to authorised (normally military) users. The control segment consists of a master control station and five monitor stations. The user segment consists of the GPS receivers, which are used to derive navigation and time information.

GLONASS

The GLONASS is the Russian equivalent to GPS and is a completely independent satellite navigation system.

The space segment of the full GLONASS constellation consists of 24 satellites in 19,150km orbits with an inclination of 64.8°. However, currently there are many gaps in the constellation and only 14 satellites are operational. Despite continuing rumours that new satellites will be launched, the last launch of a GLONASS satellite was in December 1995.

GLONASS transmits spread spectrum signals around two frequencies in the L-band. Unlike GPS, the GLONASS satellites transmit on different frequencies within the two bands, around 1.25GHz and 1.6GHz. This allows for simpler receiver design and provides some protection against interference or jamming. In order to avoid clashed with the Mobile Satellite Communication Systems the size of the bands will shortly be reduced. This operation will be achieved by causing GLONASS satellites on opposite sides of the Earth to transmit on the same frequencies.

There is no artificial degradation such as S/A on the GLONASS system, which means that with a full GLONASS constellation the accuracy of the stand alone performance is better than stand alone GPS.

Positions determined from GLONASS are in the PZ-90 co-ordinate frame and work is underway to calculate the precise transformation parameters between PZ-90 and the WGS-84 frame used by GPS.

SBAS

The SBAS enhances GPS SPS information by providing the GPS user segment with corrections for the errors in the GPS. In addition, the ranging information transmitted by the satellite is transmitted in a similar way to GPS, so that a receiver can extract navigation information from it. This technique improves the availability of satellites by increasing the effective number of satellites in the constellation. The WAAS ground segment consists of 24 wide area reference stations (WRS), two wide area master stations (WMS) and Geostationary Earth Orbit (GEO) Uplink Stations (GUS). Each WRS calculates corrections for the GPS signals received by it and passes the information to the WMS where the corrections are calculated, based on the information received from a number of WRSs. The correction data is sent to the GEO Satellites via the GUS for onward reception by the users. It is expected that the performance available from the initial implementation of WAAS will be insufficient to meet the needs of a precision guidance system. However, it is expected that a GPS receiver aided by such SBAS signals will be capable of providing non-precision guidance. Implementation of precision guidance to CAT 1 levels has been considered in the final implementation of WAAS. To meet these CAT 1 requirements additional reference stations and communication satellites are needed to meet the higher levels of accuracy and integrity.

GBAS

GBAS, intended to be used as a compliment to the SBAS service, uses a single differential correction that accounts for all expected common errors between a local reference and users. The coverage area will normally be approximately 25 NM, encompassing a typical airport and approach. The system has a greater accuracy than the SBAS signal due to the localised nature of the corrections. This increase in accuracy provides the capability to meet CAT 1 requirements. Future improvements to the GBAS system such as pseudolites may provide the additional requirements for CAT II or CAT III operations.

Turbulence Warning System

This section concentrates on the turbulence effects created by the wake of aircraft, which are normally known as wake vortices. The primary method used to track and analyse wake vortices is based on LIght Detection And Ranging (LIDAR). The LIDAR research is being used to validate theoretical mathematical models of the propagation of these vortices. These models can be used to provide real time estimates of the vortex behaviour using inputs from atmospheric sensors such as wind velocity, air temperature and air pressure along with knowledge of the aircraft type. It is expected that for an operational system the prediction system will be monitored by a deployed LIDAR sensor, which can be used to validate the predictions in real time and provide a safety net for unexpected vortex behaviour.

Wake Vortices

Wake vortices are generated whenever an aircraft wing produces lift. The strength of the vortex is a function of the aircraft mass, airspeed, configuration (i.e. state of flaps) and wingspan. The strength is greatest when the aircraft is heavy, in a clean configuration and is flying slowly. They form due to the flow of air from the high pressure below the wing to low pressure above the wing and are generated at both wing tips to producing two counter rotating air masses trailing aft of the aircraft.

ICAO introduced procedures in 1978 to put every aircraft into one of three groups based on its take-off weight.

These were defined as:

- Heavy - All aircraft types of 136,000 Kg or more;
- Medium - Aircraft types of less than 136,000 Kg and more than 7,000 Kg; and
- Light - Aircraft types of 7,000 Kg or less.

These limits do not reflect the depth of the problem. Some aircraft, such as the Boeing 757, produce a stronger vortex than would be expected. Some countries including the UK have modified the ICAO definitions. The UK has split the medium category into "Upper Medium" and "Lower Medium" and has introduced an additional "Small" category.

LIDAR

The principle behind LIDAR is similar to that employed by RADAR, but uses low powered laser beams instead of radio beams. The laser light hits particles in the atmosphere and is variously scattered, reflected, absorbed, frequency shifted or depolarised. A receiver collects and measures the Doppler shift in the returning light to derive velocity information in order to obtain an understanding of the airflow.

VHF Datalink (VDL)

Datalink over VHF is used in the aeronautical domain since the 1980s with the use of ACARS (Aircraft Communication Addressing and Reporting System), developed initially for AOC (Aeronautical Operational Communications) purposes. ACARS is a data link system in the VHF radio band that allows communications of character-oriented data between aircraft systems and ground systems. A form of minimum-shift keying (MSK) modulation is used; however full advantage of digital modulation is not realised because of the necessity of reducing the modulation to the audio baseband for interfacing with existing VHF radios. This, coupled with the current VHF channelisation (25 kHz), limits the channel data rate to 2400 bps.

Moreover during the past several years various standards organisations within the aviation community have been participating in, or supporting the development of a new architecture for use in the aeronautical data communications environment. This architecture, the Aeronautical Telecommunications Network (ATN) supports interoperability between the various terrestrial, air/ground, and avionics sub-networks through conformance with a single bit-oriented ATN Inter-networking Protocol, ATN Addressing Plan, and ATN Routing Plan. The ATN architecture provides a single network service interface for the applications and application information may be transmitted over the different air/ground sub-networks transparently. The Air Transport industry has endorsed this ATN architecture and has incorporated ATN-conforming guidelines in the standards being developed for the three main possible air/ground sub-networks, or data links: Mode-S, Satellite and VHF.

The VHF Data Link (VDL) or Aviation VHF Packet Communications (AVPAC) protocol, defined by ICAO supports bit-oriented air/ground data transfer and is intended to allow VHF air/ground access in the frame of the ATN architecture.

Besides, in order to overcome the limitations of the existing radio system and to provide high speed data transfer capability, ICAO and AEEC developed the characteristics of a new digital radio to be used for air-ground communications: the VHF Data Radio (VDR) transceiver.

Different modes of VDL have been defined and standardised:

VDL Mode 1 & 2 is based on CSMA scheme (MSK modulation for Mode 1 and D8PSK modulation for Mode 2). Promoted by European CAA, VDL Mode 2 is the logical successor of the ACARS. VDL Mode 1 offering the same capacity as ACARS is not recommended and will not be mentioned any more.

VDL Mode 3 integrates digital voice and data with a TDMA technique and D8PSK modulation. Promoted by the FAA, the objective of this architecture is to support a spectrum-efficient voice system to meet near-term needs for increased voice capacity, while providing a natural time-phased evolution toward a mixed voice and data environment that maintains spectrum efficiency with increasing levels of data traffic.

VDL mode 4, called STDMA (Self Organising TDMA). Promoted by the Swedish CAA, as a candidate for the future VHF system, for navigation and surveillance applications, STDMA is defined as a multiple access scheme based on time-shared use of an RF channel employing:

- discrete contiguous time slots as the fundamental shared resource; and
- a set of operating protocols that allows users to mediate access to these time slots without reliance on a master control station.

The STDMA concept of operations is based on:

- a GNSS receiver for the determination of user position and accurate system time; and
- ADS-B capabilities.

Other Technologies

This section details the environmental mitigation technologies that were screened as significant but not taken to the technology workshop

Aeronautical Telecommunication Network (ATN)

The ATN is a data communications inter-network that provides a common communications service for all Air Traffic Services Communications (ATSC) and Aeronautical Industry Service Communication (AINSC) applications that require either ground/ground or air/ground communications services.

Use of Existing Infrastructure. The ATN integrates and uses existing communication networks and infrastructure wherever possible. ATN Routers act as gateways between those networks (LANs, leased lines, CIDIN and X.25). ATN can make full use of emerging network technologies (Gatelink, Frame Relay and ATM).

Application Service. The ATN provides operational users with a communication service customised for each application. The ATN End Systems are responsible for ensuring the integrity of the end-to-end communication and the structured transfer of operational data.

High Availability. The ATN has been designed to provide a high availability network by ensuring that there is no single point of failure, and by permitting the availability of multiple alternative routes to the same destination.

Mobile Communications. The ATN fully supports mobile communications over a wide variety of mobile communications networks including AMSS, VDL and Mode S. With the ATN, it is possible for a ground system to communicate with airborne avionics in any part of the world.

Policy based Routing. The ATN routing procedures support a wide range of organisational and national policies, including the enforcing of restrictions on what types of traffic can pass over both ground and air/ground data links, and control over which air/ground data link types are used by which applications.

Airborne Radar

Overview

The airborne radar is used primarily for weather detection, ranging and analysis. Its secondary role is to provide navigation information by ground mapping of significant land contours.

Traditionally the weather radar has provided the pilot with a display, which presents the density of precipitation in a sector in front of the aircraft. The pilot can use the information to navigate a route avoiding the worst weather conditions. More recently however, the weather radar has been improved to provide turbulence indication and windshear/microburst prediction.

Operation

Weather radar emits microwave radiation in the centimetric or 'X' band. Objects typically large enough to reflect the microwaves that are emitted by weather radars include:

- Precipitation i.e. rain drops, snowflakes, hailstones;
- Airborne dust and sand;
- Birds;
- Insects;
- Aircraft (including balloons, powered and unpowered aircraft and projectiles above a certain size); and
- Terrain.

It is important to note that weather radars do not detect clouds. Clouds are aggregates of vast numbers of liquid water droplets and/or ice crystals suspended in the air. Under the right circumstances, these small cloud particles coalesce to form larger precipitation particles. Approximately one million cloud particles make one precipitation particle. Only these larger particles are big enough to reflect microwaves.

The use of doppler information provides indications of the particles velocity with respect to the aircraft. This allows the radar system to provide a map of relative wind velocities in front of the aircraft. This wind information can be analysed to detect windshear and turbulence, and provide warning to the pilot. The term windshear is used to describe a variety of atmospheric conditions characterised by a sudden change in air mass direction and/or speed.

Airborne radar is not suited for detection of wake vortex conditions due to the velocity components of the vortex being normal to the approach path. This provides limited Doppler variations for the radar to detect and generate associated warnings.

Airborne Separation Assurance System (ASAS)

The term ASAS is used to cover a range of concepts where the responsibility for separation from other aircraft is either partially or wholly delegated to the pilot. The use of ASAS requires information on other aircraft, which may be derived by Automatic Dependent Surveillance - Broadcast (ADS-B) or Traffic Information System (TIS). Although Airborne Collision Avoidance System (ACAS) provides some of the details required for ASAS, it is kept independent of the separation system and is used as a safety net. Once the positions of the other aircraft are obtained, the pilot is presented with a display on a Cockpit Display of Traffic Information (CDTI). This information is designed to provide the pilot with the necessary cues to ensure safe separation. In addition, this knowledge can be used to provide additional capabilities to improve flow of traffic and increase the density of airport operations.

Airport Simulator

Airport simulations are available to model many aspects of airport activities. They are used in:

- Design of new airports;
- Modification of existing airports (major - e.g. second runway, or minor - introduction of new holding points);
- Training of controllers (either generically or specifically);
- Capacity estimates;
- Re-routing;
- Effects of new technology and/or new regulations;
- Schedule optimisation; and
- Recovery from irregular operations.

Autonomous Precision Approach and Landing System (APALS)

The APALS is an autonomous precision guidance system, which uses standard avionics to determine the aircraft position. This is achieved primarily using the aircraft's weather radar to provide range and range rate from unique features on the ground, and uses map matching between terrain data stored by the system compared with the map generated by the weather radar operating in Synthetic Aperture (SA) mode.

The system is aimed at producing CAT III guidance equivalency at airports that lack the required ground equipment to support such landings.

In addition to the guidance output, the radar can be used to scan the runway to ensure that it is clear of vehicles or aircraft on the ground. This provides the pilot with increased confidence during the approach.

Developed by Westinghouse originally, however this was stopped several years ago and further development is not expected in the foreseeable future by them or others.

Technical Description

The APALS system uses small Synthetic Aperture Radar (SAR) maps provided at the end of the weather radar sweep at an angle of approximately 45°. This angle provides the required Doppler gradient for the SAR system to work. The SAR picture covers approximately 160*160 m^2 with a resolution of 4 * 4 m^2. This scene is compared to a stored reference, the co-ordinates of which have been previously surveyed. "Match" points are examined and range and range rate from that location calculated. This information is used to provide inputs into a Kalman Filter (along with INS and GPS) to provide an optimal estimate of the aircraft's state (relative position to the touchdown point, velocity, and height).

The system is initialised using position from a combined Novatel C/A GPS card integrated with a low cost Litton LN-200 Fibre Optic Gyro (FOG) based Inertial Navigation System (INS). The INS/GPS system provides an accuracy of ~100m, which is sufficient to allow the radar to cover the scene of interest. Once the SAR system provides inputs into the Kalman filter the position accuracy begins to improve.

During the approach phase, the radar correlation is used to update the onboard position until the aircraft reaches a height of 100ft. At this point the radar geometry begins to degrade and the aircraft lands using the outputs of the corrected INS/GPS position. Taking the radar out of the loop during the final stages also reduces the requirements for weather radar certification.

The guidance system provides ILS type outputs for use by existing on board displays or by an autopilot for automatic approach. In addition, APALS can provide a wire frame outline of the runway on a head up display and also can portray extended centreline and touch down zone symbols.

The database for each approach includes approximately 60 'clusters' of ground objects. In each cluster there are normally between 100-150 objects, including light poles, culverts, bridges and buildings. The objects are chosen because of the distinctive radar returns on the SAR image. The APALS system monitors each approach flown and provides a figure of merit for each cluster for subsequent downloading. This technique allows consistently bad clusters to be reviewed or deleted.

Co-operative Vehicle Tracking System

This system is dedicated to the management of vehicles moving on the airport surface. The basic function of the system is to track the position of the equipped vehicles permanently and to present the situation to the relevant control entity.

As a co-operative sensor the system implies the use of specific equipment to be installed in the vehicles. The role of this equipment is generally to calculate the position and to transmit this information periodically, in conjunction with identification, to a central system.

Different concepts are used for the determination of the position. In particular, 2 main solutions are generally proposed:

- RF Multi-lateration; and
- DGPS.

The multi-lateration solution requires the installation of beacons around the airport and is based of the reception of the beacons signals by the vehicles equipment which uses a multi-lateration algorithm in order to calculate its own position (signals from at least 3 beacons must be received to get a two dimensional position, but more is better to increase accuracy and redundancy).

The DGPS solution requires the implementation of a DGPS receiver in the vehicles and generally the installation of a Differential GPS ground station. The ground station is dedicated to the monitoring of the GPS signals (integrity) and to the processing and broadcast of differential corrections to increase the position accuracy and reliability.

Both solutions also require the presence of a transmitter in the vehicles in order to send the position, identification and other optional information to the central system. The reception of these messages is performed by a central receiver installed on the airport. RF is used for the transmission and the TDMA (Time Division Multiple Access) scheme is generally implemented for this kind of application which requires periodic and permanent access of the vehicles to the channel.

Additional functionality can complete the system. A set of examples is given below:

- Transmission of additional information from the vehicles: speed vector, current activity, fleet identifier, short messages (free text).
- Monitoring functions to prevent critical or non-authorised area incursion, speed overrun, conflict detection. These functions imply the management of alarm/warning messages which can be issued at the control entity level and/or on board the vehicles.
- Guidance functions which allow the drivers to get guidance and positioning information through an on board visualisation tool for instance. These function are useful especially in low visibility conditions on complex and large airports. They can be also of great interest for the guidance of snow-removal equipment.

Cockpit Display of Traffic Information (CDTI)

CDTI is the function of presenting surveillance information about the surrounding traffic to the flight crew. The information presented includes the relative position of other aircraft in the vicinity with respect to own aircraft. Traffic information for the CDTI may be obtained from one or more sources, including, but not limited to, broadcast automatic dependent surveillance (ADS-B), Traffic Information Service (TIS), and Airborne Collision and Avoidance System (ACAS).

ADS-B

ADS-B is a function on an aircraft or surface vehicle that periodically broadcasts position, altitude, velocity vector and other information for use by other aircraft, vehicles, or by ground facilities.

Traffic Information Service

TIS is a Mode S data link service through which ground-based radar surveillance information is sent to an airborne cockpit display. The TIS data link function provides automatic display to the pilot of nearby traffic and warnings of potentially threatening conditions. Transponder equipped targets within five nautical miles and 1200 feet altitude are uplinked. TIS generates alerts for any aircraft in Mode S coverage that carry a transponder (ATCRBS or Mode S). TIS provides relative range, altitude, and bearing of proximate aircraft than can be displayed to the pilot. It also provides trend information (climb or descent rate greater than a threshold amount) and traffic advisories similar to those of TCAS I.

