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Operational Opportunities to Minimize Fuel Use and Reduce Emissions

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FOREWORD

1. This circular identifies and reviews various operational opportunities and techniques for minimizing fuel consumption, and therefore emissions, in civil aviation operations. It is based on the premise that the most effective way to minimize aircraft emissions is to minimize the amount of fuel used in operating each flight. It is aimed at airlines, airports, air traffic management and air traffic control service providers, airworthiness authorities, environmental agencies and other government bodies, and other interested parties.

2. It should be noted that this circular is not intended to be the basis for regulatory action, and the choice of many of the operational procedures presented depends upon many factors other than environmental benefits. Safety must always be the overriding consideration in all civil aviation operations, and the operator, in conjunction with the operating crew, must remain the ultimate judge of what can be done to minimize fuel consumption while maintaining the necessary safety margins.

3. Clearly, the efficient and effective operation of the world's aircraft fleet is a complex and critical activity, and any operational changes will have a number of implications and limitations. This circular examines some of the primary considerations associated with operational opportunities and the benefits and technical limitations that may be associated with them.

4. Generally, before specific changes to aircraft operations are introduced, it is necessary for airlines to consult with aircraft manufacturers about the potential benefits and technical limitations of such changes. Before contemplating any changes to the infrastructure, a general consultation with the major aviation stakeholders is advisable.

5. This circular was developed by the ICAO Committee on Aviation Environmental Protection (CAEP), with valuable contributions being provided by representatives of the majority of aviation stakeholders, including the ICAO Secretariat, regulatory authorities, air traffic management providers, airport operators, manufacturers, airline associations and airlines.

6. The Executive Summary that follows provides a brief summary of the contents of this circular.

7. Comments from States on this circular, particularly with respect to its application and usefulness, would be appreciated. These comments will be taken into account in the preparation of subsequent editions and should be addressed to:

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EXECUTIVE SUMMARY

PURPOSE

1. This circular, which was developed by the ICAO Committee on Aviation Environmental Protection (CAEP), identifies and reviews various operational opportunities and techniques for minimizing fuel consumption, and therefore emissions, in civil aviation operations. This circular is not intended as a basis for any regulatory action. Wherever possible, it identifies specific actions to be taken by the major stakeholders in civil air transport in order to minimize fuel consumption, together with practical examples. It also describes the conditions and limitations associated with these actions.

STRUCTURE OF THE CIRCULAR

2. The circular begins by reviewing the impetus for minimizing fuel consumption in order to limit engine emissions. Next, opportunities for improvements at airports are considered. The circular then focuses on the historical record of fuel saving in the civil aircraft fleet and the anticipated continued improvement in aircraft fuel efficiency in future. This is followed by the identification of fuel-saving opportunities during ground-based activities before flight, including both maintenance and the reduction of aircraft mass. The possibilities for in-flight fuel saving are then considered, with particular focus on the input from airlines and air traffic services providers. The potential for increased efficiency through load factor improvement is then reviewed. Finally, some specific examples are provided of changes that each stakeholder (airlines, airports, ATC providers, airworthiness authorities, environmental agencies and other government bodies, and other interested parties) could consider in order to minimize the amount of fuel used.

PRINCIPLES OF FUEL SAVING

3. Minimizing the fuel consumed on each flight will generally minimize all aircraft emissions. For economic and efficiency reasons, the commercial aviation industry has already developed and implemented many techniques to minimize fuel usage. Historically, most improvements in fuel consumption have been attributable to larger and more efficient aircraft, resulting in a 70 per cent gain in fuel efficiency since 1970. It is estimated that the future medium-term improvement in fuel consumption of the world's commercial air transport fleet, per unit of productivity (e.g. tonne-kilometre), will be in the order of one per cent per year.

4. The operational opportunities and techniques for minimizing aircraft fuel consumption can be summarized as follows:

a) fly the most fuel-efficient aircraft type for the sector;

b) taxi the most fuel-efficient route;

c) fly the most fuel-efficient route;

d) fly at the most fuel-efficient speed;

e) operate at the most economical altitude;

f) maximize the aircraft's load factor;

g) minimize the empty mass of the aircraft;

h) load the minimum fuel to safely complete the flight;

i) minimize the number of non-revenue flights; and

j) maintain clean and efficient airframes and engines.

OPERATIONAL RESTRICTIONS

5. There are four major factors that restrict operational decisions or procedures: safety, legal constraints, environmental trade-offs and specific situations.

6. The overriding consideration should always be that safety standards must not be compromised by any of the changes made in the interest of fuel conservation. Indeed, many air transport regulations place legal constraints on fuel conservation.

7. Another consideration is the potential trade-off between reducing aircraft noise and reducing engine emissions. Historically, many techniques to reduce the impact of aircraft noise near airports have been developed and implemented in both aircraft/engine design and operation. Most of these techniques tend to increase fuel consumption and therefore have a negative effect on the environment. Moreover, the penalty for changes to further reduce noise is now much greater than before since technological improvements are much smaller and more difficult and costly than the simpler improvements that have already been incorporated into current production aircraft.

8. All decisions regarding changes to operational procedures depend on the specific situation (such as weather, equipment and facilities) associated with each flight, aircraft and crew. It should be noted that only a few of the techniques identified might be practical, or even possible, to incorporate into the majority of flights, and individual operators may already have incorporated a number of them into their current operations.

FINDINGS

9. Aircraft, on average, are responsible for only about half of the emissions produced at airports. The other main emissions sources and fuel consumers are ground transport and ground support equipment (GSE). Airports vary greatly in terms of their current situation and their potential for appropriate improvements. This includes the design of the airport as well as the number and variety of restrictions that may be contributing to operational inefficiencies.

10. Operational opportunities and techniques can only be considered in the context of airport and air traffic constraints, operational requirements, and individual operator circumstances on a given flight. There has been steady progress in making aircraft and airline operations more fuel-efficient, but with 14 000 aircraft

in the world's current commercial jet transport fleet, the speed of implementation of technological improvements in aircraft and engine design is limited. Changes to operating procedures or improvements to infrastructures may therefore offer significant and more immediate ways of improving efficiency.

11. Good engine and airframe maintenance procedures are an essential part of maintaining optimum fuel consumption. Engine wear and airframe imperfections, such as missing fairings and other small non-essential parts, reduce fuel efficiency. A small investment in a repair may save a substantial amount of fuel. This circular provides examples of the specific fuel-saving benefits that can be derived from various maintenance actions.

12. Reducing the aircraft mass will also reduce the fuel consumed; a potential one per cent saving has been estimated. Modern equipment, communications and procedures may allow changes while maintaining or improving safety levels. Particularly on long flights, it is important not to carry excess fuel because it makes ups such a large part of the aircraft's mass. Generally though, the amount of fuel carried is determined by legal or safety considerations.

13. Inevitably, some non-revenue airline flights will be carried out for safety, training or regulatory reasons, as well as some positioning flights to deliver an aircraft to a particular location for operational purposes. However, the amount of non-revenue flying and associated fuel consumption has decreased due to the increased use of simulation training and more sophisticated planning techniques.