Traffic Information Service - Broadcast (TIS-B)

TIS-B is a service in which the positions of all aircraft within a broad coverage area are broadcast to all users with a common message. Each user, having knowledge of its own position, could calculate the relative position of traffic. Like TIS, TIS-B will allow the first aircraft equipped with an ADS-B system to realise the benefits by being capable of receiving limited information about proximate aircraft when in coverage of a surveillance radar. During the transition to ADS-B, TIS-B would provide traffic information derived from secondary surveillance radar (SSR) on aircraft not equipped with ADS-B. As the number of ADS-B equipped aircraft increases, the need for a TIS or TIS-B would be reduced.

TCAS

TCAS is a collision avoidance system which uses a transmitter/receiver to interrogate nearby aircraft transponders. TCAS determines target range very accurately from the time to reply to the interrogation. TCAS roughly determines the relative bearing of the target with a directional antenna system. TCAS uses the altitude fields of transponder replies, if present, to determine target altitude.

The most fundamental utility of the CDTI in air traffic operations is enhanced traffic situational awareness. However, a CDTI may provide other specific benefits when certain CDTI capabilities are provided and utilised in the context of specific air traffic procedures.

Implicit within such potential enhancements is the assumption that pilots would be able to conduct an existing task easier with the CDTI, or may be required to and able to conduct

tasks not currently possible or authorised. Either way, the required CDTI capabilities would depend on the required procedures.

To display traffic information, the CDTI may use a dedicated display device or a shared multi-function display. Although a visual/graphical presentation of the traffic on a head-down display will be most common in the near term, other types of presentation (e.g., aural, graphical head-up) are also possible, as discussed below. The specific information presented may vary based on the intended operational use of the information. However, the general characteristics are expected to be as follows.

A CDTI consists of the following minimum and optional attributes:

A) Minimum Features and Target Information:

- Own aircraft symbol
- Target aircraft symbol
- Target aircraft relative bearing
- Target aircraft relative range
- Target aircraft altitude (barometric)

Note: Target information may be conveyed graphically or alphanumerically.

B) Application Dependent Display Features and Target Information:

- Call sign
- Closure rate
- Ground speed
- Ground track indication
- Target selection
- Target highlighting
- Extended display range
- Range reference
- Vertical rate indication
- Traffic alerting

Several display types can be considered for use as a CDTI:

Moving airport map

Based on the research at NASA, an electronic moving map (EMM) of the airport is recommended for surface CDTI. Displaying traffic positions on a moving map gives the crew an invaluable reference. This allows the crew to infer the intention of surface vehicles (i.e. what taxiway they are travelling on, where they may turn, and hazard potential). This display would primarily be used by non-steering crewmember so that "steerer" can maintain eyes-out and perform "see-and-avoid".

Traditional navigation-type display

Same as above without the runway/taxiway edges and/or centerline vectors. Provides flight crews with relative range/bearing information, identity, and closure rate estimate.

HUD

A head-up display of traffic is not recommended for display of traffic positions due to narrow field of view and clutter issues. However, it may be the best solution for displaying traffic alerts. This has not been tested to date.

Text

A text display could convey the position and heading of other aircraft within a specified radius, or just aircraft that can potentially intercept the ownership. This method is not recommended as it would increase pilot workload, visual attention resources, and heads-down time.

Auditory

A 3-D auditory system has been developed and tested that can be useful in providing redundant information as to the presence and general direction of other aircraft.

Controller Pilot Data Link Communication (CPDLC)

Controller Pilot Data Link Communications (CPDLC) is a mean of communication between Controller and Aircrew, using data link for ATC communication.

For Airport and TMA operations, the envisaged applications are for instance (but not limited to):

- Departure Clearance (DCL)

  DCL is a tool dedicated to airport control and more specifically to the pre-flight working position. It aims to integrate flight plan management and data-link departure clearance in a sole user interface. DCL encompasses the user interface itself and the datalink gateway.

- Push back Clearance[53]

  The Push back Clearance operationally follows the DCL and is provided to the aircraft to initiate the push back from its gate.

- Taxi Clearance

  Taxi Clearance occurs after the push back (once the aircraft is able to taxi autonomously) to indicate to the pilot the authorisation to taxi and the route to reach the take-off runway threshold.

[53] DCL is already a defined sub-service, by the EATCHIP/EATMP IDIAC Sub Group. However the ‘Push Back’ and ‘Taxi Clearance’ have yet to be formally defined.

Controller Safety Net in TMA (STCA)

Air Conflict detection implemented in ground systems and applicable in terminal area are the following:

- Short Term Conflict Alert (STCA) for air segments of flight.
- Minimum Safe Altitude Warning (MSAW) for final approach segment.

Existing STCA devoted to approach control are derived from *En-route* STCA where separation criteria are adapted to approach separation standard (3 instead of 5 NM). The conflict prediction is based on the extrapolation of aircraft tracks. Improvements in predicting aircraft tracks (enhanced surveillance etc.) provides improved reliability and accuracy in conflict detection with fewer false alarms.

Even if the separation criteria are reduced, the increased potential for aircraft to manoeuvre in approach areas makes track extrapolation difficult. The rate of false alarms remains very high.

STCA specifically dedicated to aerodrome control (particularly runway circuit, and integration of the final segment of the approach procedure in the circuit) has never been developed.

The MSAW system was introduced in the United States in 1976, therefore it is a mature technology and is not discussed further in this report.

Data Link Flight Information Service (D-FIS)

D-FIS (Data Link Flight Information Service) is a mean of providing flight information (e.g. ATIS and meteorological information) to Aircrew using air/ground data communications.

Two modes of operations are proposed: "on request" mode or "update contract" mode:

Aircrew will have access on request to aeronautical information of interest to flights, such as weather reports and forecasts, notice to airmen (NOTAM), Automatic Terminal Information Service (ATIS) and Instantaneous Runway Visual Range readouts. Additionally Controllers are discharged of delivering such information to Aircrew via voice.

It is also envisaged to include the concept of contract between the aircraft and the ground concerning the delivery of this information. When a contract exist, the ground will automatically send an update of the information as soon as it changes (new conditions…).

The ground system generally generates the contents of messages thanks to the connection to existing information servers (meteo, AFTN…).

For instance ATIS messages could be automatically prepared and proposed to the controller for validation. In addition, ATIS message is currently broadcast over a radio channel as a voice recorded message. Automatic systems often include a capability for using a synthetic voice generator and thus does not require any more from the controller to verbally record the successive updates of ATIS.

Docking Guidance System (DGS)

The Docking Guidance System is a system dedicated to the aircraft parking phase, to facilitate precision positioning of the aircraft in close co-ordination with the passenger boarding bridges when entering parking stand.

The system is located on the axle of the view of the pilots, so that pilots can see all necessary information without turning their heads. The system gives information related to the stand number, the aircraft type, the azimuth guidance and the closing rate information.

The system provides visual displays readable by all aircraft types specified at each parking position.

Fully automated DGS ensure the docking procedure as follows:

The DGS analyses the docking area, and controls that everything corresponds to the operational calibration check for a normal aircraft docking. When self tested and operational, the system switches to capture mode, and detects an approaching or departing aircraft. After data collection, parameters are compared to a database and the selected type of aircraft is displayed so that pilots can see the aircraft has been correctly caught by the DGS.

Then the system enters the tracking mode. The DGS continuously measures the position of the aircraft in relation to the aircraft stand centreline and the stop position. During the tracking, the visual display gives pilots relative position of the plane in a real time process, correction to align the aircraft to the centreline and the remaining distance to be covered until the stop bar.

Technology for azimuthal guidance: Moired target, parallax finger,

Technology for closing rate guidance: Induction loops, luminous barrier,

Technology for both: Laser scanning system, video scanning system.

Enhanced Vision System (EVS)

The terms Synthetic Vision and Enhanced Vision are often inter used, for this document the following definitions will be used.

Enhanced Vision:

This involves the use of forward looking sensors (including Forward Looking Infra Red (FLIR) and millimetric Wave (mmW) Radar) with the images fused and displayed on a pilot's Head Up Display (HUD) to provide an equivalent visual image of the view in front of the aircraft.

Synthetic Vision:

This again, involves the generation of an equivalent visual image of the view in front of the aircraft, and may indeed contain an enhanced vision image. However, in this case additional computer generated symbology is added based on the aircraft position. This may range from simple wire cage runway symbology to advanced airport views based on a large database.

This document applies only to the enhanced vision system.

The enhanced vision system is designed to provide the equivalent of visual contact with the runway prior to reaching Cat I decision height when flying in CAT III conditions, and requires no additional systems to be based on the ground. The system combines imaging sensors, (mmW radar and FLIR), image processors and a wide field of view HUD. The display is used to provide enhanced vision of the real world scene to enable the pilot to land the aircraft in poor visibility. The HUD fuses the mmW and FLIR information and combines this with flight director symbology to provide the information required by the pilot during the approach, landing and roll out.

Gatelink

Gatelink is a high speed, multi-media communications link that transfers large volumes of information between airline landside end systems and aircraft end systems, regardless of location. Gatelink provides the communications connectivity for a parked aircraft located at the airport terminal, maintenance bay, or remote parking area. This gatelink connectivity can be used to transmit most forms of operational, administrative, and passenger information, and is capable of simultaneous voice, data, video and graphic transfers.

The gatelink environment can be divided into three segments:

1. The landside segment requires the interface of all applicable airlines host computers running the various operational applications, as well as the gate-supported PABX or central office.
2. The interface between the aircraft and the landside segment requires either an RF, infrared or hardwire connection to link landside facilities to parked aircraft through Gatelink.
3. The on-board segment is routed through the Communications Management Unit (CMU) or the Aircraft Information Management System (AIMS). These units transfer and direct the flow of data received from gatelink to the host computers and the appropriate on-board systems.

Microwave Landing System (MLS)

Overview

MLS is a precision approach and instrument landing guidance system operating in the microwave spectrum (5 GHz). The position information provided to the aircraft is determined by azimuth angle measurement, an elevation angle measurement and a distance measurement.

The specific advantage of MLS is its capability to provide shortened approach path (comparing to ILS) using curved trajectory.

A typical basic system configuration is:

- approach azimuth equipment
- approach elevation equipment
- a means for the encoding and transmission of essential data words
- DME (Distance Measuring Equipment)

This can be augmented by:

- back azimuth equipment
- flare elevation equipment
- a means for the encoding and transmission of additional auxiliary data words
- a wider proportional guidance sector
- or DME/P (Precision Distance Measuring Equipment)

Technical Details

MLS provides guidance information over an azimuth sector of +/- 40°from the runway centre line to a range of 20 nm and elevation guidance between +1° and +15° enabling the use of steeper glidepaths. An additional Back Azimuth facility provides +/- 40° lateral guidance for missed approach and departure guidance. MLS also contains a ground to air datalink enabling the automatic transmission of essential information such as minimum allowable glidepath, RVR, surface wind etc.

MLS operates in the frequency band 5030 MHz to 5090 MHz. Two hundred channels are currently available overcoming ILS problems with frequency allocation.

The system operates on a principle known as Time Reference Scanning Beam (TRSB). The TRSB system operates by producing a narrow beam, which is electronically scanned TO and FRO at 20,000 degrees per second across the coverage sector. The aircraft receiver detects the passing beams and measures the elapsed time between the TO and FRO beams. This gives a very precise measure of the angle of the aircraft with respect to the centreline. The system used is identical for azimuth, back azimuth and elevation with time division multiplexing used so that whilst each part of the system is transmitting the others remain silent. Each transmission is prefixed by an identify code enabling the aircraft receiver to determine which ground transmitter is radiating. The system is designed to provide an update rate of 39 Hz for each guidance function.

Mode S Gate

A Mode S Gate is a simple Mode S interrogator station to be installed near parking exits or runway access.

The purpose of a Mode S Gate is to detect and identify departing aircraft. The system is to be integrated in a A-SMGCS system as a complementary co-operative sensor dedicated to the identification of departing aircraft.

The system receives the Mode S squitter signal (including the 24 bit mode S address) from the Mode S transponder of aircraft. To detect departing aircraft, the equipment includes a narrow beam antenna maximising neighbouring aircraft discrimination. To complete the identification, the Mode S interrogator module extracts from the aircraft transponder BDS (Comm B Data Selector) the 12 bit transponder code A as well as the aircraft Call Sign.

Mode S Multilateration

The Mode S[54] Multilateration is a system dedicated to the localisation and identification of mobiles equipped with Mode S transponders. The system includes multiple transceiver stations located around the airport area and linked to a centralised Master Workstation.

This system is a co-operative sensor (i.e. providing the ability of automated identification of equipped object). The positioning of the mobiles is calculated with a multilateration algorithm based on the signals coming from the Mode S transponders. Two kinds of messages are transmitted by a Mode S transponder:

- the automatic squitter signal is self-triggered by the transponder randomly about once per second; and
- the replies to ground station interrogations.

Each of these signals can be used by the system. At least three ground stations receive the messages and measure the Time of Arrival (TOA) in order to perform the triangulation. Constant difference in TOA between two stations form hyperbolic lines of location. With three stations, the point of intersection of two hyperbolic lines of TOA differences indicates the location of the transmitting antenna. As this method is based on TOA differences, it is independent of knowing the absolute time of transmission.

The identification of the mobiles is permanently performed through the unique 24 bit address stored in the Mode S transponder. An association table is generally implemented within the ground system to get the Call Sign.

Multi-Mode Receiver (MMR)

[54] The Mode S Secondary Surveillance Radar system (SSR Mode S) is a significant improvement to conventional Secondary Surveillance Radar (SSR Mode 3/A/C). Mode S includes selective interrogation capability, automatic transmission of «squitter», unique 24-bit aircraft address, and datalink capability.

The MMR provides the airborne segment of the precision guidance systems based on the following three systems:

Instrument Landing Systems (ILS)

The localiser signal is transmitted from an antenna located on the opposite of the landing runway providing a maximum full scale indicated displacement of 700ft at the landing runway threshold. The guidance signal provides accurate guidance up to approximately 18 nautical miles. Reliable indications of being off course to the left or right can be received 35° either side of the runway centreline to a distance of 10nm and 10° either side of the runway centreline to a distance of 18nm.

The glideslope antenna is normally situated level with the touchdown point, offset between 250 and 650 ft from the runway centreline. The beam is 1.4° wide and angled at approximately 3° to and is normally usable to a distance of 10nm from the antenna site.

Microwave Landing Systems (MLS)

MLS provides guidance information over an azimuth sector of +/- 40° from the runway centre line to a range of 20nm and elevation guidance between +1° and +15° enabling the use of steeper glidepaths. An additional back azimuth facility provides +/- 40° lateral guidance for missed approach and departure clearance. MLS also contains a ground to air datalink enabling the automatic transmission of essential information such as minimum allowable glidepath, RVR, surface wind etc.

Satellite Landing System (SLS)

The SLS uses differential corrections transmitted from the ground to improve the accuracy of the GNSS receiver in the aircraft. The SLS calculates guidance to the touch down point and provides pseudo ILS signals to the onboard systems.

The MMR is designed to contain the airborne elements of each of these systems inside a single unit. The output from this unit is designed to mimic ILS type signals when using the SLS or MLS inputs. This feature is aimed at providing a compatible system with existing certified landing systems and allows transparent operation independent of the guidance source.

Although the MLS is an option the majority of current receivers are designed to provide ILS/SLS functionality only.

To allow differential corrections from a specific ground station to be provided to the on board GNSS sensor, a datalink decoding capability is normally provided within the MMR. However, the option exists for an external datalink receiver to be used if already fitted to the aircraft.

Although the MMR is designed to provide a GNSS receiver embedded within it, the option exists for external GNSS receivers to connected via a databus if it is already fitted to the aircraft.

The system is designed to provide ILS functionality independent of the true source of the data. This functionality is aimed at minimising the impact on existing autopilots and certification by not requiring any modifications to be made to other on board avionics systems.

Multi-Sensor Data Fusion System

It is currently assumed that no one of the existing sensors is able to provide a complete coverage of all mobiles (aircraft and vehicles) involved in airport ground movement.

On the other hand different sensors, each of them providing data dedicated to one area or one kind of mobile, exist and, combined together, could provide a better assessment of the traffic situation.

The sensor fusion builds a traffic situation picture either by combining the data coming from different sources from one mobile into a single track when sensors coverage overlap or by building one continuous track for one mobile using data from successive sensors.

An additional point is, when one of the sensors provides the target identity, to use it to display labels associated to the tracks.

Runway Incursion Detection System

A runway incursion detection system is a DPS component which analyses the surveillance data coming from different sensors (in general the main sensor is a primary surface movement radar) and issues alarms to the controller when a potential conflict is detected inside the runway sensitive area.

This module is developed according to some rules defined by the Air Traffic Control. According to the complexity of the airport configuration and to the level of false alarm to be reached, the definition of the rules can be more or less complicated. Generally, operational procedures define a sensitive area around the runways where no vehicle or aircraft are allowed to enter when the runway is active (take off or landing phases). The dimension of this area depends on the visibility conditions (the worst the visibility, the bigger the area).

Some example of rules to issue an alert are given below:

- non identified object located in the sensitive area;
- identified mobile located in the sensitive area when an aircraft is about to take off or to land;
- aircraft intending to land or to take off on a closed runway;
- two aircraft intending to land on the same runway in reverse landing direction;
- too close separation between two landing aircraft in short final; and
- a landing aircraft holding position in the critical area for a long time or located out of a taxiway.

Runway Management System (RMS)

The number of parameters the aerodrome controller takes into account to deliver landing or take-off clearances is consequent.

The number of procedures the aerodrome controller can use to perform the runway capacity in safe but effective way is also very consequent and cannot be decided a long time in advance. The choice between two alternative procedure will depend on instantaneous conditions which cannot be expected even 3 minutes in advance.

Therefore the sequences, arrival, departure, line-up sequences calculated and proposed by the other planning tools will never have the precision needed in an effective runway management process.

The average Runway Occupancy Time (ROT) is 45 seconds for an arrival aircraft on a well equipped runway, and often less than this value for departure. Aerodrome controller will take decision based on less than 30 seconds time scale.

RMS is a decision assistance tool in which the tuning of the aircraft sequence for take off, integrating accurate position of arrival will be the main function. The advice address to the Aerodrome controller will include the timing of lining up and the procedure to be applied with a revised CTOT including a margin of less than one minute.

Satellite Datalink

The aim of satellite datalinks is to provide a communication media between the aircraft and ground during periods when the aircraft is out of coverage of other terrain based systems.

The distance the satellite is on orbit around the earth dictates both the number of satellites required to provide the required coverage and power and antenna requirements for communication with the satellite. Satellites in geostationary (GEO) orbits maintain a fixed coverage with limited coverage at polar latitudes and require large antennas to provide high bandwidth communications. Next generation satellite systems are in low earth orbit (LEO) and require a high number of satellites to provide coverage. The primary advantages are the reduced power levels required to communicate with the satellites and global coverage.

INMARSAT

Satellite communications allow an aircraft to establish a link with a Ground Earth Station (GES) via a satellite.

Today, INMARSAT geostationary satellites are used for aeronautical mobile communications. The following services are proposed:

Aero-H: it requires large antenna (12 dBi) 50 x 50 cm, 80 kg. Global beams are used for this service.

Aero-I: in service since December 1997, it require smaller antenna (6 dBi), 20 kg. Spot beams are used for this service, and the coverage is worse.

LEO

Iridium

The Iridium constellation consists of 72 satellites of which 66 were intended to be operational. The iridium system was designed to encompass commercial Aviation Systems, though since going bankrupt other uses are being found for the satellites. Originally, the entry-level system for fitting on board aircraft consisted of a small transceiver unit and a low gain antenna. This system provided two way voice only communications. Other more capable products conforming to ARINC 761 included multiple channels and the capability to provide all standard aviation services such as APC, AAC, AOC and ATS.

Globalstar

The Globalstar constellation consists of 52 satellites of which 48 will be operational. The satellites will by in a 750nm orbit with a 113 minute orbit period and is designed to give coverage between 70°S and 70°N.

Secondary Surveillance Radar (SSR) & Mode S

Secondary Surveillance

Secondary Surveillance Radar (SSR) interrogates co-operative targets, whose transponders reply at another frequency with coded information. Range and azimuth are measured by antenna azimuth and the delay between transmitted and received pulses. SSR only detects targets with correctly functioning transponders within range, uncooperative targets go undetected. The transmitted power requirement for SSR is much less than for primary radar as there is a transmitter at the target.

Current SSR transponders reply with Mode A (ident) and Mode C (altitude) codes.

Azimuth accuracy is improved by the monopulse technique, where sum and difference channels from the same antenna make measurement of the azimuth of each and every pulse entering the system to a high degree of accuracy. All current SSR in production are Monopulse SSR (MSSR). One of the aims of MSSR was to reduce the radar PRF (fewer pulse hits on target required for azimuth information), but most manufacturers did not bother to do this.

A new technology of radar, based on E-SCAN antenna, is developed by Allied Signal and is called PRM (Precision Runway Monitor). This system allows high azimuth accuracy and a higher update rate than that of conventional airport surveillance radar (less than 1 second). This type of radar was designed to cope with the management of closely spaced parallel runways to take advantage of the maximum capacity gains possible from the use of simultaneous approach procedures. Parallel approaches are simultaneously conducted with a radar controller monitoring traffic on each approach path. Arriving aircraft guided onto the parallel courses are monitored at a one-second update rate to ensure they do not enter the no transgression zone that lies between the runways.

Mode S

The Mode S is an evolution of the traditional Secondary Surveillance Radar (SSR), which is based upon Mode A/C interrogation/reply scheme. In the Mode S system, this scheme has been enhanced, by uniquely identifying each aircraft using a world-wide 24 bit aircraft address, and by allowing the transmission of interrogations selectively addressed to a single aircraft, instead of being broadcast in the whole antenna beam.

A Mode S radar is able to perform surveillance (i.e. to output the aircraft position, plus the standard SSR modes (Mode 3/A, Mode C)). It is also able to perform datalink, i.e. to send or extract frames containing binary data. The datalink can be operated only on each aircraft being tracked by the surveillance processing. From an operational point of view, priority is always given to the surveillance processing (the detection of a target and the sending of the corresponding information shall never be degraded for any datalink reasons).

In order to provide standard services, ICAO has standardised the Mode S subnetwork, which is an ATN compatible air-ground subnetwork, making use of the Mode S interrogators datalink features. Such a subnetwork is also able to provide non-ATN services, known as Mode S Specific Services.

Enhanced Surveillance

The Mode S transponder contains 256 registers, called BDS (Comm B Data Selector), note that the register 0 is used for AICB. Each of these registers is 56 bits long, and can be read at any time by interrogators. These registers will be filled with derived information, such as aircraft speed, waypoints, meteorological information, Call Sign, ACAS (Airborne Collision Avoidance System) information.

Some of these BDS are useful only when used together with the aircraft position at the time of extraction (such as speed, meteorological report, ...), some others are useful independent of the aircraft's position (such as waypoints, aircraft capability, Call Sign, ...).

It is interesting to enhance the usual target report, produced as part of the surveillance processing, with the contents of several of these BDS. This use of BDS is called "Enhanced Surveillance".

The extraction of these BDS may be decided by the interrogator, on a simple periodic basis, or on a more sophisticated criterion such track initiation, turn detection, ... (routine enhanced surveillance). In a further step, the user may decide additional extraction based on their own criteria, and request them to one interrogator (directed enhanced surveillance).

Each radar will extract the BDS involved in routine enhanced surveillance for all targets. It should also be noted that these BDS may also be used to enhance the radar processing itself.

This enhanced surveillance can be considered as a datalink application making use of the GICB (Ground Initiated Comm B) specific service, but may use other protocols beyond GICB.

Datalink and Specific Services

The datalink services can be supported by Mode S SSR. The Mode S datalink is defined at two levels.

The first level concerns the dialogue between one interrogator and one transponder, and provides a service comparable to a datalink layer in the ISO scheme, by allowing the exchange of frames of up to 1280 bits. In addition, three additional services are available:

- the uplink broadcast service, which allows an interrogator to send a 84 bit message to all aircraft in the beam;
- the downlink broadcast, which allows an aircraft to send a 56 bit message to all interrogators in view; and
- the GICB service, which allows an interrogator to extract one of the BDS registers.

Above this first level, a second level has been defined by ICAO, in order to offer a more complete and more inter-operable service. This second level:

- offers an ISO 8208 service, compliant with the ATN specifications, (called in the document SVC services);
- offers Mode S specific services (i.e. data transfer specific to Mode S, making optimal use of Mode S features); and

- allows the management of several interrogators transparently to the user (a flying time in a single interrogator coverage could be very short).

Mode S Transponder

The Mode S transponder co-operates with one or more Mode S interrogators, in order to achieve surveillance and datalink protocols. A Mode S transponder is also fully compatible with the standard Mode A/C operation.

Mode S selective interrogations (including datalink) are addressed to a given aircraft, using its unique 24-bit aircraft address.

The transponder is composed of:

- an antenna;
- a receiver;
- a transmitter; and
- a processing chain which decodes the type of interrogation, and generates the proper replies.

Several types of transponders have been defined by ICAO, resulting in various datalink capabilities. These transponder levels are given below, in order of increasing capability:

- Level 1 transponder, which does not have any datalink capabilities;
- Level 2 transponder, which is the first transponder capable of datalink. This transponder allows uplink and downlink broadcast, GICB, and SLM (Standard Length Message, i.e. Comm A/Comm B frames) transfer;
- Level 3 transponder, which allows uplink ELM (Extended Length Message, i.e. Comm C frames) in addition to level 2 features;
- Level 4 transponder, which allows downlink ELM (i.e. Comm D frames) in addition to level 3 features; and
- Level 5 transponder, which is a level 4 transponder with the ability to operate with more than one interrogator at a time, in order to provide higher throughput.

Surface Management System (SMS)

The Surface Management system (SMS) is the planning/routing tool for ground movements.

It addresses the routing and scheduling of aircraft and specific vehicles that could influence aircraft movements. It is related to the A-SMGCS routing function including planning aspects.

This system operates between:

- the stand allocation system supporting the efficient use of the gates; and
- the Runway management system supporting the efficient use of the runway(s) including HIRO procedures.

Surface planning automation functions will be integrated with approach/departure operations and will support time-based air traffic management concepts.

For arrivals, the arrival sequence for each runway and stand assignments will be used to make accurate estimates of arrival times at the stands. This information will improve aircraft handling and turnaround time.

For departures, engine start and push back times can be co-ordinated and managed to gain optimum departure sequencing, taking into account the planned route and departure fix loading. Also aerodrome configuration changes will be timed and implemented more efficiently, thereby minimising the impact on the aerodrome utilisation rate.

The surface movements manager (SMS) is to be considered as a combination of the Routing and Planning functions of A-SMGCS.

Taxi Route Conflict Detection System

The runway conflict detection or incursion detection system is specifically addressed to the sensitive area around the runway. By application of ICAO definition 55 this is only a part of the manoeuvring area.

The remaining part of the manoeuvring area which is the taxiway network and the traffic areas or aprons, could also be surveyed and protected with a conflict detection system.

The word "taxi route" is used here to integrate both the taxi lanes on the aprons and the taxiways between the aprons and the sensitive area.

A Taxi Route Conflict Detection System is a module which analyses the surveillance data coming from different sensors (in general the main sensor is a primary surface movement radar) and issues alarms to the controller when a potential conflict is detected inside the movement area.

This module is developed according to some rules defined by the Air Traffic Control.

According to the complexity of the airport configuration and to the level of false alarm to be reached, the definition of the rules and the conflict detection parameters setting can be more or less complicated.

[55] In ICAO Annex 14 definitions, the movement area is divided in the manoeuvring area (runway + taxiway network) on one hand and the traffic area (Aprons) on the other hand.

Taxiway Guidance System

The aim of the Taxiway Guidance System is to provide surface visual information to pilots during aircraft taxiing phase.

Its principle is based on the remote control (either manual from orders sent by the tower controller or automatic thanks to a computer-driven system 56) of taxiway centre line lights and stop bars. In addition, the system is able to monitor typical devices (lights and sensors) so as to determine their status at any time.

Two main technologies can be used to perform this control and monitoring:

- communication on serial circuit by coupling the control signal on the high voltage airfield lighting circuit; in that case, an interface is needed on the CCR's output[57]; and
- communication on separate data cable.

In both cases, an addressable monitoring and switching unit is to be connected to the secondary (low-voltage side) of the isolating transformer. The aim of this unit is to ensure the interface between a master connected to the airfield lighting controller (PC or PLC58) and the light (or group of lights) or sensor/detection device (e.g. microwave sensor, induction loop).

In an automatic system, the master - based on the input from the sensors - determines which groups of taxiway lights need to be illuminated to provide the necessary visual guidance to the aircraft's destination and detects potential routing conflicts between aircraft or incorrect aircraft turns.

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[56] The computer-driven system can be managed by an A-SMGCS software providing ATM functions such as surveillance, guidance and planning.
[57] Constant Current Regulator.
[58] Programmable Logical Controller.

Annex B Environmental Mitigation Benefit Technologies

This annex summarises the engine, airframe and aircraft environmental mitigating technologies assessed through the desktop exercise and technology workshops. It includes the following sections:

Desktop review and screening: The first part of the annex includes a list of the technologies that were reviewed and provides a summary of the technologies that were screened for taking to the workshop.

Technologies taken to Workshop: The second part of the annex provides detailed descriptions of the technologies taken to the workshop.

Other significant technologies: The third contains detailed description of technologies that were screened as significant but were not taken to the workshop.

Glossary: The final part contains a glossary of some key terminology used to describe the engine technologies in this Annex.

Desktop Review and Screening

The desktop review and screening process was used to limit and prioritise technologies to take to the technology workshop. This process included a literature survey and interviews and visits to key stakeholders from BAE systems, Rolls Royce, Cranfield University and Airbus.

The output of this process is summarised in Table 1 below and includes a list of the technologies reviewed together with brief description, prioritisation and an estimate of the period in which the technology is expected to first Entry into Service (EIS). Clearly EIS is dependent on numerous factors including interdependencies with other technologies and is therefore only a theoretical best estimate.

Technology	Entry Into Service	Brief Description	Screening Status
Staged Conventional Combustors e.g. DAC	Medium-term	Staged combustor for pilot and full throttle combustion	ααα
LPP Combustion technology	Long-term	Staged combusted with lean pre-mixed pre-vaporised fuel for reduced NO_x	ααα
Very High BPR Engines	Medium-term	Engines with very high BPR (>30), e.g. Unducted fan Engine	ααα
Active Noise Control	Long-term	Anti noise suppression or deflection technology to minimise tonal noise e.g. from engine fan	ααα
Composite material primary structures incorporating latest aerodynamic concepts	Long-term	Use of composite materials throughout the airframe, application of new manufacturing processes and introduction of Adaptive Aeroelastic Wings using smart materials and structures, actuators and digital control systems	ααα
Active laminar flow (control) systems	Long-term	Active laminar flow using suction systems for wing, fuselage, stabilisers and nacelles	ααα
Blended Wing Body	Long-term	Breakthrough aeroplane development combining wing and body	ααα
Advance Material & Cooling NO_x reduction technology	Short-term	Advanced cooling and materials technology for greater combustion control, e.g. tiled walled combustor	αα
Staged Combustor with lean burning	Long-term	Staged Combustor with lean burning for NO_x reduction	αα
Low NOx retrofit combustor (e.g. E-Kit NO_x Combustor)	Short-term	Retrofit low cost NO_x reduction combustor	αα
Reduction of aircraft noise by nacelle treatment	Medium-term	BRITE/EURAM supported technology development to reduce engine noise through negative scarfing, noise control and optimised acoustic liners	αα
Reduction of engine source noise	Short/Medium-term	BRITE/EURAM supported technology development on engine noise reduction at source focusing on turbo machinery noise	αα
Reduction of air frame and installation noise	Short/Medium-term	BRITE/EURAM project developing technology clusters to reduce air frame and installation effects using model scale and theoretical approaches	αα
Engines to generate electricity	Medium-term	Electricity generating engine to power auxiliary aeroplane systems	αα
Materials and turbo machinery improvements	Short-term	Development to improve thermal efficiency of aero-engines including increases of pressure ratio of compression, higher temperature hot section with reduced cooling and improved component efficiencies	αα
Geared Fan BPR Engines	Medium-term	European low emission recuperated engine (EULER)	αα
Micro-Electro Mechanical Systems	Long-term	Micro-electrical-mechanical systems (MEMS) to support application of innovative flow control devices, such as vortex generators.	αα

Technology	Entry Into Service	Brief Description	Screening Status
Non-Kerosene Fuelled Planes	Long-term	Breakthrough aeroplane development. For example cryogenic fuelled plane	αα
High Speed Rail	Long-term	Magnetic levitation high speed rail for journeys up to 1000km	αα
RBQQ Combustion technology	Long-term	Rich burn quick quench combustor consisting of three zones: Primary rich, dilution and lean burning zone	α
Combustion, materials and Turbo-machinery improvements	Short-term	Engine improvements for fuel efficiency covering core cycles, low weight materials, increased BPR (up to 10)	α
Landing gear Noise	Short-term	Operations and gear/flap optimisation to minimise landing gear drag and noise	α
Far Field Active Noise Control	Long-term	Far field active noise control using sensors and actuator technology	α
Advanced aluminium alloys for primary structures	Medium-term	Introduction aluminium alloys and aluminium-lithium composites for sections of primary structures, i.e. fuselage, wing and empennage, and composites for secondary structures	α
Propulsion Airframe Integration	Medium-term	Engine, nacelle and airframe integration to minimise drag and noise	α
Airframe riblets	Short-term	Attachment of riblets to fuselage, wing and tail in direction of airflow.	α
Advanced passive flow control devices	Medium-term	Vortex generators to enhance lift	α
Advanced manufacturing methods	Medium-term	Advanced manufacturing methods to improve fuselage and wing surface smoothness to reduce drag	α
Passive Laminar Flow airframes	Medium-term	Passive laminar flow concepts to create laminar flow, e.g. slotted airfoils, actively heated/cooled surfaces	α
Extended fly-by-wire systems	Medium-term	Extending fly-by-wire systems to include pitch stability augmentation and wing load alleviations	α
Supercritical wing technology	Medium-term	Supercritical wing technology to enhance and optimise cruise lift/drag	α
Advanced technology fuel cell APU	Medium-term	Fuel cell powered APU units	α
Box/Strut Wing	Long-term	Revolutionary aeroplane development based on a strut wing providing high aspect ratio	α
Double-Bubble Fuselage	Long-term	Revolutionary airframe development using double fuselage to increase lift	α
Winglets	Short-term	High-tech carbon graphite advanced blended design which gently curves out and up from the wingtip, reducing aerodynamic drag and boosting performance. Typically 5' to 14' tall	α

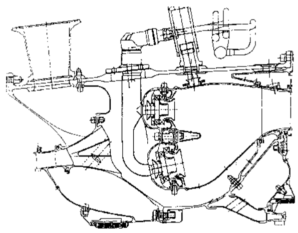
Table 1: Summary of technology screening: ααα = Assessed at workshop αα = Not taken to workshop but significant α = Not described further

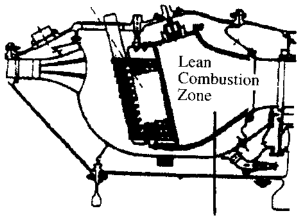
Technologies Taken to Workshop

This section details the environmental mitigation technologies that were discussed and assessed at the technology focused workshop (see Section 1 of the main report for details on the study approach).