14. One of the major factors to be considered when an airline plans its route structure as well as the flying of individual routes is optimal fuel use. Major factors that can cause less-than-optimal fuel use are excess fuel reserves and operational constraints intended to minimize noise impact.

15. There are many potential opportunities for improved efficiency during the planning and execution of a flight. This circular evaluates each phase of flight and provides examples of ways to improve efficiency and still reduce fuel burn by flying more efficient routes and at closer to optimum altitudes and speeds. Flights are planned and performed more efficiently when information about operational factors and individual aircraft performance is readily available.

16. Another way to make air transport more efficient is through a higher load factor. Civil air transport has an unusually high average load factor, which has generally increased with time. This circular examines the limited potential for improving the load factor, particularly in light of the fact that statistics usually underestimate the actual total load carried and/or overestimate the potential maximum payload.

THE MOST SIGNIFICANT FUEL SAVING

17. The most significant fuel saving is likely to come from improvements to CNS/ATM systems. ICAO defines these systems as "Communications, navigation and surveillance systems employing digital technologies, including satellite systems together with various levels of automation, applied in support of a seamless global air traffic management system." CNS/ATM will permit more direct routings and the use of more efficient flight conditions such as optimum altitude and speed. This circular provides a comprehensive review of the many relevant programmes and projects intended to optimize routes and improve the opportunities for aircraft to fly most efficiently.

18. A number of estimates of the environmental benefits associated with improvements in the current CNS/ATM infrastructure have been made. One such analysis developed by CAEP identified a saving of

about 5 per cent to be expected by 2015 in the Continental United States and Europe as a result of specific, planned changes to CNS/ATM systems. This saving does not include the effects of other possible improvements to the infrastructure or fuel saving in the rest of the world.

19. The Intergovernmental Panel on Climate Change (IPCC) Special Report on Aviation and the Global Atmosphere estimated that possible CNS/ATM enhancements worldwide could lead to a saving of between 6 and 12 per cent in fuel use, but that this would take a number of years to realize. In addition to air traffic services improvements, it is estimated that other operational improvements will lead to a 2 to 6 per cent fuel saving, resulting in a combined saving of 8 to 18 per cent. Variations in possible fuel saving can at least partly be explained by what improvements are included. Different time periods have been used and different combinations of improvements assumed.

20. Many of the items listed in this circular will result in only a small percentage of fuel reduction. However, the total fuel used by civil aviation in 2000 was of the order of 243 million tonnes, so a one per cent saving represents 2.4 million tonnes. It is projected that by 2015 the fuel saving will be a minimum of about 3.25 million tonnes — equivalent to 10.25 million tonnes of CO_2. A fuel saving of only a fraction of one per cent is therefore significant, especially if applied on a global basis.

ACTION REQUIRED

21. Each chapter discusses the concepts and measures that must be implemented in order to capitalize on the operational opportunities identified. Operational opportunities can often provide the most efficient, and usually most immediate, way of minimizing the impact of aviation on the environment. Although this circular provides a broad review of operational opportunities to be considered, it should not be used as a basis for regulatory action.

22. Many of these opportunities require cooperation among civil aviation stakeholders. All stakeholders should consider the environmental impact of all potential changes to equipment, procedures, regulations and practices to ensure the most fuel-efficient operation, while maintaining safety, reliability and cost-effectiveness.

23. Manufacturers continue to supply increasingly efficient aircraft and engines and, in cooperation with other relevant stakeholders, should endeavour to provide the operator with the best tools and information on how to use the aircraft in the most fuel-efficient way.

24. At the airport, fuel may be saved by minimizing delays, using different types of ground support equipment and using ground power to replace aircraft auxiliary power units (APUs) where practical. In order to minimize fuel burn, the operator must make many decisions concerning maintenance, flight planning and operation throughout the whole of the flight. This circular addresses airline operational opportunities to minimize fuel consumption.

25. Air traffic services should provide the most appropriate, reliable and technically up-to-date facilities and services in a cost-effective way. The single largest potential source of fuel saving is the implementation of CNS/ATM improvements worldwide.

26. Government regulators should review all relevant regulations to ensure that they do not result in unnecessary fuel burn and that they remain valid despite changes in technology, available knowledge and operating situations.

27. Other stakeholders involved in supporting civil aviation, such as local land-use policy makers and weather forecasting and recording services, can also contribute to improved operating efficiency.

28. It is intended that this circular should be disseminated as widely as possible so that all relevant stakeholders can review the techniques described herein and ensure that all practical and appropriate means are being used to minimize fuel use.

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ABBREVIATIONS

ADS	Automatic dependent surveillance
ADS-A	Automatic dependent surveillance — addressable
aFAST	Active final approach spacing tool
AMAN	Arrivals management
APU	Auxiliary power unit
ASK	Available seat-kilometres
ASM	Airspace management
ATA	Air traffic management programme
ATAG	Air Transport Action Group
ATC	Air traffic control
ATFM	Air traffic flow management
ATM	Air traffic management
ATN	Aeronautical telecommunication network
ATP	Air traffic planning and procedures
ATS	Air traffic services
AVOSS	Advance vortex spacing system
CAASD	Centre for Advanced Aviation System Development
CAEP	Committee on Aviation Environmental Protection
CDA	Continuous descent approach
CDM	Collaborative decision making
CDTI	Cockpit display of traffic information
CFMU	Central Flow Management Unit
CNG	Compressed natural gas
CNS	Communications, navigation and surveillance
CO	Carbon monoxide
CO_2	Carbon dioxide
CRCT	Collaborative routing and coordination tools
CTAS	Centre-TRACON Automation System
CTOT	Calculated take-off time
D2	Direct-to
DMAN	Departure management
DSR	Display system replacement
EATCHIP	European Air Traffic Control Harmonization and Integration Programme
EATMP	European Air Traffic Management Programme
ECAC	European Civil Aviation Conference
E/DA	En-route/descent adviser
EDP	Expedite departure path
EGT	Exhaust gas temperature
ETOPS	Extended range operations by twin-engined aeroplanes
EU	European Union
FAA	Federal Aviation Administration
FANS	Future air navigation systems
FFP1	Free Flight Phase 1
FFP2	Free Flight Phase 2
FMS	Flight management system
FRA	Free route airspace
FUA	Flexible use of airspace
GPS	Global positioning system
GPU	Ground power unit
GSE	Ground support equipment
HC	Unburned hydrocarbons
HPC	High pressure compressor
HPT	High pressure turbine
IAS	Indicated airspeed
ICAO	International Civil Aviation Organization
ICR	Initial collaborative routing
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquefied petroleum gas
LTO	Landing and take-off
MEL	Minimum equipment list

NAS	National airspace system
NAT	North Atlantic
NAVAID	Navigation aid
NEPA	National Environmental Policy Act
NEXRAD	Next generation weather radar
NLR	National Aerospace Laboratory
NONPREF	Non-preferential route
NO_x	Oxides of nitrogen
NRP	National route programme
PAC	Pacific
PARR	Problem analysis, resolution and ranking
pFAST	Passive final approach spacing tool
PM	Particulate matter
RHSM	Reduced horizontal separation minima
RNAV	Area navigation
RNP	Required navigation performance
RPK	Revenue passenger-kilometre
RTA	Required time of arrival
RVSM	Reduced vertical separation minima
SFC	Specific fuel consumption
SMA	Surface movement adviser
SMAN	Surface management
SMS	Surface management system
SO_x	Oxides of sulphur
SUA	Special use airspace
TCAS	Traffic Alert and Collision Avoidance System
TFM	Traffic flow management
TKP	Tonne-kilometres performed
TMA	Traffic management adviser
TMA-MC	Traffic management adviser — multi-centre
TMA-SC	Traffic management adviser — single centre
TRACON	Terminal radar approach control
TSFC	Thrust specific fuel consumption
UNFCCC	United Nations Framework Convention on Climate Change
UPR	User-preferred route
URET	User request evaluation tool
VKT	Vehicle-kilometres travelled
VOC	Volatile organic compounds

Chapter 1
BACKGROUND

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

1.1. The ICAO Committee on Aviation Environmental Protection (CAEP) and its predecessor, the Committee on Aircraft Engine Emissions, have been concerned with emissions Standards for new engine types, their derivatives and new production engines since the late 1970s. One of the principal results arising from their work is the ICAO provisions on engine emissions in Volume II of Annex 16 to the Convention on International Civil Aviation (Chicago Convention). Among other issues, these provisions address liquid fuel venting, smoke and some gaseous exhaust emissions (hydrocarbons, nitrogen oxides and carbon monoxide) from jet engines. They set limits on the amount of smoke and gaseous emissions in the exhaust of most civil jet engine types.

1.2 Initially, ICAO focussed its activities on local air quality around airports. The basic parameters are based on a landing and take-off (LTO) cycle, which tests engine exhaust for a specified sequence of engine powers during a typical take-off, climb-out, approach and landing, taxi and idle cycle, below 3 000 ft. More recently, there has been increasing concern about the impact of aviation and other fossil fuel users on the global environment (global warming). Clearly, the climb, cruise and descent phases of flight are a significant source of fuel consumption, and efforts have been initiated to address fuel burn and the resultant greenhouse gases during these phases.

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCCC), AND THE KYOTO PROTOCOL

1.3 Other United Nations bodies besides ICAO have been concerned in recent years with the impact of man-made emissions on the atmosphere. In the case of climate change, this has been addressed internationally through the United Nations Framework Convention on Climate Change (UNFCCC). Most States are party to this Convention, which was adopted in 1992 and seeks to stabilize atmospheric concentrations of greenhouse gases at safe levels within an acceptable time frame. Although the Convention does not specifically refer to emissions from aviation, its coverage includes emissions from all sources.

1.4 One of the commitments of parties to the Convention is to compile national inventories of their emissions sources. For domestic flights, emissions are considered to be part of the national inventory of the country within which the flights occur. For international flights, the challenge is how to equitably allocate the emissions (referred to in UNFCCC terminology as "emissions from international aviation bunker fuels", although "international" is not always specified) to national inventories. A similar challenge exists for international shipping. To date, there has been no agreement among parties to the Convention on how to resolve these challenges.

1.5 The Kyoto Protocol to the UNFCCC, which was adopted in December 1997, requires countries listed in Annex I of the Convention (industrialized countries) to reduce their collective greenhouse gas emissions, from the 1990 levels, by approximately 5 per cent by the 2008 to 2012 period, with the reduction varying from country to country. The agreed-upon targets apply to the national totals of greenhouse gases. Consequently, each Annex I country can determine how the various emission-producing sectors in its economy should be called upon to assist in achieving the country's national target.

1.6 Because international aviation and marine emissions are not included in national inventories, they are currently excluded from the agreed-upon targets. However, the treatment of aviation and marine emissions was considered in Kyoto in the context of discussions on policies and measures to be pursued by Annex I countries. A provision was included in the Kyoto Protocol calling for industrialized countries to pursue the limitation or reduction of aviation and marine emissions of greenhouse gases through ICAO and the International Maritime Organization (IMO), respectively.

ICAO ACTION

1.7 ICAO has the mandate to review how aviation can limit or reduce the emission of greenhouse gases. Aircraft emissions such as CO_2 and H_2O are generally proportional to the amount of fuel burned. CAEP has therefore focussed attention on the quantity of engine emissions in addition to the composition previously addressed. This is in the context of the worldwide impact and not just local airport effects. These developments raised the issue of which exhaust gas components to consider since some combustion products now thought to be the cause of concern are not the same as those previously addressed.

1.8 ICAO, mainly through CAEP, has taken a number of steps to implement the Kyoto remit and to recommend appropriate action. Clearly, there was a need to establish, in more detail, the current knowledge of the impact of aviation on the environment. One action taken by ICAO (1996) resulted in the preparation of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Aviation and the Global Atmosphere, issued in 1999.

1.9 During the 32nd Session of the ICAO Assembly (Montreal, September 1998), a resolution was adopted calling on CAEP to study policy options for limiting or reducing the greenhouse gas emissions from civil aviation. The Committee was required to consider the findings of the IPCC Special Report and the requirements of the Kyoto Protocol and to report back to the next session of the ICAO Assembly in 2001.

IPCC SPECIAL REPORT ON AVIATION AND THE GLOBAL ATMOSPHERE

1.10 The objective of the IPCC Special Report was to provide "comprehensive, accurate, unbiased, policy-relevant information to serve as input to any decisions that might be made to mitigate possible global atmospheric impacts of aviation." The Report, published in 1999, provides a thorough assessment of the current understanding of critical atmospheric, technological and policy issues, with emphasis on both what is known and what remains uncertain.

1.11 The IPCC Special Report estimates that aircraft contribute about 3.5 per cent of the total radiative forcing (a measure of the importance of a potential climate change mechanism) caused by all human activities. The emissions from aircraft of relevance to climate change include carbon dioxide, water vapour, nitrogen oxides, sulphur oxides and soot. The Report also acknowledges that some of the atmospheric effects of aviation emissions are not fully understood due to many remaining scientific uncertainties concerning the environmental impacts of the various types of aircraft emissions. It judges that further research is needed "to understand better the options for reducing emissions, to better inform decision-makers, and to improve the understanding of the social and economic issues associated with the demand for air transport."

1.12 The IPCC Special Report also describes the potential for technological innovation, the imposition of regulatory measures, and changes to operating procedures to mitigate the environmental impact of aviation. Consistent with IPCC practice, it makes no policy recommendations.

Technological innovation

1.13 With respect to aircraft and engine technology, the IPCC Special Report explains that technology advances have substantially reduced most emissions per passenger-kilometre. Any further technological change may involve achieving a balance among a range of environmental impacts.