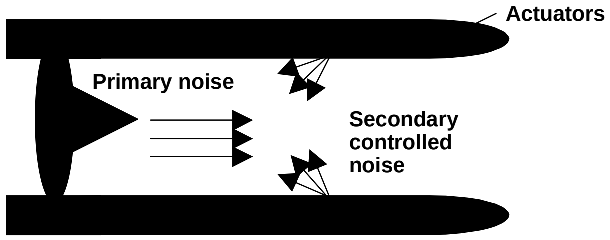
Each technology is described under the following headings:

Name/Timeframe:	Short name and predicted Entry into Service (EIS): Short (<2005), Medium (2006-2015), Long (2016-2030) term.
Technology Type:	Technologies are classified into the following categories: engine-combustion, engine-fuel efficiency, engine/airframe-noise, airframe-weight, airframe-aerodynamics and transport system.
Executive Summary:	Estimates of the capacity and environmental benefits (see Annex C and Sections 3 and 4 of the report for benefit definitions used) of the technology and Take-up potential classified into High, Medium and Low. Unless otherwise stated all environmental and capacity gains are relative to current technology.
Description:	Description of the technology together with the technical and operational basis for the predicted benefits.
Environmental and/or Capacity Benefits	Description, context setting and quantification of the expected capacity or environmental benefits of the technology.
Technology Take-Up	Description of the take-up issues affecting the likelihood of technology take-up, including investment costs, level of interdependence with other technologies, and match with business, Government policy and existing standards and constraints.

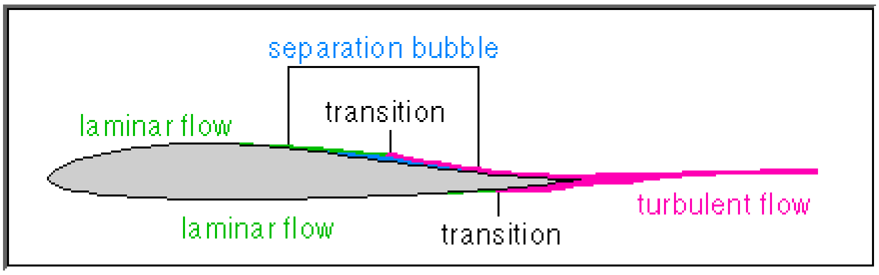
Name/ Timeframe	Staged Conventional Combustors for NO_x reduction / Short-term
Technology Type	Engine – Combustion
Executive Summary	*Capacity Benefit* – None *Environment* – 30% NO_x reduction *Take-up potential* – **High**. Initial designs already in service
Description	 Staged conventional combustors have been developed to improve or provide an additional degree of freedom between operational and emission requirements. The high power stage of the combustor optimises for low NO_x and does not have to cope with lower stability requirements, which are dealt with by bringing in other parts of the staged combustor as required. Low NO_x emissions are achieved with lean fuel/air mixtures, which reduce flame temperatures, and high throughout velocities, which reduce the residence time available to form NO_x.
Environmental and/or Capacity Benefits	Relative to current state-of the art baseline combustors, staged combustors in an engine having a pressure ratio of approximately 30 achieve approximately 30% reduction in LTO NO_x emissions. These levels equate to roughly 40% below CAEP/2 standards. The trade-off for improved NO_x performance is an increase in CO emissions and 0.3% reduction in fuel efficiency. The NO_x benefit is reduced in higher pressure ratio engines because of the increased competition for airflow to meet the conflicting requirements of durability and emissions.
Technology Take up	A few versions are already in production for medium pressure ratio engines, e.g. CFM56 and all manufactures are working on developments of this technology. There are however significant take-up issues relating to the technology relating primarily around the high development costs, additional complexity, and stringent safety requirements and low production volumes which prevent field trials and practically limit payback. It is not unusual to have a successful aircraft engine model that has a production volume of less than 100 units per year. Retrofitting an older engine model with one of these advanced combustors is technically feasible. However, it could involve significant engine modifications and entail a cost of about 1/3 of the price of a new engine. It is therefore likely that combustion system improvements of this type will be considered only for application in new production engine units.

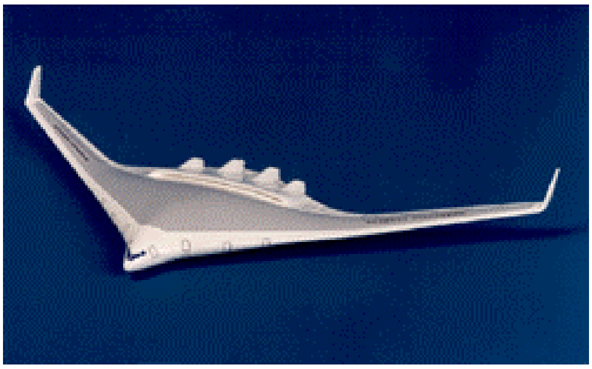
Name/ Timeframe	Staged Combustor with Lean Pre-mixed Pre-vaporised (LPP) Fuel for reducing NO_x / Long-term	
Technology Type	Engine - Combustion	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– Indirect only – 80% NO_x reduction – **Low** without central funding but increasing economic incentives for take-up after 2010.
Description	In lean premixing and pre-vaporising combustor technology the burning zone is fed with a lean and homogeneous fuel/air mixture that is just above the flame extinction limit. This approach results in a low flame temperature with enough  residence time to complete combustion and produce low NO_x. Maintaining uniform fuel/air mixtures throughout the Combustor is critical since NO_x increases rapidly with any local fuel/air maldistribution. In practise, pre-mixing is achieved with large numbers of small-diameter premixers.	
Environmental and/or Capacity Benefits	Relative to current state-of the art baseline combustors, LPP technology is estimated to reduces NO_x to 85-90% below CAEP/2 levels.	
Technology Take up	These combustors are primarily being developed for future supersonic engines with their relatively low engine pressure ratio and requirement for long periods at a single, high speed cruise operation. Application of this concept to future subsonic engines would be difficult because of the higher pressure ratio and the problems this may cause, e.g. flashback causing damage to the combustor. There are also significant challenges characterised through high development costs, additional complexity, and stringent safety requirements. Technical challenges also exist relating to variable geometry mechanics and new material developments. Apart from CAEP NO_x emission targets, some European countries now impose a scale of emission related landing charges at their airports (e.g. Zurich), which provides additional incentive to reduce emissions. Over the next 10 years regulations of increasing stringency are expected and their scope may be extended to include NO_x produced during cruise. Therefore beyond 2010 further demand for emission reduction is anticipated	

Name/ Timeframe	Very High By-Pass-Ratio Engines, e.g. Unducted Fan (UDF) / Long-term
Technology Type	Engine – Fuel Efficiency
Executive Summary	*Capacity Benefit*: – Indirect only *Environment*: – 25% fuel efficiency gain, rising to 30% if propulsive unit is integrated into new airframe – Risk of significant noise increase due to unducted fan. Effects remain largely uncertain. *Take-up potential*: – **Low**. Would require new development of engines, airframe and airport.
Description	Increasing the BPR improves the propulsive efficiency of the engine. At BPR>15, the duct must be removed to contain weight and drag. Unducted propulsers resembling large, swept propellers, with BPR of more than 30, have been flight tested and offer gains in propulsive efficiency of approximately 25% compared to modern transport engines.
Environmental and/or Capacity Benefits	Unducted fan (UDF) engines offer up to 25% fuel efficiency gains. However community and passenger noise considerations of such engines remain largely unresolved.
Technology Take up	UDF engines with large diameter propulsers (5-10m) are simply not feasible for installation on existing aircraft because they do not fit within the dimensional limits of the wing and landing gear. Consequently the introduction of UDF engines is restricted to new aircraft designs for which special accommodation of the propulsive unit can be made. There would be additional costs to adapt airport facilities to handle aircraft of markedly different layout.

Name/ Timeframe	Active Noise Control (ANC) / Long-term
Technology Type	Engine/Airframe – Noise
Executive Summary	*Capacity Benefit* – Indirect only. Given absolute noise limitations at airports ANC technology could provide additional capacity *Environment* – Noise reduction of 5-10dBA predicted in addition to noise reduction achieved by 2015. Airframe noise remains. *Take-up potential* – **Low**. Introduces significant capital and maintenance cost and only likely as part of a total aircraft package
Description	 **ACTIVE NOISE CONTROL** **(optimisation of far field radiation)** Active noise systems are designed to address major fan and engine noise sources. By actively producing anti-noise the systems aim to shift or cancel tonal noise sources. The technology is largely ineffective against broadband noise and therefore is not suitable for airframe noise sources.
Environmental and/or Capacity Benefits	ANC systems are predicted to reduce engine noise sources by 5 to 10 dBA in addition to any noise reduction obtained by 2015. The additional weight introduced by the ANC system may increment fuel burn requirements.
Technology Take up	ANC technology is currently under development and early demonstrations have been carried out by SNECMA. The technology is largely consistent with airline, airport operators and local concerns to minimise noise. However the technology remains largely uncertain and the capital and maintenance costs are likely to be significant. It is considered that the most likely route for introduction will be through new aeroplane developments that will incorporate new propulsion and airframe concepts.

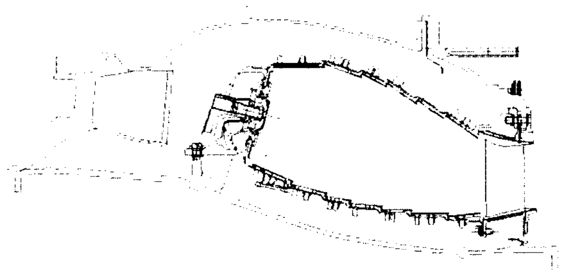
Name/ Timeframe	Composite Material Airframe Structures, Active Aerodynamic Wing (AAW) technology and Improved Manufacturing Processes / Medium to Long-term
Technology Type	Airframe – Weight
Executive Summary	*Capacity Benefit* – Indirect. Lower noise footprint may increment capacity *Environment* – Up to 30% fuel efficiency gain through improved drag and weight reduction (assumes application of composites and AAW) and reduced noise. *Take-up potential* – **Medium**. Significant barriers to certification and development costs
Description	Airframe weight reductions will be possible through introduction of composite materials. Nearer terms improvements will include improved aluminium alloys and aluminium-lithium composites for primary structures and composites for secondary structures, however in the longer-term technological advances will spread the use of composites to primary structures such as the wing. Improved manufacturing processes such as friction stir welding, rolling of jointless fuselage barrels and stitching of composite plies together are reducing number of parts, joints and fasteners and reducing overall weight and simplifying assembly. Composites can also enable new aerodynamic concepts such as NASA's Active Aeroelastic Wing (AAW), which aims to make the entire wing a control surface by taking advantage of its inherent flexibility. Active leading and trailing edge wing control surfaces will shape the wing to provide roll control, and the wing structure will no longer be burdened with stiffness requirements
Environmental and/or Capacity Benefits	The use of composite materials and application of Aeroelastic Wing technology is predicted to lower drag and result in a potential 30% reduction in take-off gross weight. Initial advances will involve weight reduction through replacement of secondary structures and longer term will involve use of composites throughout all the airframe structures, and adoption of AAW technology. Reduced airframe weight will also bring improved noise performance as may improved aerodynamics.
Technology Take up	For primary structures, the process of new material introduction is slow because of the certification process for structural design, material property characterisation, and safety issues, which involve lengthy and costly durability and strength test programmes. These factors are compounded by high development costs and external competing factors such as the cost of alternative materials. Nonetheless improved airframe performance characterised through lower fuel burn provides a financial driver for take-up of this technology. Boeing have produced a test section of a full scale all composite wing box which is expected to demonstrate production cost savings of 20% relative to conventional aluminium wing, while weighing 25-30% less. Whilst NASA are predicting to test AAW technology in 2001 on a Boeing F/A-18

Name/ Timeframe	Active Laminar Flow (control) Systems / Long-term	
Technology Type	Airframe – Aerodynamics	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– None – 15-20% reduction in drag, but fuel savings could be significantly compromised from this level due to increased weight and power requirements – **Low**: Cost benefits of the device remain uncertain
Description	 Smooth laminar flow over a body creates less drag than turbulent flow. Laminar flow research is carried out with two basic types of experimental devices; active and passive. Active test sections contain tiny holes or slots through which most of the turbulent layer of air is siphoned off by an integral suction system built into the wing. This decreases drag and enhances aerodynamic lift by either eliminating the turbulent airflow or reducing its effect. Data to control the laminar flow device is fed from sensors and other instrumentation built into or attached to the wing to measure airflow characteristics (especially the region of transformation from laminar to turbulent flow) and pressure distribution.	
Environmental and/or Capacity Benefits	Reduced drag of up to 15-20% is being predicted. However the net benefit in terms of reduced fuel burn could be reduced due to additional weight introduced to the airframe.	
Technology Take up	Active laminar flow devices are considered to be a high-risk technical challenge for full development and introduction. A key consideration remains the weight of the laminar flow system (and the power requirement) compared to the drag reduction over a typical journey. Contamination of the porous skin remains a significant practical challenge and introduces inefficiencies and high maintenance costs. Work in this field has not reached the point where the disbenefits outweigh benefits in the form of reduced fuel costs. Practical development remains dependant on CFD research and development of mathematical models of surface tension, multiphase flow, wear and turbulence, and fluid flow simulation. Extensive continues to be carried out by Airbus, which has been flying an A320 with a hybrid laminar flow fin since 1998.	

Name/ Timeframe	Blended Wing Body (BWB) / Long-term	
Technology Type	Transport System	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– Up to 800 passengers – Reduced noise and at least 30% fuel efficiency gain. – **Low**. Significant uncertainty remains on technical and commercial viability of design.
Description	 Breakthrough technology predicted to carry 800 passengers over 7000 miles at a cruise speed of approximately 560mph. BWB airframe combines the wing and body and offers shielded integrated engines, low wetted area to volume ratio, favourable span loading and huge volumetric capacity. Due to its highly integrated design, a multidisciplinary optimisation process is used to address technical issues in configuration design, aerodynamics, structures, propulsions and flight dynamics.	
Environmental and/or Capacity Benefits	Blended Wing Body research suggests significant cost and performance benefits over conventional configurations: a 30-50% percent increase in lift-drag ratio and a 10 percent decrease in the operating empty weight resulting in at least 30% reduction in fuel burn per passenger mile. Shielded engines offer significant noise reduction of at least 10dBA and higher altitude flying and reduced thrust during LTO offer additional noise reduction	
Technology Take up	Significant work is being carried out by NASA, Boeing and Stamford University in the USA funded by US Government. In the UK efforts are being led by Cranfield University. Validation of potential fuel burn benefits will require extensive full-scale testing. The principal challenges lie in the overall structural integrity of the oval pressure vessel, integration of propulsion and airframe, emergency egress (evacuation of passengers on land and water) and passenger acceptance. Airport compatibility is also an issue since the airframe may not fit within the 80x80m conventional footprint and may require terminal redesign and other infrastructure changes. Initial estimates are that a BWB concept could enter service after 2020, however, passenger size and range of the initial design remains unknown.	