1.14 According to the IPCC Special Report, subsonic aircraft being produced today are about 70 per cent more fuel-efficient per passenger-kilometre than those of forty years ago. The majority of this gain has been achieved through engine improvements and the remainder from airframe design improvements. Relative to aircraft produced today, a further 20 per cent improvement in fuel efficiency is projected by 2015 and a 40 to 50 per cent improvement by 2050. Engine efficiency improvements reduce fuel consumption and most types of emissions. Without advances in combustor technology, however, NO_x emissions may increase because improving fuel efficiency necessitates the burning of fuel at ever-increasing temperatures and pressures. High temperatures and pressures generally produce more NO_x per unit of fuel.

1.15 The IPCC Special Report recognizes that future engine and airframe design involves complicated technical challenges and a complex decision-making process in which competing environmental impacts, such as potential tradeoffs between reduction of CO_2 and NO_x emissions, and between noise and emissions reduction, must be considered.

Regulatory measures

1.16 The IPCC Special Report discusses various regulatory approaches to mitigating the impact of aviation emissions. It states that possible regulatory approaches to reducing emissions include more stringent aircraft engine emissions regulations, the removal of subsidies and incentives that have negative environmental consequences, the use of market-based options such as environmental levies (charges and taxes), emissions trading, voluntary agreements, research programmes, and the use of alternate modes of transport (i.e. rail and bus). The Report notes that many of these approaches have not been fully investigated or tested in aviation and that their outcomes are uncertain. Further, IPCC noted that mode substitution was beyond the scope of this first Special Report on the aviation sector.

Operational improvements

1.17 The IPCC Special Report states that air traffic management (ATM) improvements and other operational measures could reduce aviation fuel burn by a total of between 8 and 18 per cent. Existing national and international ATM systems have constraints that result, for example, in aircraft holding (e.g. aircraft flying in a fixed pattern waiting for permission to land), inefficient routings and suboptimal flight profiles. These constraints result in excess fuel burn and, consequently, excess emissions.

1.18 According to the IPCC Special Report, addressing only the ATM system constraints on the current aircraft fleet and operations could reduce fuel burned by 6 to 12 per cent. The Report states that the improvements needed for these fuel-burn reductions are anticipated to be fully implemented in the next twenty years, provided that the necessary institutional and regulatory arrangements have already been put in place.

1.19 The IPCC Special Report identifies other possible operational measures for reducing the amount of fuel burned per passenger-kilometre such as increasing the load factor (carrying more passengers or freight on a given aircraft), eliminating non-essential aircraft mass, optimizing aircraft speed, limiting the use of auxiliary power units and reducing taxiing. The report concludes that potential improvements to these areas could reduce fuel burned and emissions by 2 to 6 per cent.

ICAO'S APPROACH TO ENGINE EMISSIONS

General

1.20 ICAO's Committee on Aviation Environmental Protection (CAEP) has been pursuing three main approaches to address aviation emissions, namely technological innovation and certification standards, operational measures and the possible use of market-based options. On balance, operational measures have the potential to provide substantial near-term reductions in fuel use and emissions.

Emissions and technical issues

1.21 CAEP has considered the extent to which technological innovation can help, through improved engine and airframe design, to achieve reductions in emissions. It has analysed the appropriateness of current and alternative regulatory frameworks for the assessment of the atmospheric effects caused by engine exhaust emissions. It has begun work to assess the need for a certification methodology for emissions in climb and cruise conditions to complement existing airport-related landing and take-off (LTO) standards for NO_x and other emissions. Low-NO_x technology and long-term emissions technology goals are also being examined.

1.22 ICAO Standards for emissions certification of new and derived types of aircraft engines and for new production engines are a means of addressing specific emissions. In addition to considering the types of emissions already covered by ICAO Standards, new methodologies may take into account the fuel efficiency and productivity of the whole aircraft, which would have a direct bearing on CO_2 and other emissions. The results of this work will help improve ICAO's understanding of potential technological innovations and the effects of new Standards. One major challenge ICAO faces in setting new emissions Standards is how to balance competing effects upon various engine emissions, such as trade-offs between CO_2 and NO_x reduction that may result from alternative engine and airframe designs and/or noise reduction. In addition, the task of developing and implementing new Standards is necessarily complex and lengthy.

Operational issues

1.23 This circular is part of ICAO's effort in this area. The work focussed on three key issues:

a) quantification of the benefits of CNS/ATM measures;

b) increased liaison with ICAO's planning and regional implementation groups to help maximize the emissions benefits of regional CNS/ATM implementation plans; and

c) identification and discussion of operational opportunities in the air and on the ground for reducing fuel burn.

Market-based options

1.24 CAEP has examined certain market-based options, namely, environmental levies (charges and taxes) and emissions trading schemes, and has also evaluated voluntary programmes as possible mechanisms for limiting or reducing aviation emissions of CO_2. An evaluative framework was developed to allow for clear comparisons of the strengths and weaknesses of potential market-based options.

1.25 The results have contributed to ICAO's knowledge of the relative merits and limits of these market-based options, as well as of voluntary programmes. Development and implementation of market-based options will take time. Among other issues, some market-based options are incompatible with existing aviation multilateral and bilateral legal agreements and therefore raise substantial legal and policy issues that would require some time to resolve.

SUMMARY

1.26 Recent developments highlighting the concerns about the impact of aviation on the environment have been summarized together with the organizations involved.

1.27 Emissions can be minimized by different means. The operational opportunities described in this circular present advantages over other approaches to addressing aviation-related emissions in several important respects. Operational measures provide not only an effective and quantifiable means, but also the most immediate way, of minimizing aircraft emissions. Operational measures also present fewer of the legal, economic and technical challenges (e.g. engine redesign and replacement or modification) that are associated with other approaches.

Chapter 2
AIRPORT OPERATIONS

INTRODUCTION

2.1 This chapter summarizes operational opportunities at airports to minimize gaseous emissions from aircraft and ground support equipment (GSE). Operational opportunities are broadly defined as minimizing fuel use, optimizing airport design, modifying current operating practices, retrofitting existing GSE and purchasing new, fuel-efficient GSE. It must be appreciated that site-specific limitations or conditions may preclude the application of a given technology or operational measure. However, fuel refining and blending practices, airport traffic management, engine design, and emissions control technology continue to evolve, possibly leading to innovative fuel conservation and emissions reduction opportunities.

PREVIOUS WORK BY ICAO

2.2 ICAO has been concerned with emissions at airports for many years. ICAO's Committee on Aviation Environmental Protection (CAEP) noted in a 1995 report that "studies have, in general, confirmed earlier findings that air quality in the vicinity of airports is generally good and the contribution of aircraft and airside ground sources to pollution levels continues to be small." It also reported that studies of the future trends in air quality around airports indicated that pollutant levels would remain at present levels or be reduced at least until 2015. Although it would remain a small part of the total, the relative contribution of aircraft to NO_x levels would nevertheless rise in the future because of expected air traffic growth and progressively cleaner road vehicle fleets.

2.3 ICAO has also published the *Airport Planning Manual*, Part 2 — *Land Use and Environmental Control* (Doc 9184), which provides some information on means of reducing emissions and improving fuel efficiency. Another general issue is the environmental management of airports, including the application of the International Organization for Standardization (ISO) 14001 standards.

AIRPORT DESIGN AND FACILITIES

2.4 The first opportunity to minimize fuel use and emissions production at an airport is when it is designed or when it is expanded or modified. This includes the layout of the buildings, pavement and related facilities, and the provision of adequate capacity. Table 2-1 summarizes the opportunities for minimizing fuel usage and resulting emissions.

GROUND SUPPORT EQUIPMENT

2.5 The term "ground support equipment" (GSE) refers to the broad category of vehicles and equipment that service aircraft, including those used for towing, maintenance, loading and unloading of passengers and cargo, and for providing electric power, fuel and other services to the aircraft.

Table 2-1. Summary of airport features that minimize fuel usage and emissions

Airport feature	Description	Emissions affected*	Comments
Layout	Provide a good runway, taxiway and apron layout	All	Minimizes taxiing and congestion. Allows high-speed turnouts.
	Provide sufficient runways	All	Minimizes delays.
Infrastructure	Provide pre-conditioned air and 400 Hz of power at gates and maintenance areas	All	Reduces or eliminates APU, GPU and air-conditioning unit usage. Typically requires substantial capital investment, but often realizes fuel and maintenance saving.
	Provide surface movement guidance system	All	Reduces congestion and delays in bad weather.
Operations	Scheduling improvements	All	Reduces congestion and delays in bad weather.

* Emissions affected include nitrogen oxides (NO_x), sulphur oxides (SO_x), particulate matter less than 10 microns (PM-10), hydrocarbons (HC) (which include volatile organic compounds (VOCs)), carbon monoxide (CO) and carbon dioxide (CO_2).

2.6 Note that airports in different regions of the world have divergent responsibilities for the provision and operation of GSE services. For example, in North America, the responsibility for conversion or replacement of most GSE rests with individual operators, rather than with the airport authority.

2.7 The most common types of GSE are:

a) *Aircraft tractors*. Also known as aircraft tugs, they are used in three separate duty cycles:

1) pushback service, where the tug pushes the aircraft back from the gate;

2) operational towing, where tractors are used to reposition the aircraft; and

3) maintenance towing, where tugs are used to tow aircraft between the terminal and remote maintenance areas.

Aircraft tugs are available in two sizes, for narrow- and wide-body aircraft. Towbarless tractors are being used more often. They are capable of higher speeds for maintenance and operational towing. They are much lighter than conventional ballasted towbar tractors because they use the weight of the aircraft to increase traction. Therefore, they use much less fuel while positioning between aircraft.

b) *Air-conditioning units*. Air-conditioning units are trailer- or truck-mounted units used to supply preconditioned air to stationary aircraft at the terminal and also during maintenance. As discussed elsewhere, gates are increasingly being modified to provide preconditioned air from dedicated electrically-powered compressors, thereby avoiding the use of internal combustion engines.

c) *Air start units*. Air start units are trailer- or truck-mounted compressors that provide compressed air for starting an aircraft's main engines. The flow of high pressure air through a hose impinges on the turbine blades, causing the turbine to rotate and allowing a start-up. These units must provide a continuous, reliable supply of compressed air to avoid "hot starts" or "hung starts," which cause severe damage to engines. Air starts are typically used only when an aircraft is not equipped with an auxiliary power unit (APU), or the APU is not operational. The APU is a small turbine generator that provides compressed air as well as electrical power for on-board equipment such as lights, avionics, galleys and instrumentation.

d) *Baggage tractors*. These are used to transport luggage or cargo between the aircraft and the terminal. Tractors dedicated to cargo services often have unique design features, such as side hitches to allow for quick turnarounds. The duty cycle for baggage and cargo tractors typically varies as well. Cargo tractors are typically rated for 45 000 kg loads and are used continuously during freight loading and unloading over a three- to eight-hour period, whereas baggage tractors typically require 13 500 to 27 000 kg ratings and operate sporadically over an eight-hour shift.

e) *Belt loaders and container loaders*. A belt loader is a self-propelled conveyor belt used to move baggage and cargo between the ground and the aircraft. Airline handling of cargo is typically associated with short travel distances between the terminal and the aircraft, whereas loaders used by cargo carriers may travel up to four or five miles per day. Furthermore, cargo-loading operations typically require specialized platform loaders — self-propelled platform lifts designed for rapid transfer of containerized cargo between the ground and the aircraft. There are two types of cargo loaders: lower lobe platform loaders rated at 7 000 kg lift capacity, and wide-body main deck loaders rated at 13 500 kg lift capacity that lift containerized cargo onto the main deck of wide-body aircraft.

f) *Bobtail tractors*. Bobtail tractors are used to provide high-speed transport of cargo and baggage over longer distances within the airport (i.e. from the terminal to remote cargo, mail and baggage sorting facilities). These units are modified on-road vehicles with a shortened chassis to allow for the tighter turning radius required at airport terminals.

g) *De-icers*. De-icers typically consist of an on-road truck equipped with a tank, a pump, a hose and a spray gun to transport de/anti-icing fluid and spray it on aircraft.

h) *Lavatory service trucks and carts*. Lavatory trucks are self-propelled units equipped with stainless steel tanks, a pump and a hose used to service aircraft lavatories. Lavatory carts are also used; these units, which are not self-propelled, have small engines used to power pumps that transfer lavatory fluids between the ground and the aircraft.

i) *Lifts*. This broad category includes forklifts, scissor lifts, and loaders that allow access to the aircraft for servicing at the terminal and at the maintenance base. Lifts typically include a substantial proportion of medium- and heavy-duty on-road equipment, modified for the specific duty requirements.

j) *Ground power units (GPU)*. These provide 400 Hz of electrical power to aircraft when the aircraft's APU and main engines are not operating. Given a choice between GPU and APU, airlines typically use GPU because they cost less to operate. There are two basic types of GPU. The first type is a mobile trailer or truck-mounted generator powered by a diesel or gasoline engine that generates 400 Hz of electricity for the aircraft. The second type is a frequency converter (frequency to 400 Hz) installed on the bottom of a passenger bridge or on a fixed stand on the tarmac near the parked aircraft's nose (i.e. bridge-mounted power) and drawing power from the airport's electrical grid.

k) *Passenger ground transport*. This includes passenger buses, passenger steps and mobile lounges (which replace buses and steps).

2.8 Mitigation options for GSE emissions can realize significant reductions. Table 2-2 summarizes the operational opportunities that may exist to reduce GSE fuel usage and emissions.