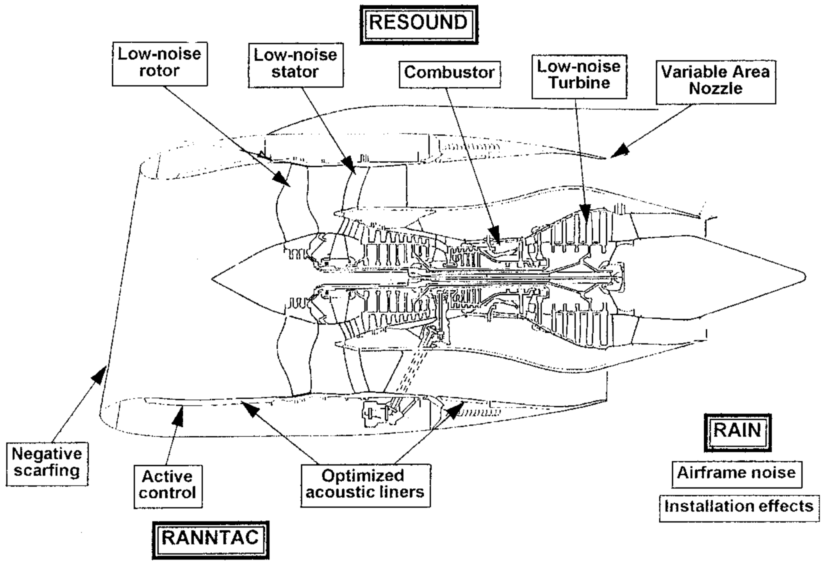
Other Technologies

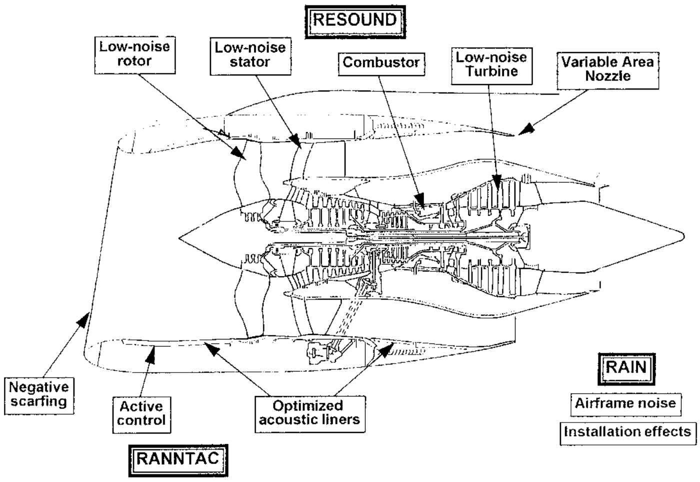
This section details the environmental mitigation technologies that were screened as significant but not taken to the technology workshop.

Name/ Timeframe	NO_x Reduction Combustion Technology – Advanced Materials and Cooling / Short-term
Technology Type	Engine – Combustion
Executive Summary	*Capacity Benefit* – None *Environment* – 10-20% reduction in NO_x emissions compared to today's technology *Take-up potential* – **High**: Under development by all manufacturers and variations already entering service
Description	 Near term combustor improvements are based on existing combustor designs, that incorporate changes to the liner and or fuel nozzle designs. Examples include the use of tiled walls and introduction of tiny angled effusion cooling holes
Environmental and/or Capacity Benefits	Near term combustor improvements are estimated to contribute between 10-20% reduction in NO_x emissions.
Technology Take up	Although this category of technology improvement entails relatively minor changes, the development and engine recertification process remains long. Since safety remains the overriding concern for aviation, the time and cost to introduce changes can be considerable. Nevertheless examples of this type of technology are now in production.

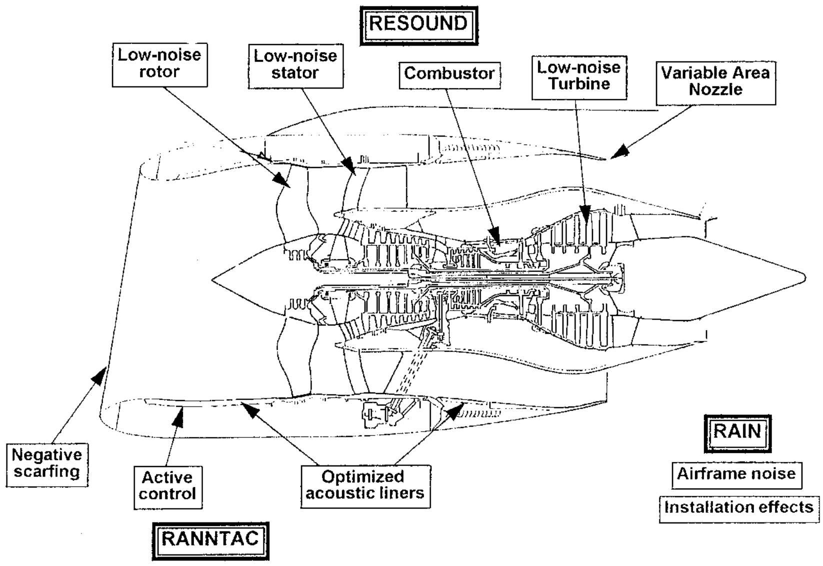
Name/ Timeframe	Staged Combustor with Lean Burning for NO_x reduction / Medium-term	
Technology Type	Engine – Combustion	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– None – Up to 50% reduction in NO_x emissions compared to today's technology – **Medium**: Already within manufacturers product plans
Description	Reductions in NO_x levels are being sought through optimisation of staged combustors (see Staged Conventional Combustors for NO_x reduction). This approach involves further improvements in fuel injection uniformity, better fuel/air mixing, reduction in combustor liner coolant flow (making more air available for combustion), and decreases in hot gas residence time.	
Environmental and/or Capacity Benefits	Reductions in NO_x levels by up to 50% are predicted. The trade-off for improved NO_x performance is an increase in CO emissions and 0.3% reduction in fuel efficiency.	
Technology Take up	Not withstanding recertification challenges the first examples of this type of technology now exist in manufacturer's product plans for the next 5 to 10 years.	

Name/ Timeframe	Low NOx retrofit combustor e.g. (Environmental Kit Combustor System) / Short-term	
Technology Type	Engine – Combustion	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– Indirect only – 25% NO_x reduction – **High**: Low cost retrofit option to high volume production/in service engine family (JT8D)
Description	The E-Kit converter uses a unique fuel nozzle and burner can system to optimise fuel mixing and airflow distribution. It is designed as a retrofit option for JT8D-217, 217A, 217C and 219 engine models. The 200 engine series is the successor to the original JT8D engine, which together make up the most successful jet engine family in commercial aviation with more than 14,000 produced.	
Environmental and/or Capacity Benefits	The E-Kit burner reduces NO_x emissions by 25%, unburnt hydrocarbons by 99% and smoke by 52% relative to current models.	
Technology Take up	The E-Kit offers a commercially viable option for retrofit and is suitable for a significant proportion of in service engines.	

Name/ Timeframe	Reduction of Aircraft Noise by Nacelle Treatment and Active Control (RANNTAC) / Medium-term
Technology Type	Engine/Airframe-Noise
Executive Summary	*Capacity Benefit* – Given absolute noise limitations at airports noise abatement technology could provide additional capacity *Environment* – 4 dBA engine noise reduction *Take-up potential* – **Low** without central funding.
Description	 As part of the 4th Framework programme, BRITE/EURAM 3 the RANNTAC project aims to acquire the technology necessary to support the development and manufacturing of turbofan engine nacelles featuring noise reduction devices. Specific technology elements are: negative scarfing, active noise control and optimised acoustic liners.
Environmental and/or Capacity Benefits	Technologies covered under RANNTAC aim to deliver –4dBA noise reduction.
Technology Take up	High research and development costs means it is necessary to adopt a partnership approach. The RANNTAC programme forms part of the X-NOISE thematic network that has been formed as a result of the EU Forth Framework Environmentally Friendly Aircraft study (TEFA). Such a combined effort is necessary to meet the challenge of the US industry, which is backed by a fully funded programme of 200MUSD over 7 years.

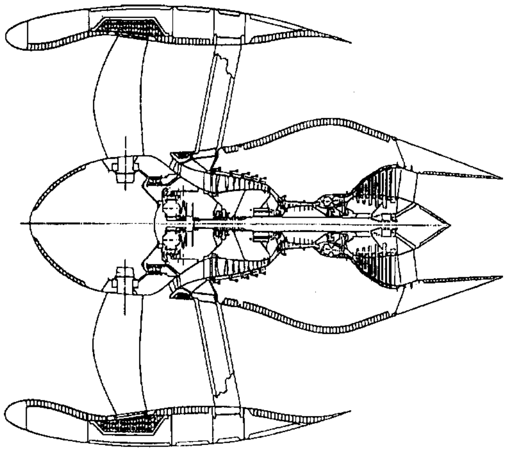
<table>
<tr><td>Name/
Timeframe</td><td colspan="2">Reduction of Engine Source Noise Through Understanding and Novel Design (RESOUND) / Short and medium-term</td></tr>
<tr><td>Technology Type</td><td colspan="2">Engine/Airframe-Noise</td></tr>
<tr><td rowspan="3">Executive Summary</td><td>Capacity Benefit</td><td>– Given absolute noise limitations at airports noise abatement technology could provide additional capacity</td></tr>
<tr><td>Environment</td><td>– 4 dBA engine noise reduction</td></tr>
<tr><td>Take-up potential</td><td>– Low without central funding.</td></tr>
<tr><td>Description</td><td colspan="2">


As part of the 4th Framework programme, BRITE/EURAM 3 the RESOUND project aims to acquire the technology necessary to support the design of derivative and new aero-engines with reduced noise levels. RESOUND addresses the challenge of reducing the noise at source, in particular turbomachinary noise, through 1) engine component aeroacoustic design and 2) through novel noise controlling devices that can be integrated within the engine structure. These technologies will include: fan noise reduction through reduced tip speed and pressure ratio optimisation, noise reduction with fan and stator axial sweep, circumferential lean fan noise reduction with variable by-pass nozzle and passive fan tip treatments, combustion noise reduction through improved and validated generation and propagation model assessment of potential noise hazards of low NO_x combustors, LP turbine noise reduction through exit guide vane design, turbomachinery noise reduction through active stator design, turbomachinery noise reduction by means of auxiliary aeroacoustic control devices.</td></tr>
<tr><td>Environmental and/or Capacity Benefits</td><td colspan="2">Technologies covered under RESOUND aim to deliver –4dBA noise reduction.</td></tr>
<tr><td>Technology Take up</td><td colspan="2">High research and development costs means it is necessary to adopts a partnership approach. The RESOUND programme forms part of the X-NOISE thematic network that has been formed as a result of the EU forth Framework Environmentally Friendly Aircraft study (TEFA). Such a combined effort is necessary to meet the challenge of the US industry, which is backed by a fully funded programme of 200MUSD over 7 years.</td></tr>
</table>

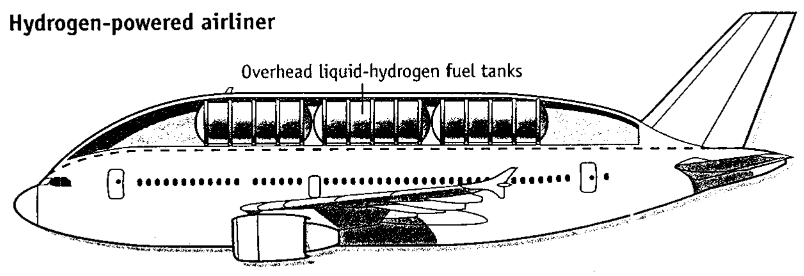
Name/ Timeframe	Reduction of Airframe and Installation Noise (RAIN)) / Short and medium-term		
Technology Type	Engine/Airframe-Noise		
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– Given absolute noise limitations at airports noise abatement technology could provide additional capacity – 5 to 10 dBA airframe noise reduction – **Low** without central funding.	
Description	 As part of the 4th Framework programme, BRITE/EURAM 3 the RAIN project aims to support the development of airframe and installation noise effects. Advanced analysis tools will be developed based on a sound theoretical approach at the component level. New improved model scale experimental noise databases will be established and used in the development and calibration of these new design tools. Full scale flight test data will be used to establish scale effects and for confirmation of the overall prediction capability.		
Environmental and/or Capacity Benefits	The project is executed to realise at component level reductions in noise of the order of 5-10dBA. Full impact will be realised when the airframe related technologies are integrated with that of the engine on an overall aircraft noise level basis.		
Technology Take up	High research and development costs means it is necessary to adopt a partnership approach. The RAIN programme forms part of the X-NOISE thematic network that has been formed as a result of the EU forth Framework Environmentally Friendly Aircraft study (TEFA). Such a combined effort is necessary to meet the challenge of the US industry, which is backed by a fully funded programme of 200MUSD over 7 years.		

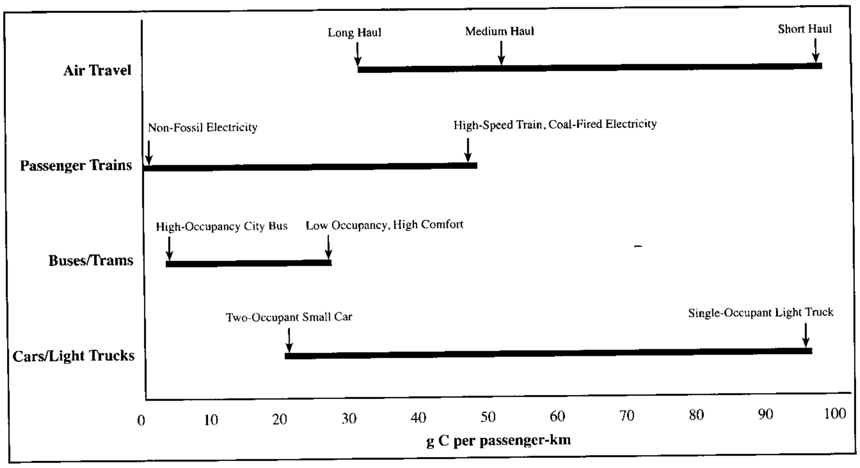
Name/ Timeframe	Engines to generate electricity to power auxiliary systems / Medium-term	
Technology Type	Engine – Fuel Efficiency	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– None – Up to 10% fuel efficiency gain – **Medium**. Currently under development. Fuel efficiency gains offer mechanism for payback.
Description	Engine development that generates electricity to power aeroplane auxiliary systems. This allows conventional pneumatic systems fed from the engine to be displaced through lighter electrical systems, thereby reducing aircraft Operating Empty Weight (OEW) and inefficient air-bleed requirement on the engine.	
Environmental and/or Capacity Benefits	Up to 10% fuel efficiency improvements are predicted from more electric aeroplanes powered by electricity generating engines. Reduced OEW also results in reduced airframe weight and therefore noise.	
Technology Take up	There is clearly a high degree of technology inter-dependence since the benefits of electricity generating engines can only be realised through airframe developments that feed on the generated electricity. More electric engines and aeroplanes are currently under development.	

Name/ Timeframe	Materials and Turbo-machinery Improvements for Improved Fuel Efficiency / Short-term	
Technology Type	Engine – Fuel Efficiency	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– None – 10% fuel efficiency gains in the short-term – **High to medium**. All manufacturers pursuing strategies to exploit fuel saving gains driven by operator demand.
Description	Developments to improve the overall efficiencies of aero-engines focus on incremental changes to raise core thermal efficiency and propulsive efficiency. In terms of propulsive efficiency relatively few options are available, the most practical is to increase the bypass ratio (enlarging the diameter of the propulsion). Working within the practical constraints of current designs (e.g. not requiring additional equipment) this can reach up to 10. In terms of thermal efficiency improvements the range of possibilities can be grouped into further increases in the pressure ratio of compression, higher temperature hot sections with reduced (or eliminated) cooling requirement, and improved component efficiencies. There are also opportunities to reduce the weight of aircraft engines through use of improved materials, improved aerodynamics (to reduce the number of turbine and compressor stages) and increased turbine entry temperatures (to reduce airframe thus core engine size required for a given output).	
Environmental and/or Capacity Benefits	Current studies suggest that the total gains from near term improvements in thermal, propulsive and weight saving efficiencies over current designs is in the order of 10% saving in fuel burn requirement.	
Technology Take up	Realisation of any or all of the above improvements will require substantial investments in a wide range of research and development fields including aerodynamics, cooling technology, materials, mechanical design and engine control. All manufacturers are pursuing strategies that exploit these improvements, however progress and success will be paced by the scale of investment by industry and / or Government supporting the work.	

Name/ Timeframe	Geared Fan Engine – European Low Emission Recuperated Engine (EULER) / Medium-term	
Technology Type	Engine – Fuel Efficiency	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– Indirect. Given absolute noise constraints could increment capacity – Reduced noise and up to 15% fuel efficiency gain – **Medium**. EULER type engine could be tested in four years' time, but unlikely to enter service before 2015.
Description	 MTU plan to develop a geared-fan "European low-emission recuperated engine" (EULER) with Snecma, Volvo and Fiat, as part of the European Union's Fifth Framework research programme. The principle involves feeding air from the LPC through a heat exchanger in the bypass flow, where it is cooled, and then fed into the HPC. Compressed air leaving the HPC is then passed though another heat exchanger in the engine nozzle, drawing heat energy from the exhaust gases, and back to the combustor.	
Environmental and/or Capacity Benefits	This technology could reduce fuel consumption and emissions by 10-15%. As well as boosting efficiency and reducing noise, the concept promises a 10-15% cut in engine weight.	
Technology Take up	The environmental benefits are, to a degree, offset by an increase in engine complexity. According to MTU, a EULER-type engine could be tested in around four years' time, but would be unlikely to enter service before 2015.	