2.9 The cost of operational modifications varies widely; any analysis should include the cost of required enhancements to the infrastructure. The infrastructure costs for alternate fuels (e.g. compressed natural gas (CNG) and electric) are typically substantial:

a) CNG retrofits typically require the installation of fast-fill CNG dispensing systems capable of serving sixty to eighty vehicles. These units can cost up to U.S.$1 000 000 or more to install and may require additional environmental approvals because of accidental release regulations and other safety considerations. Slow-fill dispensing systems cost less than one-tenth of the price to install, but require ten times longer to dispense the same amount of fuel.

b) For electric GSE, even assuming an adequate supply of electrical power to an airport, the cost of installing distribution and charging systems is significant. Fast-charging systems (systems capable of recharging eight to twelve battery pack units concurrently in less than one hour) typically cost U.S.$80 000 to $150 000. Further, equipment costs for electrically-powered units typically do not include the cost of batteries (U.S.$2 000 to $4 000 per GSE), and batteries must be replaced every three to five years. If additional power must be supplied to the airport/terminal, the cost will be greater.

c) Although infrastructure and purchase costs for alternative-fuel GSE are typically greater than for gasoline and diesel-engine units, alternative-fuel vehicles typically require reduced maintenance and lower operating and fuel costs compared with gasoline and diesel-powered equipment.

2.10 In comparison, gasoline engines that use existing fuel distribution systems can be retrofitted with three-way catalysts or replaced with new technology without any infrastructure improvements. These retrofits or modifications may realize a 90 per cent or more reduction in HC and NO_x. Compared with CNG/electric conversions, the saving in infrastructure improvement costs could allow for additional engine conversions of uncontrolled GSE, i.e. more units could be retrofitted with 90 per cent control technology than could be electrified. Under such circumstances, additional conversions of existing uncontrolled engines may lead to a greater reduction in total emissions than would electrification. Thus, the relative cost of possible conversion projects needs to be carefully evaluated.

2.11 As with cost considerations, any operational change must continue to ensure that the minimum duty and performance requirements are met. Considerations that may limit electric conversion options include the availability of equipment and the ability of electrical units to:

a) have sufficient capacity to provide continuous power over a typical operating day;

b) provide sufficient power;

Table 2-2. Summary of operational opportunities to minimize fuel usage and emissions from GSE

Operational measure	Description	Emissions affected *	Comments
Modify GSE operations	Enhanced maintenance	All	Difficult to predict emissions reduction. Existing maintenance may already be optimized, limiting the reductions that may be realized.
	Reduced driving distances through route planning	All	Emissions reduction and fuel saving are route-specific.
	Avoid unnecessary idling of equipment	CO, CO_2, HC, PM-10	Emissions reduction and fuel saving are site-specific.
GSE engine retrofit	Gasoline engines retrofitted with oxidation catalyst	CO, HC	Depending on the retrofit, may achieve 90 per cent plus control.**
	Gasoline engines retrofitted with three-way catalysts	NO_x, CO, HC	Depending on the retrofit, may achieve 90 per cent plus control.
	Diesel engines retrofitted with oxidation catalysts	PM-10, HC, CO	Depending on the retrofit, may reduce PM by up to 30 per cent, HC by up to 50 per cent and CO by up to 90 per cent.
	Diesel engines retrofitted with particulate traps	PM-10	Depending on the retrofit, may reduce PM by 85 to 95 per cent; retrofit filter may require ultra-low sulphur fuel (15 to 25 ppm sulphur).
	Installing turbo-charging, intercooling and timing retard	NO_x	Depending on the modifications, may reduce NO_x by 20 to 40 per cent; retrofits available only for some models.
	Reduced sulphur content in diesel fuel	SO_x, PM	Low sulphur diesel fuel (0.05 per cent sulphur by mass) is relatively common in the United States; ultra-low sulphur fuel is proposed for 2005 to 2006 in the United States.
	Diesel fuel additives and emulsifiers	NO_x	May reduce NO_x by 10 to 20 per cent; many additives are still experimental.
	Engine heater for diesel engine coolant		Assists start-up.
GSE engine replacement	Replacing uncontrolled diesel and gasoline engines with new fuel-injected gasoline engines equipped with a three-way catalyst	All	Depending on the application of engine technologies, may achieve an 85 to 90 per cent reduction in NO_x and may achieve a 90 to 95 per cent reduction in HC and CO. Availability of new off-road engine technology may be limited. Retrofit of on-road equipment for non-road use typically requires additional modifications.
	Replacing uncontrolled gasoline or diesel engines with new diesel engines equipped with computer-controlled fuel delivery system, turbo-charging, intercooling and timing retard	All	Depending on the application of engine technologies, may realize a 75 per cent reduction in NO_x and HC by 2006; additional NO_x reduction could be achieved under proposed new United States standards, which seek a 90 per cent plus reduction in NO_x and HC by 2007.

Operational measure	Description	Emissions affected *	Comments
	Replacing two-stroke gasoline engines with four-stroke gasoline engines	HC, CO, PM, NO_x	Uncontrolled two-stroke gasoline engines emit about 7 times the HC, 1.5 times the CO and about 10 times the PM of uncontrolled four-stroke engines. Two-stroke NO_x is about 20 per cent of that of four-stroke engines. For the near term, replacement of existing two-stroke equipment can make significant reductions in HC and PM.
CNG/LPG GSE after treatment devices	Installation of oxidation catalyst	HC, CO	Depending on the retrofit, may reduce HC by 50 to 70 per cent and CO by 90 per cent.
	Installation of three-way catalyst	HC, CO, NO_x	Depending on the retrofit, may reduce HC, CO, and NO_x by 90 per cent.
Alternative fuels	Retrofit/replace diesel engines with CNG/LPG-fuelled engines	NO_x, PM	Relative to uncontrolled gasoline and diesel engines, the purchase of new CNG/LPG engines may realize a 60 to 80 per cent reduction in NO_x, 90 to 95 per cent reduction in PM, but will increase CO and HC emissions. The CNG option typically requires substantial infrastructure improvements; such improvements must properly address safety and reliability issues. Retrofits of existing engines may increase emissions if not properly installed and maintained.
	Retrofit/replace gasoline engines with CNG/LPG-fuelled engines	NO_x, HC, CO, PM	Depending on the application may achieve a 10 to 25 per cent NO_x reduction, a 40 to 75 per cent reduction in HC, a 20 to 50 per cent reduction in CO and a 15 to 35 per cent reduction in PM. The CNG fuel option typically requires substantial infrastructure improvements; such improvements must properly address safety and reliability issues. Retrofits of existing engines may increase emissions if not properly installed and maintained.
	Replace with electric GSE	All	May achieve up to 100 per cent reduction in ramp emissions (excludes emissions arising from electric power generation). Electrification may require substantial investment in infrastructure; such improvements must properly address safety and reliability issues. Electric GSE may not be available or able to meet duty requirements for cargo tractors, aircraft tractors, cargo loaders, air starts, mobile GPU/air-conditioning units; service trucks and lifts.

* Emissions affected include nitrogen oxides (NO_x), sulphur oxides (SO_x), particulate matter less than 10 microns (PM-10), hydrocarbons (HC) (which include volatile organic compounds (VOCs)), carbon monoxide (CO) and carbon dioxide (CO_2).

** Estimated reductions are for each GSE unit, relative to an in-use, uncontrolled gas or diesel engine. The total emissions reduction potential from a given operational measure is site-specific and cannot be estimated.

c) provide the reliability required of emergency back-up units; and

d) perform in cold climates.