Name/ Timeframe	Micro-Electro-Mechanical-Systems (MEMS) / Long-term	
Technology Type	Engine – Fuel Efficiency	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– None – Unknown but potential fuel efficiency gains – **Low**. Technology and cost benefits remain uncertain
Description	The development of micro-electro-mechanical systems (MEMS), under development in Europe and USA, promises to allow the use of innovative flow control devices such as vortex generators that can fold flat or align with the airflow when not required. They may also allow aerodynamicists to control turbulence using tiny jets of air to quell turbulent bursts in the boundary layer.	
Environmental and/or Capacity Benefits	Reduced drag associated with improved flow control will produce aerodynamic and associated fuel saving benefits, however estimates remain uncertain as does the net benefit since fuel burn gains could be reduced due to additional weight introduced to the airframe.	
Technology Take up	Flow control devices are considered a high risk technology development. A key consideration remains the maintenance cost, reliability and safety of the systems	

Name/ Timeframe	Non-Kerosene Fuelled Planes, e.g. CRYOPLANE / Long-term	
Technology Type	Transport System	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– Unknown – For hydrogen, the only primary combustion product is water and the only secondary emissions of potential significant are NO_x. There will be no CO_2, CO, Soot, unburned HC, SO_x, although water vapour contrail forming can contribute to greenhouse effects. – **Low**. Significant development, infrastructure, technical, safety and perception barriers.
Description	 Alternative fuels to Kerosene include ethanol, methanol, and liquid methane and hydrogen. Ethanol and methanol are liquid fuels that can be pumped and metered in conventional fuel systems, however they are impractical for aviation due to their very low heat content, in mass and volume terms. Of the cryogenic fuels hydrogen is more attractive from an emission standpoint since CO_2 and SO_x emissions would be eliminated.	
Environmental and/or Capacity Benefits	For hydrogen, CO_2 and SO_x emissions would be eliminated, however, water vapour would increase significantly despite the reduction in energy consumption. Nevertheless the net greenhouse effects of hydrogen assuming efficient hydrogen production are more favourable than Kerosene.	
Technology Take up	Introduction of alternative fuels to Kerosene that appear to be less environmentally detrimental are severely hampered by significant technical problems to adapting these fuels to current aircraft and airport infrastructures. The introduction of a new cryogenic fleet would require the design and development of a new fleet of aircraft and well as a new supporting infrastructure for the storage, handling and manufacture of the fuel. The feasibility of the cryoplane has been proven by the Tupolev Tu 155 (First flight in 1988). Russians are currently aiming for service introduction of LNG air craft in the near future whilst Daimler Benz aerospace are concentrating on the development of a hydrogen fuelled aircraft.	

Name/ Timeframe	Magnetic Levitation High Speed Rail / Long-term	
Technology Type	Transport System	
Executive Summary	*Capacity Benefit* *Environment* *Take-up potential*	– Offers alternative transport medium for journeys of up to 100km. – CO_2 gains are highly dependent on source of electricity, but on average offers significant savings in CO_2/passenger km over aviation. – **Medium**. Single routes becoming available. Larger network dependent on central funding.
Description	Alternative transport systems for short to medium haul journeys are becoming available in the form of high speed rail systems. These offer similar point to point journey times based on speeds of up to 420 km/hr.	
Environmental and/or Capacity Benefits	High speed trains offer reduced CO_2 per passenger km, although the size of the benefit is highly dependent on the form of energy used.  Source (IPCC,1999)	
Technology Take up	Magnetic levitation high speed rail links are being developed. In the medium-term single routes will become available, for example a commercial link between Berlin and Hamburg is planned for completion before 2015. Development of an integrated and comprehensive regional system however remains uncertain and highly dependent on central funding and future transport policies. Furthermore, outstanding health concerns around electromagnetic effects may hinder take-up.	

Glossary of Key Engine Technology Terminology

Terminology	Description
Bypass Ratio	The ratio of air ducted around the core of a turbofan engine to the air that passes through the core. For example, in a 6 to 1 bypass ratio engine, six parts of air pass around the core compared to one part that passes through it. In a high bypass ratio engine, the fan at the front of the engine develops the bulk of the engine's total thrust. The air that passes through the core or basic engine is called primary airflow. The air that bypasses the core is called secondary airflow. Bypass ratio is the ratio between secondary and primary airflow. High bypass ratio turbofans were developed for fuel efficiency. It is more efficient to accelerate a large mass of air moderately through the fan to develop thrust than to greatly accelerate a smaller mass of air through the core to develop the equivalent thrust.
Combustor or Burner	This is the section of the engine where the air passing out of the compressor is mixed with fuel, typically kerosene-based, and ignited. Fuel is introduced through an array of spray nozzles that atomise the fuel as in a home heating oil burner. An electric ignitor is used to begin combustion. The combustor adds heat energy to the core engine air stream and raises its temperature, which can reach 3,500 degrees Fahrenheit. This energy is extracted by the turbines and used to drive the compressors and fan. Any energy not extracted by the turbines is expanded through the exhaust nozzle to produce thrust.
Composite Materials	Metal alloys or plastics used in jet engines that contain filaments, foils or flakes of a strong material to increase their strength.
Compressor	The combustion of fuel and air at sea level pressure will not produce significant thrust. In order to produce thrust the air must be compressed or squeezed before the fuel is added. In a car engine this is done by the pistons inside the engine's cylinders and is referred to as compression ratio. In most jet engines a compressor is used. This is a series of spinning blades that continually compress the engine air stream and speed it up before it enters the combustor. A way to visualise this is to imagine a household fan with a long shaft and several rows of fan blades all turning together. As the air is compressed, it is forced into a smaller and smaller area as it passes through the compressor's stages, thus raising the pressure ratio. In the automotive world the compression ratio is typically 10-to-1. In a jet engine the compression ratio can be as high as 40-to-1. In most modern engines the compressor is divided into low pressure and high pressure sections which run off two different shafts.
Compressor Pressure Ratio	The ratio of the air pressure exiting the compressor as compared to that entering. It shows the amount of compression the air experiences as it passes through the compressor.

Terminology	Description
Core Engine	A term used to refer to the basic engine which includes the compressors, diffuser/combustor and turbines.
Diffuser	The diffuser is a large round structure immediately behind an engine's compressor and immediately in front of the combustor. It slows down compressor discharge air and prepares the air to enter the combustor at a lower velocity so that it can mix with the fuel properly for efficient combustion.
Engine Pressure Ratio	A method of measuring the thrust or power of an engine. It is not used by all engine manufactures. EPR (pronounced Eeeper) is the ratio of the pressure of the engine air at the rear of the turbine section as opposed to the pressure of the air entering the compressor. For instance, in a typical wide-body commercial aircraft engine, EPR might be 1.55 at takeoff and 1.39 at cruise.
Extended Twin Operations (ETOPS)	A certification granted by the Federal Aviation Administration and similar regulatory authorities that allows an aircraft to fly across water or remote land away from a suitable diversion airport. ETOPS is typically granted in increments of 90, 120 and 180 minutes. An aircraft with 180-minute certification can fly routes that at any given point can be three hours from the nearest suitable airport.
Fan	The large disc of blades, resembling an automobile fan, at the front of a turbofan engine. The fan takes in vast amounts of air and provides most of the engine's thrust.
Inlet Duct	The large round structure, installed by the aircraft manufacturer, at the front of an engine. The inlet duct presents air to the front of the engine in the most efficient, stable way possible to assure smooth engine operation. It must also be designed to have as little drag on the aircraft as possible.
Nacelle	The cylindrical structure that surrounds an engine on the aircraft. The nacelle protects the engine and improves aerodynamics. It contains the engine and thrust reverser and many other mechanical components that run aircraft systems.
Nozzle	The rear portion of a jet engine in which the gases produced in the combustor are accelerated to high velocities.
Thrust	Thrust is the measurement of engine power. Although it is difficult to equate this directly with the commonly used term "horsepower," multiplying an engine's maximum thrust rating by .62 will give a rough equivalent horsepower.

Terminology	Description
Thrust Specific Fuel Consumption	The pounds of fuel used per hour for each pound of thrust an engine produces.
Turbine	The turbine consists of one or more rows of blades mounted on a disc or drum immediately behind the combustor. The turbine extracts energy from the hot gases coming out of the combustor. The spinning of the turbine turns the shafts which run the compressors and the fan, as well as engine accessories such as generators and pumps. Like the compressor, the turbine is divided into a low- pressure and a high-pressure section. The high-pressure turbine is closest to the combustor and drives the high-pressure compressor through a shaft connecting the two. The low-pressure turbine is next to the exhaust nozzle and drives the low-pressure compressor and fan through a different shaft. The low-pressure shaft is the longest and fits through the hollow high-pressure shaft. Temperatures at the entrance to a turbine can be as high as 3,000 degrees Fahrenheit, considerably above the metal's melting point. Complex cooling schemes are required to keep turbine blades from melting. Many turbine airfoils are hollow so cooler air can be passed through them and out hundreds of small holes in the blade. In addition, some blades are coated with a ceramic thermal barrier.

Annex C Benefit Criteria

This annex provides detailed background data on the definition of the capacity and environmental benefits criteria.

Definition of Capacity Benefit Criteria

Capacity enhancement has been defined for passenger throughput and for aircraft throughput. Aircraft throughput can mean a wide range of different things, depending upon which phase of flight is being addressed. For this study, we have decided to relate aircraft throughput to the number of arrivals and departures at an airport since this is the major influence on airport capacity in the UK. Therefore, where a capacity benefit exists (e.g. in the approach phase) it needs to be related to the potential capacity improvement this could provide in terms of numbers of arrivals and departures at an airport. In this way, it is possible to make a simple qualitative comparison between the different technologies.

These benefit criteria are more closely defined in table C.1 below

Criteria	Definition
Capacity enhancement: Aircraft throughput	**Number of aircraft arrivals and departures per unit time at an airport or group of airports within a TMA** Typically, measures are provided for total and peak numbers of arrivals and departures at an airport. These measures depend upon many factors such as runway layout, whether considering a hub, major regional or smaller regional airport, ratio of arrivals to departures, weather conditions, operating restrictions, and so on. It is proposed to apply the most applicable combination of factors when assessing the potential capacity enhancement of the technology under study.
Capacity enhancement: Passenger throughput	**Number of passenger movements through an airport per unit time** In its simplest form, this is taken to be the sum of passengers arriving and exiting the airport, passengers entering the airport and departing and passengers in transit. The ratio of these different types of passengers will vary enormously between airports, hubs having many more transit passengers than regional airports. Typically, measures are provided for total and peak numbers of passengers handled by an airport. Although freight is not explicitly identified as a criterion, for this assessment it is related to passengers through 1 tonne of cargo being equivalent to 10 revenue passengers. It is proposed to apply the most relevant combination of passenger types and passenger measures when assessing the potential capacity enhancement of the technology under study.

Table C.1: Capacity Benefit Criteria

Environmental Benefit Criteria

A four step screening methodology is used to limit and define the final list of environmental benefit criteria and this is summarised in Figure C-1.

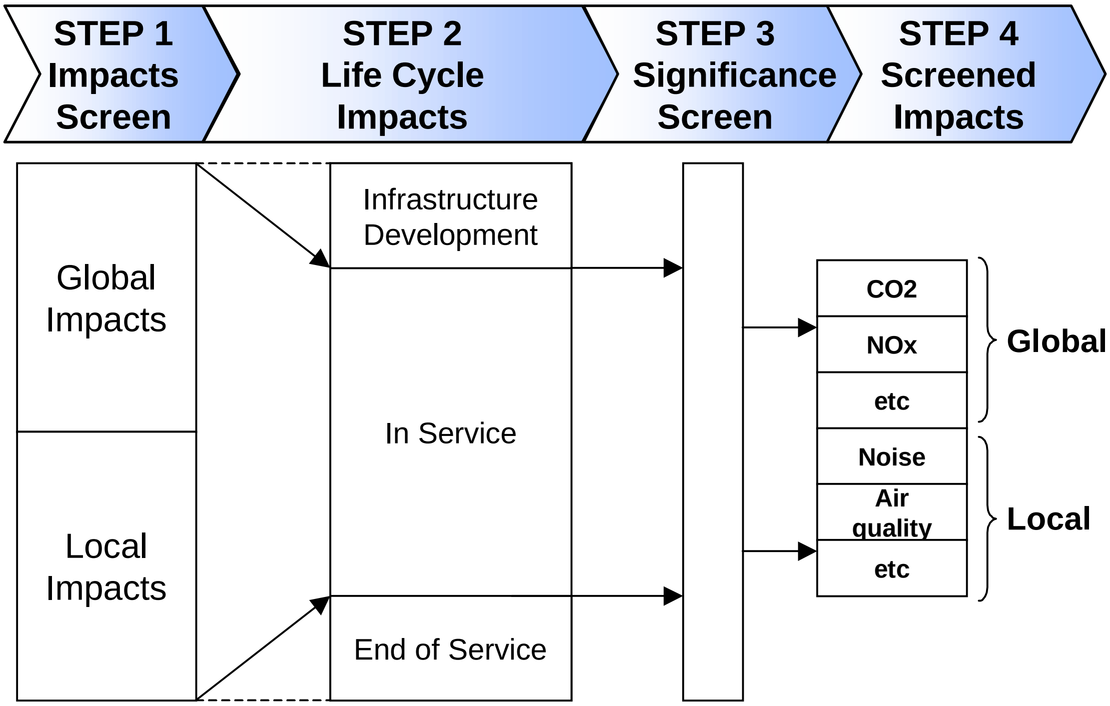


Figure C-0-1: Screening Methodology

The output from these steps is detailed below.

Step 1: Identify and describe the various and diverse impacts of the sector at a global and local level.

Section 2 describes the major impacts of the aviation industry. For the purposes of this study these impacts can be summarised as global (contribution to global warming potential and ozone depletion), and local (noise, local air quality, land take and intermodal integration).

Step 2 Consider the whole life cycle impact of the sector and conclude on the most significant life cycle stage.

The environmental impacts of aviation are varied and diverse. Following a classical life cycle approach to impacts suggests that these impacts can be spilt into the major life cycle periods of the industry. Given that the principal service of the industry is air travel (of passengers and freight) then the life cycle impacts of this service are:

Infrastructure development: Environmental impacts due to the building of airport terminals and intermodal transport systems and production of aeroplanes.

In service: Environmental impacts due to operation of airports, aircraft and transfer of passengers and freight to airports.

End of Service: Environmental impacts due to decommissioning of airports and disposal of aircraft.

Given the long in service lifetimes of the aviation sectors infrastructure (airports and aircraft) and in common with other transport services it is widely recognised that the significant environmental impacts of the aviation industry (certainly in excess of 90%) accrue during the 'in service' life cycle.

Therefore this study will focus on 'in service' impacts. Indeed this approach is consistent with current policy and also the primary concern of the industry's stakeholders. For example, review of the environmental reports of major service providers such as British Airways (BA, 1999) and BAA (BAA, 1999) illustrates the emphasis on 'in service' impacts as does major global studies such as the recent IPCC report (IPCC, 1999).

Step 3: Describe environmental impacts and characterise importance through overall impact, importance to stakeholders and degree of regulation.

The major local and global impacts of the industry reviewed as step 1 are analysed in terms of their overall effects and relevance to this study and are detailed in Tables C.2 to C.8. In this context relevance is characterised through the significance of the impact, degree of reporting (which is an indicator of stakeholder concern) and degree of associated legislation and regulations.

Step 4: Impact Screening

The final step involves defining performance indicators to describe the environmental benefits (mitigation potential) of aircraft and airframe technologies for impacts defined as significant (determined through step 3).

Tables C.2 to C.8 summarise the output of this four step screening methodology and therefore provide the basis for the environment benefit criteria used in this study and applied through the Technology Workshop.

Global climate change impact	
Description	Contribution to global climate change through aircraft emissions of CO_2, NO_x (forming ozone and reducing methane), H_2O, soot, sulphate and formation of contrails and cirrus clouds.
Regulation	Emissions from domestic (but not international) aviation are included in the amounts allocated to states agreed at Kyoto. The parties agreed at Kyoto to work through ICAO to limit emissions from international aviation.
Reporting of Performance	Fuel efficiency, CO_2 and NO_x emissions are reported by airlines and manufacturers (see for example British Airways,1999; Rolls-Royce, 1999a). Aviation is the first industry to be assessed through an industry specific IPCC special report (IPCC 1999)
Overall Significance	**High** :Although absolute amounts of CO_2 and NO_x emission compared to other anthropogenic activities are currently small (2-3%), these are forecast to increase disproportionately to other sectors due to air traffic growth
Benefit Criteria	Fuel Efficiency: An indicator of the amount of fuel and therefore global emissions (CO_2 and NO_x) required to transport passengers and freight a given distance. Combustion technology implies a trade-off between CO_2 and NO_x. CO_2 Intensity: Grammes of carbon dioxide emissions per passenger km. Studies show that CO_2 intensity of air transport varies between 30g per passenger-km (long haul) and 110 (short haul) (IPCC 1999) NO_x[59]: Percentage of CAEP/2 LTO NO_x limits achieved by aero-engine. Technologies that reduce NO_x emissions at high power, near the ground, also reduce NO_x levels at high altitude, though not necessarily at the same amount.

Table C.2: Global Climate Change Impact and Benefit Criteria

59 High level NO_x emissions act to decrease high level concentrations of Methane while also increasing concentrations of Ozone. Both methane and ozone are radiatively actively substances, however the decrease in methane does not necessarily cancel the increases of ozone since the geographical distribution of each of these substances differs. Changes in Ozone are mainly located near the flight routes in the Northern hemisphere, while those of methane are globally mixed. This implies that global emissions of NO_x continue to be a problem in the upper troposphere.

Solar Ultraviolet Irradiance	
Description	For a given solar elevation, the transmission of UV sunlight through the atmosphere depends on absorption, predominately by ozone but also by scattering and absorption by aerosols and scattering by clouds. Aircraft emissions have the potential to alter each of these processes, and hence to influence the solar radiation field at biologically relevant UV wavelengths.
Regulation	Indirectly only through engine certification regulations to limit NO_x, sulphate and soot emissions.
Reporting of Performance	Low
Overall Significance	**Low**: Ozone, most of which resides in the stratosphere, provides a shield against solar ultraviolet radiation. The IPCC (IPPC, 1999) report that the net effect of subsonic aircraft appears to be an increase in column ozone and a decrease in UV radiation, which is mainly due to aircraft. Although supersonic aircraft can significantly deplete stratospheric ozone and result in increased UV-B, future scenarios for growth of supersonic airliners within the 2030 timeframe of this study are not considered significant.
Benefit Criteria	N/A

Table C.3: Solar Ultraviolet Irradiance Impact and Benefit Criteria

Noise	
Description	Day and night time noise due to aircraft landing and take-off (LTO) and from airport operations.
Regulations	National and international frameworks exist to control aircraft noise at source and due to operation. Noise control at source falls under ICAO who are responsible for the introduction of noise certification limits for jet aircraft. Current agreements centre on phase out of non Chapter 3 aircraft by March 2002. Operational controls fall under chapters 78 and 79 of the civil aviation act 1982 and subsequent amendments and additions and control take-off noise, night time restrictions and other operational procedures.
Reporting of Performance	Indicators of noise performance are routinely reported by the major airport and airline operators, whilst the Department publishes noise contours for Heathrow, Stansted and Gatwick.
Overall Significance	**High**: Aircraft noise is and continues to be a key performance indicator influencing future development plans for Airports in the UK and worldwide. For example, Gatwick Airport has recently signed a section 106 legal agreement committing it to manage air noise so that the 57db Leg contour in 2008 (when passenger numbers are planned to be 33% higher than in 2000) is equal to 50% of that in 1996. (Gatwick, 2000)
Benefit Criteria	Noise is highly subjective, however the following quantitative measures are commonly used to assess noise pollution – The area and population within 57 leq noise contour around airports. – Total population affected by noise levels exceeding 94 dBA daytime and 87dBA night-time. – Aircraft noise level versus Chapter 3 standard. – Absolute dBA of engines and airframe

Table C.4: Local Noise Impact and Benefit Criteria

Local Air Quality	
Description	Aviation’s impact on local air quality. In terms of aircraft and airport contributors the most significant air pollutants are NO_x, PM10 and VOC emissions (BAA 1998).
Regulations	The Air Quality Strategy for England, Scotland, Wales and Northern Ireland sets objectives for eight main pollutants, including Benzene, PM_{10}, and NO_2, to protect health. These objectives have to be achieved by various deadlines, and the deadlines for Benzene, PM_{10} and NO_2 are 2003, 2004 and 2005 respectively. Part IV of the Environment Act 1995, introduced the system of local air quality management (LAQM). Under the LAQM system, local authorities have a duty to review and assess the current, and likely future, air quality in their areas, and to designate these areas, where air quality objectives are unlikely to be met, as air quality management areas (AQMAs). Engine emissions during the LTO cycle are also controlled through CAEP certification. The CAEP/2 certification standard applies to all new production from 2000 and CAEP/4 from 2002
Reporting of Performance	Air quality performance indicators are widely reported by airport authorities, airlines and manufacturers (see for example British Airways, 1999; Rolls Royce, 1999a; BAA, 1999a).
Overall Significance	**High** Future local authority planning permissions are likely to have increasing emphasis on maintaining and improving local air quality.
Benefit Criteria	It is difficult to model the air quality impact of individual technologies, however the following are possible benchmarks against which to judge the impact of technologies Airport technologies: The Air Quality Strategy for England, Scotland, Wales and Northern Ireland (UK AQS) specify maximum levels of pollutants. For airports the most relevant pollutants are NO_x, PM10 and Benzene emissions. Aircraft Technologies:CAEP/2 specify NO_x emission limits for aero-engines operating under different conditions (idle, cruise and take-off thrust) and apply to engines entering service in 2000. Technologies are often rated by their relative performance to the CAEP/2 target, e.g. % NO_x CAEP/2.

Table C.5: Local Air Quality Impact and Benefit Criteria

Land Take[60]	
Description	The impact of airport operations on the use of local land, in particular the development of Greenfield land and disturbance to local population.
Regulations	Local planning restrictions apply as does Government policy to restrict the development of Greenfield land.
Reporting of Performance	Land use is not directly reported by airport authorities, although alternate performance measures such as reporting by BAA (BAA, 1999) on construction, contaminated land strategy and community disturbance are quasi indicators.
Overall Significance	**Medium**: Limiting Greenfield site development is focal to future Government policy.
Benefit Criteria	Measures include passenger throughput per m^2 of airport and reduction in number of people disturbed by airport operations.

Table C.6: Land Take Impact and Benefit Criteria

Intermodal Integration	
Description	Intermodal integration of airport facilities with other transport mechanisms. Most air trips are automatically multimodal because of the necessity to travel to and from the airport. The local and regional traffic thus generated is in itself a major source of air pollution, noise and congestion. Indeed efficient public transport between airport and city centres is not only a requirement on environmental grounds, it also lowers the risk of delay through congestion and reduces parking requirements
Regulations	The UK Government's Integrated Transport Policy.
Reporting of Performance	Airport authorities report on the number of passengers and employees using public transport and indicate that they encourage greater use of public transport.
Overall Significance	**Medium**: Congestion and associated time loss and air quality impacts remain high on the agenda of local residents and authorities. Pressures are increasing on UK airport authorities to tackle the problem, and to adopt intermodal solutions found in continental airports such as Schiphol.
Benefit Criteria	Outside the main scope of this study, however, indicators should model knock-on environmental effect of a technology on other transport mechanisms which interface with air transport. For example, impact on the percentage of passengers and employees travelling to and from airport by public transport.

Table C.7: Intermodal Transport Impact and Benefit Criteria

[60] Land take issues apply to all life cycle stages and are not limited to the 'in-service' life cycle.

Water, Waste, Visual, Energy, Ecology	
Description	Airport and airline environmental performance in terms of energy efficiency, waste disposal, impact on sensitive ecology and water emissions
Regulations	Local authority regulations on water, land contamination and waste.
Reporting of Performance	Published by airport authorities and main airlines (see for example British Airways, 1999; BAA, 1999a).
Overall Significance	**Low**: The overall impacts of aviation on water, waste and energy impacts at the local level tend to be controlled through environmental management systems and absolute impacts are not significant within the context of this study.
Benefit Criteria	N/A

Table C.8: Other Local Impacts and Benefit Criteria

Annex D Study Terms of Reference

The Department's terms of reference for the study are copied below for reference. Text which does not address study context, objectives, approach or boundaries is not included.

Introduction

The Department wishes to commission a study of future technology developments in the aviation industry and their potential impact on the way air transport services are provided in the UK. The work forms part of a programme of preparatory studies which the Department is commissioning to support development of a new airports policy statement announced in the Government's Transport White Paper "*A New Deal for Transport*" in July 1998.

The Remit

The Department recognises the significant contribution made by the aviation industry both directly and indirectly to the UK economy, but also recognises the existing and potential environment impacts associated with air transport. In order to assist it in drawing together a new policy framework, it has commissioned a range of studies evaluating the demand for, and facilities available to, air transport in each of the major regions of the UK.

The Department now wishes to investigate the likely impact of changes in technology on the demand, development and operation of air services to, from and within the UK; and to identify possible policy responses to reflect such technology developments. The study is not intended to review the technologies themselves, nor to become involved in ongoing research programmes, but to enable the Department to gain an understanding of their potential contribution in three key areas:

– enhancing airport capacity,

– mitigating their environmental impact, and

– the implications of the above for prospective Government policy.

The study will seek to draw together in one report an understanding of the key technology developments which are in prospect across the aviation sector, the potential benefits in terms of enhanced system capacity (airport and ATC) and environmental mitigation they could deliver and the likelihood and time-scale of their implementation. Given the range of technologies under development, a fundamental aim of the study will therefore be to identify those technological developments that are most likely to make a substantial difference to future airports policy.

Scope of Work

Sub-paragraphs (i) to (iv) below describes in more detail the work which The Department invites consultants to tender to carry out.

(i) Key Objectives

The study will concentrate on looking forward at significant long-term technology developments within the air transport industry and associated sectors which could affect two key areas of particular relevance to airport policy:

- Future capacity (growth, development, operations, service standards, access), and;
- The environmental impact of the industry (noise, local air quality and climate change effects).

The study should cover the period until 2030, the approximately time horizon of the proposed airports policy statement.

(ii) Identification and assessment of technology improvements

The study will seek to identify and assess those technological developments which are likely to have the greatest impact, both positive and negative, on capacity and / or the environment. The study will need to consider impacts on a range of interests having regard both to the time scales of any impacts and their geographical coverage.

The study should concentrate on areas where there is a role for Government action or which will affect Government policies on capacity and the environment. It should identify potential policy responses for the Government to consider – the aim being to maximise the potential positive effects for each of the UK interests and minimising any negative impact, whilst considering the international context both within the EU and ICAO. These responses will need to recognise the need for flexibility and for managing risk and change in an uncertain and rapidly changing industry which is subject to international as well as local influences.

(iii) Regulatory Issues

The study must consider how the benefits of any technological developments identified might be introduced, determine whether there are any institutional or international barriers to such developments, and suggest how these might be resolved.

The study should consider the extent to which economic instruments or regulatory policy at international, regional, national and local level could encourage or delay their implementation.

(iv) The scale and level of the study

The Department expects the appointed Consultants to produce work which is high level and strategic in nature. The study should include an assessment of the likely technological developments that might be developed and how changes in technology might subsequently impact on associated/interface areas.

The appointed Consultants will collate and access existing knowledge and add value to it efficiently, objectively and with clarity to assist the Department in drafting a fully integrated policy.

Working Methods

It is anticipated that the chosen consultant will draw from the following techniques as part of the research for the study:

- Desk research reviewing industry and academic papers, seminars and conference proceedings.
- Discussion with a selection of the major stakeholders in the industry drawn from:
  - Airlines (and their representative groups)
  - Airports (and their representative groups)
  - Aircraft and Engine manufacturers (and their representative groups)
  - Air Traffic Control operators and equipment suppliers
  - Alternative service providers e.g. high speed rail, remote baggage facilities etc.
  - Academic institutions
  - Directorate of Airspace Policy
  - Environmental groups
- A series of topic based seminars for experts from airlines, airports, manufacturers, commerce and academia. Each session would include a presentation of a summary of the desk research and research visits undertaken beforehand and would be designed to focus future work.
- A "Hot House" think tank off-site with a group of experts drawn from Government/industry/commerce/academia, invited to give “evidence” to a panel drawn from the consultants and client groups.
- A survey of a broader group of stakeholders covering hard (e.g. runway/terminal etc.) and soft (e.g. "e" tickets etc.) issues/opinions on the likely impact of technology on the industry; how it should be put to best use, and the policies Government should enact to achieve this.
- An open seminar to present, discuss and review the studies emerging findings.

The aim is to develop a participative methodology where clear experience can be gathered and set in context with wider opinion on what is needed and how Government should respond.

Annex E Workshop Design and List of Study Participants

Workshop Design

A central element to the studies approach were two one day participative workshops. The first of these, the technology workshop, addressed the performance characteristics of selected capacity and environmental technologies (screened through tasks 1 to 3 of the study methodology and summarised in Annex A and B) and take-up issues. The second workshop, the issues workshop, focused on the wider implications of growth of the industry, the capacity and regulatory constraints this could impose and the implications for technologies development and Government policy. Each workshop is described in more detail below.

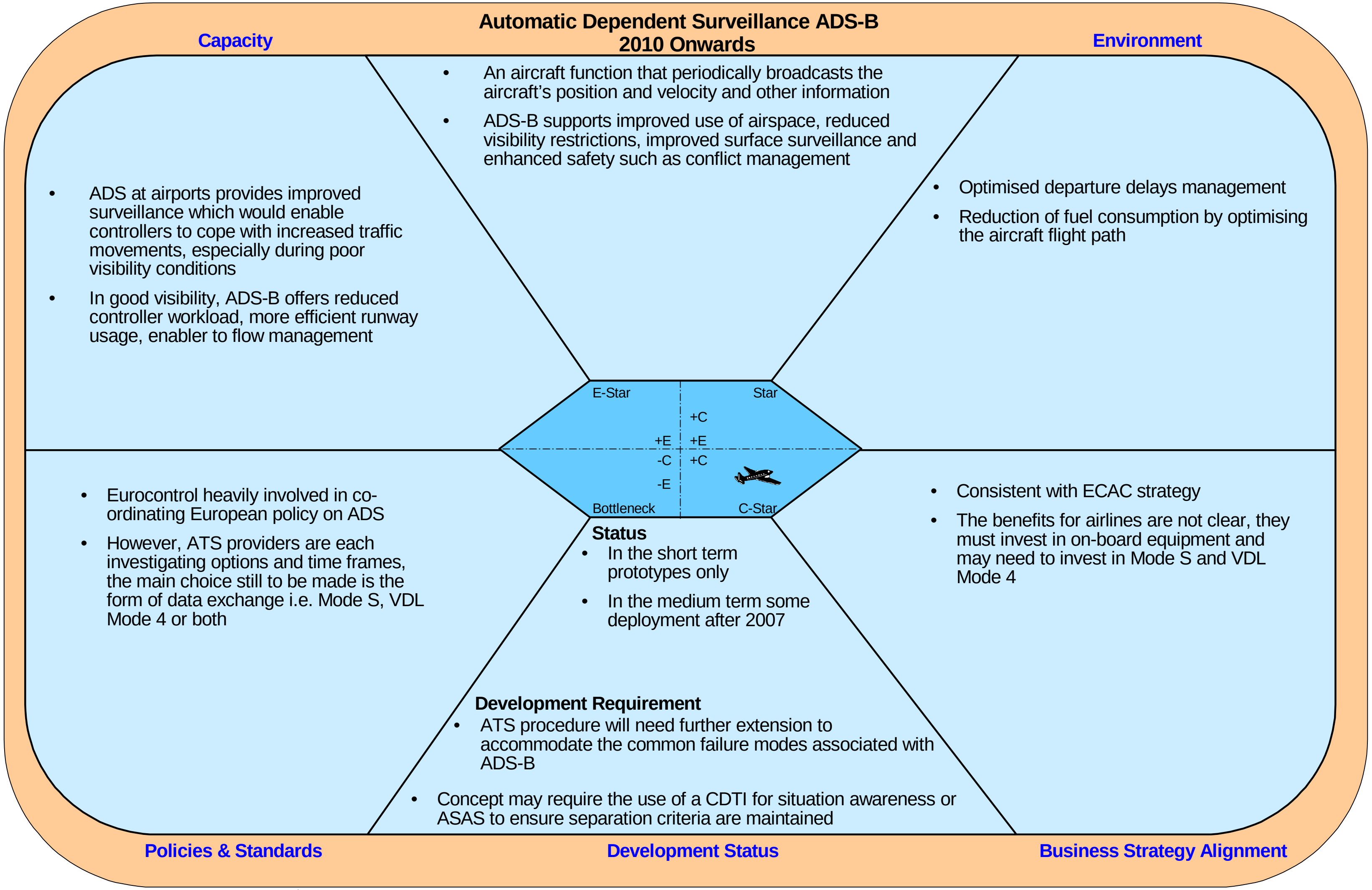
Technology Workshop

The objective of the technology workshop was to assess a sample of the most promising technologies to:

- Confirm their potential for capacity enhancement
- Confirm their potential for environmental mitigation
- Establish their potential environmental impact
- Use a simple scoring mechanism to gain a relative view of the most promising technologies

To facilitate this process each technology (technologies taken to the workshop are described in Annex A for capacity and B for environmental technologies) was described in the workshop through a visual and powerful template summarising the technology's environmental and capacity performance and take up issues. Figure E-1 illustrates an example template used in the workshop. The results from this workshop are summarised in a separate document (Arthur D. Little, 1999a).

Figure E-1: Example technology template



Issues Workshop

The objective of the issues workshop was to identify the key issues surrounding the take-up of future technologies in the context of:

- Acceptability of the environmental impact
- Sustainability of the capacity growth
- Major influences on the take-up of new technologies
- Prospective role for future Government policy

To facilitate the exercise four scenarios were developed to address the key issues underlying development and take-up of future technologies. These scenarios were described through two orthogonal axis, one relating to environmental regulation and the other to technological advances and their likelihood of take-up. Figure E-2 describes these scenarios.