2.12 However, these limitations should not preclude the use of electric GSE where it could operate in a satisfactory manner. Due to the nature of electric GSE, energy is not consumed when work is not performed — there is no idle mode for electric GSE. Usually, due to the less complex nature of electric GSE, the unit is easier to operate and may require less maintenance than equipment powered by gasoline, diesel, compressed natural gas (CNG) or liquefied petroleum gas (LPG).

2.13 Thus, as with overall project costs, the selection of a given control strategy must involve careful consideration of site-specific performance limitations.

GROUND TRANSPORT

2.14 Depending on their size, airports serve as destinations for hundreds of thousands of vehicles daily. These vehicles in turn represent millions of kilometres travelled daily. Thus, reducing the total vehicle kilometres travelled (VKT) to and from an airport, and the emissions from ground transport while at the airport, can achieve substantial emissions reduction.

2.15 Ground transport emissions reduction measures typically focus on reducing VKT by:

a) employees of airlines, airport authorities and other companies located on airport properties; and

b) passengers and freight.

Recommendations for reducing VKT for on-airport activities are provided in Table 2-3. Additional measures such as installation and/or improvement of rail transport, alternative-fuel bus transport and dedicated high-occupancy vehicle lanes may achieve reduced VKT but are not considered here. Given the high percentage of emissions associated with vehicle travel to and from some airports, it is critical to consider all possible means of reducing this segment's contribution.

AIRCRAFT OPERATIONS

2.16 As with airport design and facilities, GSE and ground transport, there are a variety of operational measures that may be used to reduce emissions from aircraft engines while at, or in the vicinity of, an airport. These operational measures can be categorized as: changes in noise mitigation procedures, discretionary measures that pilots may elect to use to reduce fuel and emissions (if determined safe and appropriate), and other procedures (see Table 2-4). Opportunities to reduce emissions through new engine and aircraft design are discussed elsewhere in this circular.

2.17 Given the site-specific limitations and conditions, it is very difficult to estimate the emissions reduction that may be realized by these operational measures. Improvement in the efficiency of airport operations will probably have benefits beyond gaseous emissions reduction, which may offset any capital costs incurred.

Table 2-3. Summary of operational opportunities to minimize ground transport fuel usage and emissions

Operational measure	Description	Emissions affected *	Comments
Employee trip reduction	Compressed workweek/telecommuting: • 10 hr/day, 4 days/wk, etc.; and • working at home where appropriate, etc.	All	May realize up to a 5 per cent reduction in VKT. Requires substantial planning and implementation.**
	Employee rideshare/carpool incentives: • carpool matching; and • enhanced compensation or benefits for rideshare.	All	Reduction in VKT varies based on the programme, but can be up to 10 per cent. If poorly implemented, may increase VKT.
	Parking pricing and subsidies: • increased fees for single occupancy of vehicles; and • subsidizing of alternative-fuel and zero emission vehicles (ZEV).	All	Reduction in VKT varies based on the programme, but can be up 10 per cent.
	Public transit and alternate mode incentives: • discounted or free public transport; and • enhanced compensation for use of ZEV/alternative fuels.	All	Depending on the incentives and existing transit system, may increase public transport usage by up to 10 per cent.
Passenger transport control options	Public transit and alternate mode incentives (see above).	All	Same as for employee trip reduction (see above).
	Alternative fuels for taxis, shuttles, rental cars and heavy-duty vehicles: • retrofit existing units with catalysts/traps/filters; • accelerate retirement; and • purchase new alternate-fuel/ZEV vehicles for replacement and growth.	All	Voluntary measures have been introduced at many airports. Unlike GSE, most on-highway equipment already has controls on specific emissions. Reductions are substantially less than for GSE and are site-specific and require study.
	Increase long-term parking rates.	All	May potentially decrease VKT, but may result in higher idling periods and increased VKT from offsite/remote parking areas.
	Idle restrictions on cars, taxis, buses and delivery vehicles.	Principally CO and HC	Possible emissions reduction.
	Circulation management for cars, taxis, vans and buses.	All	Potential decrease in VKT is site-specific.

* Emissions affected include nitrogen oxides (NO_x), sulphur oxides (SO_x), particulate matter less than 10 microns (PM-10), hydrocarbons (HC), (which include volatile organic compounds (VOCs)), carbon monoxide (CO) and carbon dioxide (CO_2).

** Estimates represent potential reductions in VKT for each category. Reductions are site-specific and depend on average speed travelled during a trip, average emissions per kilometre, average number of passengers per trip, average length of trip, and the degree of adoption of the operational measure.

Table 2-4. Summary of operational opportunities to minimize aircraft fuel usage and emissions at airports

Operational measure	Description	Emissions affected *	Comments
Reconsideration of noise reduction procedures	Noise abatement procedures	All	These procedures tend to increase horizontal distances flown and cause extra fuel burn due to the vertical profile required.
	Land-use control	All	Land-use planning and control near airports can shift the emphasis away from noise abatement procedures towards other more efficient strategies.
	Curfews	All	Can result in congestion leading to delays and holding, extra landings and take-offs, and flying at non-optimum speeds.
	Preferential runway	All	Leads to extra flying and taxi time.
	Noise fines	All	Can result in changes to procedures or take-off mass that reduce efficiency.
Discretionary pilot actions	Minimizing use of reverse thrust on landing	Primarily NO_x; HC emissions may increase	Pilot must retain full authority on whether to implement.
	Engine(s)-out taxi	Primarily CO_2, HC and CO	Pilot must retain full authority over safe operation of aircraft. Emissions reductions are site- and aircraft-specific. Effect on NO_x is uncertain.
Other procedures	Reduced engine idling time	Primarily HC and CO	HC and CO emissions are greatest during engine idling. Reducing idling can also result in decreased engine operation.
	Aircraft towing	All	Less engine use when the aircraft is towed from the gate to the runway. Can also result in increased safety concerns.

* Air emissions affected include nitrogen oxides (NO_x), sulphur oxides (SO_x), particulate matter less than 10 microns (PM-10), hydrocarbons (HC) (which include volatile organic compounds (VOCs)), carbon monoxide (CO) and carbon dioxide (CO_2).

SUMMARY

2.18 The gaseous emissions of concern at and near airports have been addressed in this chapter. However, the emphasis of this circular as a whole is on the impact of aviation on the global environment and that provides a somewhat different list of priorities.

2.19 Depending on the area included and the airport concerned, aircraft are, in general, the source of only about half of the total emissions. It is therefore well worthwhile attempting to reduce emissions from ramp equipment and from ground transport to and from the airport.

2.20 Minimizing taxiing time and perhaps taxiing with one or more engines inoperative could reduce an aircraft's contribution to airport emissions. Measures to reduce the impact of aircraft noise, such as land-use control near the airport, may allow fewer restrictions on aircraft operations, which will often result in more efficient operations and a consequent reduction in emissions.