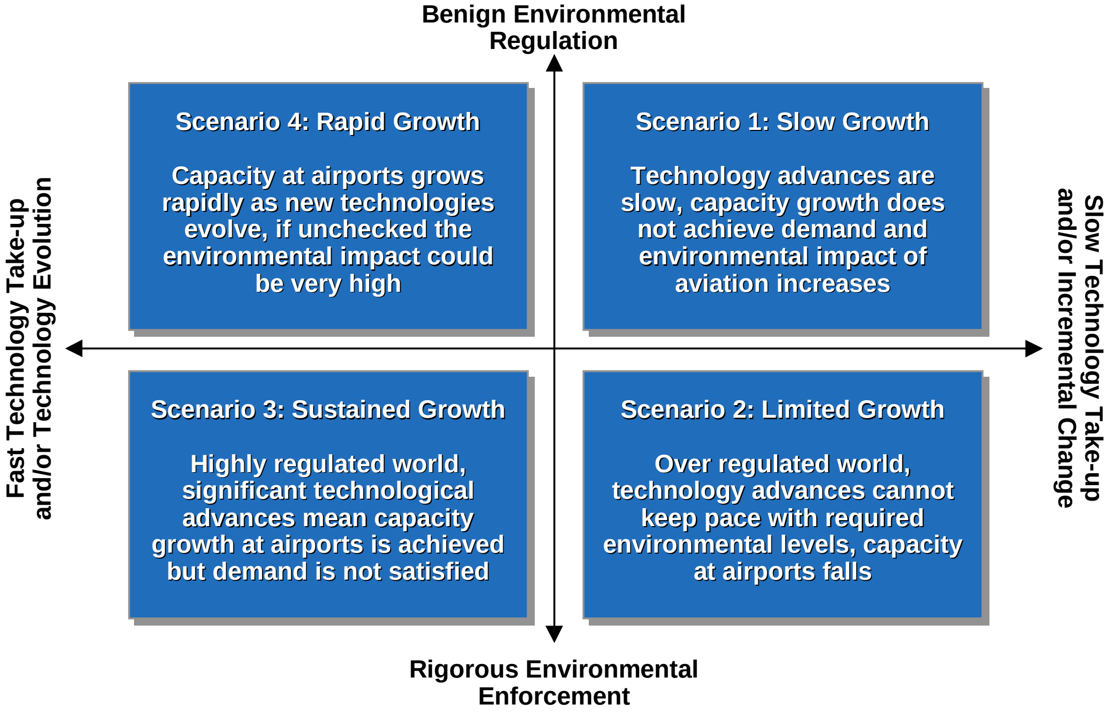


Figure E-2: Workshop Scenarios

With reference to Figure E-2 the context for the first scenario is intended to represent technology advances in line with what is anticipated today. For the second scenario the context represents a drop-off in demand with 'pricing' as the main signal to service providers and customers forcing, perhaps, the take-up of alternative modes of transport. The context for the third scenario is also one of strong regulation but either as a result of technology evolution or the way in which regulation is applied the industry is still able to expand capacity. For the fourth scenario the context is where capacity requirements are the dominant driver and technology advances are aimed primarily at satisfying demand, possibly at the expense of environmental factors.

To ensure comprehensive breadth of stakeholder views were expressed the workshop participants were split into three groups with each group being asked to represent a different "selfish" stakeholder perspective, and to change this with each scenario. This "rota" is summarised in Table E-1 below.

Scenario	**The "Selfish" stakeholders**		
	Group 1	Group 2	Group 3
Slow growth	ATS providers	Airlines	Airport operators
Limited growth	Airport operators	Local authorities	Aircraft manufacturers
Sustained growth	Aircraft manufacturers	Regulators	Airlines
Rapid growth	Airports operators	ATS providers	Airlines

Table E-1: Stakeholder Perspectives by Scenario and Group

Working within the scenario definitions and selfish stakeholder perspectives, each group was facilitated using a structured but participative process. To ensure that each scenario would be provocative and would therefore stretch the delegates thinking each scenario was further qualified through a "dominant issue" and hypothesis.

Working within these common definitions each group was asked to:

– List the issues that make the scenarios' hypothesis true and not true

– Decide on the top two to three priority issues,

Each priority issue was then addressed from the "selfish" perspective to determine

– The evidence underlying the issue

– what the "selfish" stakeholder group could do to address the issue, and

– what the role for Government should be.

Table E-2 provides and example output from this process.

This process therefore provided a flexible yet structured process to identify important issues relating to capacity enhancement and environmental mitigation from different stakeholder perspectives and importantly to define solutions in terms of what the stakeholder themselves can do and the role for Government. The output from the issues workshop is captured in a separate document (Arthur D. Little, 1999b).

Stakeholder Perspective	ATS providers	
Scenario 1:	**Technology advances are slow, capacity growth does not achieve air travel demand, and environmental impact of aviation increases.**	
Hypothesis	**The extent and pace of technology advances in ATC will lag behind what is needed to satisfy demand**	
ISSUES:	**No one sets the long-term ATC vision**	**There is no competition for ATC provision**
Evidence:	No coherent vision across all stakeholders	• There are no purely private ATC providers.
What can we do	• Accept always in catch up mode. • We need a concept of SLA's. • Minimise the number of aircraft flying specific routes - fewer, bigger aircraft will reduce delays. However, if the commercial backdrop for ATS provision changes, e.g. become commercial, this selfish viewpoint could change and ATS would press for more slot take up – need regulation.	• Introduce greater flexibility to enable aircraft to route through different airspace, but need to include a time element to improve efficiency. • Find ways to get multiple providers and still optimise airspace usage. • There is a desire to reduce the number of ATC providers which is counter to the wish to increase competition.
How we can do it	• The other stakeholders need visions that are more predictable, so ATC can plan. • Need to promote mobility so that airline self interest is not the driver for some journeys, therefore increase availability of slots for journeys that can only be done by aircraft (at the expense of journeys that can be done by, say, rail). • Reaction of the carriers will be to further coalesce and for schedule rationalisation.	• Overlapping service provision is the key but there are nationalistic issues. • Allow service organisations to bid for FIRs.
Role for Government	• Strong view that there is a need for an aviation policy. Last done in the 80s. High time to look at it again and look at an integrated approach	• Government must be prepared to say that they will permit others to provide ATC over the UK. • Selfish view: level playing field, therefore the incumbent ATC provider must also be allowed to compete for provision of services in other's airspace. • Government must progress privatisation.

Table E-2: Summery Output from Issues Workshop

List of Study Participants

The table below summarises the organisations and participants interviewed as part of this study.

Interviewee	Organisation	Technology Area
Philippe Renaud	Eurocontrol	Communications technology, including datalink
Nick Loghides	Eurocontrol	Head of Airport Operational Team (Airport – airside)
Gerard McAuley	Eurocontrol	Airspace design/modelling
Adrian Magill	DERA	Routing
Patrick Abbott	Eurocontrol	Communications technologies (inc. A/G datalink) and information flow, gate-to-gate
Patrice Behier	Eurocontrol	Communications and information flow (inc. A/G and A/A), gate-to-gate
Paul Seaton	Computer Sciences Corporation	Smart ticketing, automatic passenger check-in, tracking and baggage tracking
Andrew Harvey	Eurocontrol	Real-time ATC simulation
Colin Beesley	Rolls Royce plc	Company environmental strategy, CAEP market based options
Paul Madden	Rolls Royce plc	Pollutant emissions reduction focussing on NO_x technology
Bryn Jones	Rolls Royce plc	Pollutant emissions reduction focussing on NO_x technology
Joe Walsh	Rolls Royce plc	Noise technology and fleet noise improvement
Mike Provost	Rolls Royce plc	CO_2 reduction technologies and future whole engine design
Peter Potocki de Montalk	Airbus	Air Traffic Systems
Dr Rainer Von Wrede	Airbus	Environment performance
Thomas Rotger	Airbus	Airbus A3XX development
Christine Bickerstaff	Airbus	Environmental performance: emissions and noise
Peter Bruce	BAe Airbus	Regulatory and market options, airframe technologies
Graham Stamp	NATS ATMDC	ATC technologies (*en-route*)
Andrew Price	NATS ATMDC	ATC technologies (*en-route*)

Interviewee	Organisation	Technology Area
Neil May	NATS	ATC technologies (airports)
Rob Hunter	NATS	ATC technologies (airports)
Brandon Chapman	NATS	ATC technologies (airports)
John Turnbull	NATS	Communications technologies
Peter Havelock	NATS	Environment
Bill Armit	CAA	Airspace design
Martin Dixon	British Airways	Smart technologies
Rob Stewart	Eurocontrol	EATMP future technologies
Henk Hoff	Eurocontrol	Strategic Performance Analysis and Forecasting

The table below summarises the organisations and stakeholder groups represented at the technology and issues focus workshops.

STAKEHOLDER GROUP	REPRESENTATION
Airlines	British Airways Virgin Britannia Air2000
Airport Operators	BAA Manchester
European Bodies	Eurocontrol
Research Institutes	Cranfield College of Aeronautics
Aircraft, Engine and Airframe Manufacturers	Rolls Royce Airbus (Toulouse) Boeing BAe Airbus (Filton)
Regulators	CAA
Interest Groups	Aviation Environment Federation Strategic Aviation Special Interest Group
Policy Advisers	The Department DTI

Annex F List of References

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Annex G Glossary of Abbreviations

AAW	Active Aeroelastic Wing
ACARS	Aircraft Communication Addressing and Report System
ACAS	Airborne Collision Avoidance System
ACC	Area Control Centre
ACDA	Advanced Continuous Descent Approach
ADS-B	Automatic Dependent Surveillance Broadcast
AEA	Association of European Airlines
AED	Aviation Environmental Division
AILS	Airborne Information for Lateral Separation
AIMS	Aircraft Information Management System
AINSC	Aeronautical Industry Service Communications
AMS	Arrivals Management System
ANC	Active Noise Control
ANDES	Aircraft Noise Design Effects Study
AOC	Aeronautical Operational Communications
APALS	Autonomous Precision Approach and Landing
APP	Approach
APU	Auxiliary Power Unit
AQMA	Air Quality Management Area
AQS	Air Quality Strategy
ASAS	Airborne Separation Assurance System
ASK	Available Seat Kilometre
A-SMGCS	Advanced Surface Movement, Guidance and Control System
ATAG	Air Transport Action Group
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Service
ATSC	Air Traffic Services Communications
AVOL	Airports Visibility Operational Level

AVPAC	Aviation VHF Packet Communications
BA	British Airways
BAA	British Airports Authority
BDS	Comm B Data Selector
BPR	By-Pass-Ratio
BWB	Blended Wing Body
C/A	Coarse Acquisition
CAA	Civil Aviation Authority
CAEP	Committee on Aviation Environment Protection
CANSO	Civil Aviation Navigation Services Organisation
CARFM	Conference on Airport and Route facility management
CDA	Continuous Descent Approaches
CDG	Charles de Gaulle
CDTI	Cockpit Display of Traffic Information
CFD	Computational Fluid Dynamics
CFMU	Central Flow Management Unit
CIP	Convergence and Implementation Programme
CMU	Communications Management Unit
CNS	Communications Navigation and Surveillance
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CODA	Central Office for Delay Analysis
CPDLC	Controller Pilot Data Link Communication
CSMA	Carrier Sense Multiple Access
CTOT	Calculated Take-Off Time
DAC	Dual Annular Combustor
dBA	A-weighted Decibel
DCL	Departure Clearance
DETR	Department of the Environment, Transport and the Regions
D-FIS	Data Link Flight Information Service
DGNSS	Differential Global Navigation Satellite System
DGPS	Differential GPS
DGS	Docking Guidance System
DME	Distance Measuring Equipment

DME/P	Precision Distance Measuring Equipment
DMS	Departure Management System
DoD	United States Department of Defence
DPS	Data Processing System
DTI	Department Trade and Industry
EATCHIP	European ATC Harmonisation and Integration Programme
EATMP	European Air Traffic Management Programme
EATMS	European Air Traffic Management System
ECAC	European Civil Aviation Conference
EGNOS	European Geostationary Navigation Overlay System
EIS	Enter into Service
ELM	Extended Length Message
EULER	European Union Low Emission Recuperated Engine
EMM	Electronic Moving Map
ETOPS	Extended Twin Operations
ETSI	European Telecommunications Standards Institution
EU	European Union
EUROCONTROL	European Organisation for Safety and Navigation
EVS	Enhanced Vision System
FAA	Federal Aviation Administration, USA
FADEC	Full Authority Digital Engine Control
FANS	Flight Air Navigation System
FAST	Final Approach Spacing Tool
FDPS	Flight Data Processing System
FLIR	Forward Looking Infra Red
FMS	Flight Management System
FOG	Fibre Optic Gyro
FRAC	Free Route Airspace Concept
FUA	Flexible Use of Airspace
GBAS	Ground Based Augmentation Systems
GDP	Gross Domestic Product
GEO	Geostationary Earth Orbit
GES	Ground Earth Station
GICB	Ground Initiated Comm B

GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GTG	Gate to Gate
GUS	Ground Uplink Stations
HC	Hydrocarbon
HUD	Head Up Display
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ICCAIA	International Co-ordinating Council of Aerospace Industries Association
ID	Identifier
IFR	Instrument Flight Rule
ILS	Instrument Landing Systems
INMARSAT	International Maritime Satellite Organisation
INS	Inertial Navigation System
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention & Control
ISO	International Standards Organisation
JAA	Joint Aviation Authority
LAAS	Local Area Augmentation Systems
LAQM	Local Air Quality Management
LEO	Low Earth Orbit
Leq	Equivalent Continuous Sound Level
LIDAR	Light Detection And Ranging
LNG	Liquid National Gas
LP	Low Pressure
LPP	Lean Pre mixed Pre-vaporised
LTA	London Terminal Area
LTO	Landing and Take off
MATSE	ECAC Transport Ministers Meeting on the Air Traffic Systems in Europe
MLS	Microwave Landing System
MMR	Multi Mode Receiver
MmW	Millimetric Wave
MSAW	Minimum Safe Altitude Warning

MSK	Minimum-shift keying
MSSR	Monopulse Secondary Surveillance Radar
NAQS	National Air Quality Strategy
NASA	National Aeronautics and Space Agency
NATS	National Air Traffic Services
NAV	Navigation
NERC	New *En-Route* Centre
NIMBY	Not In My Back Yard
NLR	Nationaal Lucht-en-Ruimtevaartlaboratorium
NOTAM	notice to airmen
NO_x	Nitrogen Oxide
Nm	Nautical Miles
O&D	Origins and Destinations
OEW	Operating Empty Weight
OH	Hydroxyl Radical
PAI	Propulsion / Airframe Integration
PHARE	Programme for Harmonisation of ATM Research in Eurocontrol
PIN	Personal Identification Number
PM	Particulate Matter
PPP	Public Private Partnership
PPS	Precise Positioning Service
PRC	Performance Review Council
PRM	Precision Runway Monitor
R&D	Research & Development
RAIN	Reduction of Air force and Installation Noise
RANNTAC	Reduction of Aircraft Noise by Nacelle Treatment and Active Control
RBQQ	Rich Burn Quick Quench
RDPS	Radar Data Processing System
RESOUND	Reduction of Engine Source Noise through understanding Novel Design
RF	Radio Frequency
RMS	Runway Management System
RNAV	Area Navigation
ROI	Return on Investment
ROT	Runway Occupancy Time

RPK	Revenue Passenger Kilometres
RVSM	Reduced Vertical Separation
S/A	Selective Availability
SA	Synthetic Aperture
SAR	Synthetic Aperture Radar
SBAS	Space Based Augmentation Systems
SBSTA	Subsidiary Body for Scientific and Technical Advice
SID	Standard Instrument Departure
SLM	Standard Length Message
SLS	Satellite Landing System
SMGCS	Surface Movement, Guidance and Control System
SMR	Surface Movement Radar
SMS	Surface Management System
SO_x	Sulphur Oxides
SPS	Standard Positioning Service
SSR	Secondary Surveillance Radar
STA	Scheduled Time of Arrival
STARS	Standard Terminal Arrival Route
STCA	Short Term Conflict Alert
STDMA	Self-organised Time Division Multiple Access
SUR	Surveillance
TATM	Terminal Air Traffic Management System
TDMA	Time Division Multiple Access
Tg	Millions of Tonnes
TIS	Traffic Information System
TIS-B	Traffic Information Service – Broadcast
TMA	Terminal Manoeuvring Area
TOA	Time of Arrival
TRSB	Time Reference Scanning Beam
TWR	Tower
UDF	Un-Ducted Fan
UEET	Ultra Efficient Engine Technology
UK AQS	Air Quality Strategy for England, Scotland, Wales and Northern Ireland
UNFCC	United Nations Framework on Climate Change

UV	Ultra Violet
UV-B	Ultra Violet-B
VDL	VHF Data Link
VDR	VHF Data Radio
VHF	Very High Frequency
VLA	Very Large Aircraft
VOC	Volatile Organic Compound
WAAS	Wide Area Augmentation Systems
WHO	World Health Organisation
WMS	Wide area Master Station
WRC	World Radio Conference
WRS	Wide area Reference Station

Annex H Glossary of Figures