2.21 Identification and selection of any operational measures to reduce fuel and associated gaseous emissions at airports must be made in consultation with airport authorities, local planning agencies, airlines and affected suppliers. Given site-specific limitations, safety considerations and potential impacts on the overall efficiency of air transport, it is not possible to define a single set of operational measures that is appropriate for all airports. However, significant gaseous emissions reductions may be achieved from implementation of these operational measures. If implemented properly, these measures may also result in improvements in system efficiency and reductions in system operating costs.

2.22 Airport operations need to be integrated with flight operations and air traffic management for maximum fuel saving. Chapter 6 addresses air traffic management aspects.

Chapter 3
AIRCRAFT ENVIRONMENTAL PERFORMANCE

INTRODUCTION

3.1 Fundamental to keeping fuel usage and emissions to a minimum is designing airframes and engines, from the outset, with these objectives in mind. Historically, the marketplace has always encouraged the lowest possible fuel consumption for obvious economic reasons, but designing engines to reduce emissions is more recent. Great improvements have been made over the years, and although concerted efforts by designers will continue, the opportunities are inevitably diminishing.

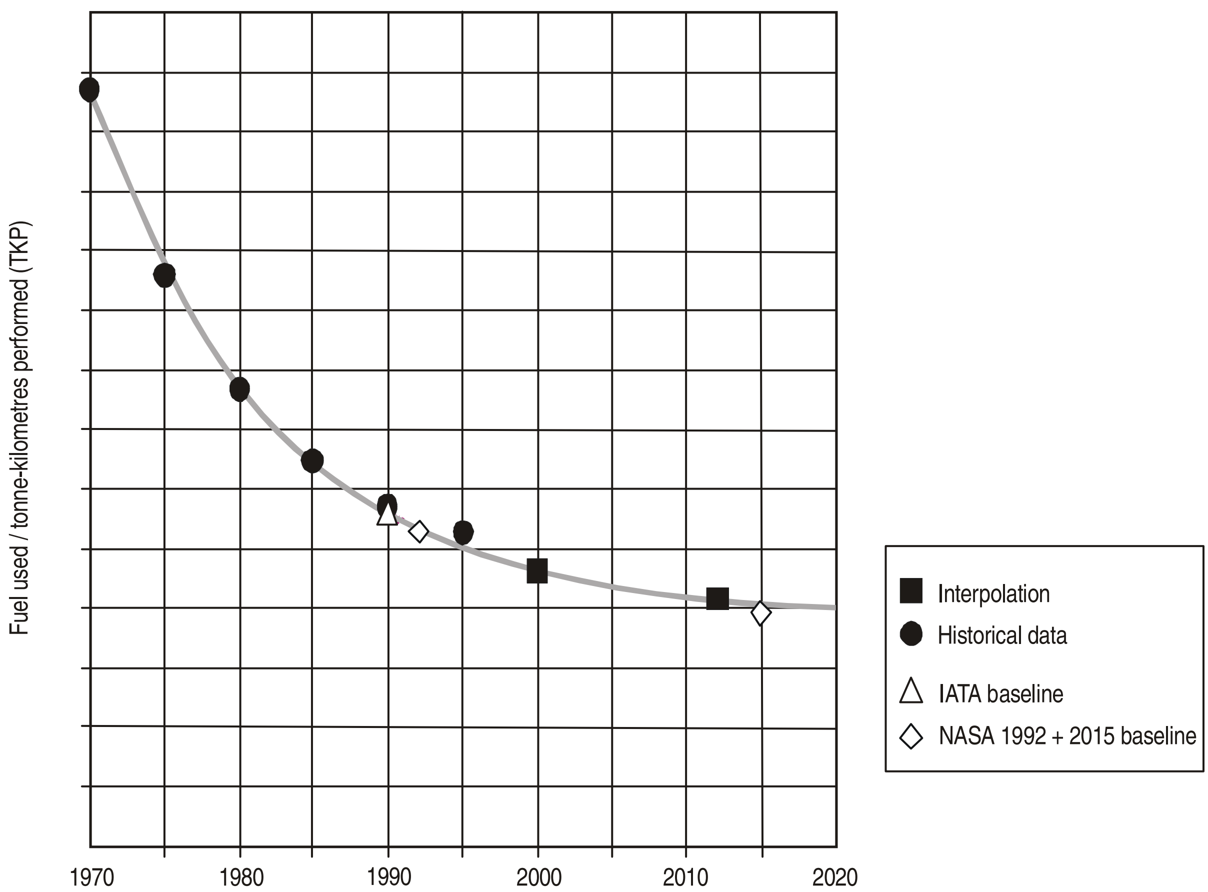
FUEL EFFICIENCY IMPROVEMENTS AND ADVANCES IN AIRCRAFT AND ENGINE DESIGN

3.2 The entire commercial aviation industry continues to strive to improve energy efficiency. While demanded by the economic business realities of all participants in the air transport service industry, such efficiencies are also universally recognized as responsible environmental stewardship. During the more than forty years of commercial jet operation, aircraft fuel efficiency has improved by about 70 per cent, a continuing record of improving economic and environmental performance. See Figure 3-1 for a summary of improvements since 1970 and anticipated improvements up to 2020. From the introduction of routine jet services in the early 1950s to the present day, advances in engine technology and design are responsible for somewhat more than half of these improvements. The balance has been accomplished through innovative airframe design. During the entire history of commercial aviation, the overriding technological design consideration has been, and continues to be, safety of flight. Commercial aviation continues to show improving safety trends while energy efficiency is also improving.

FLEET COMPOSITION AND UTILIZATION

3.3 In 2000, the worldwide active fleet of commercial jet transport aircraft numbered about 14 000. The smallest regional jets have less than 50 seats. The largest passenger aircraft have more than 500 seats for wide-body domestic service. Figure 3-2 shows the worldwide distribution in 1999, by aircraft size, with the average aircraft size being about 197 seats (209 seats without the significant number of regional jets introduced in recent years). The slow growth in the average size of larger jets over most of the last two decades is shown in Figure 3-3 (excluding regional jets). Similarly, the maximum range capability of various commercial jet types ranges from less than 1 500 nautical miles for some small jets to more than 8 000 nautical miles for some intercontinental-capable wide-bodies.

3.4 In order to justify their considerable capital costs, each commercial aircraft must be utilized in revenue-generating service for many hours per day for many years. For passenger jets larger than 100 seats, the worldwide average is nearly ten block hours per day, every day of every year, for operating lives of more than thirty years. Due to the special service characteristics of the air cargo industry, the daily utilization of air transport freighters is usually somewhat less than that of equivalent size passenger aircraft.



Relative fuel efficiency improvement

	1990–2000	2000–2012	1990–2012
Total	17%	10%	26%
Per year	1.6%	0.5%	1.1%

NASA inventory	(ASK/kg)	(1/100 RPK)	(1/100 TKP)
Baseline 1992	31	5.8	52.9
Baseline 2015	41.8	4.3	39.2

Figure 3-1. Fuel efficiency of IATA industry fleet based on data and IPCC/NASA 2015 inventory

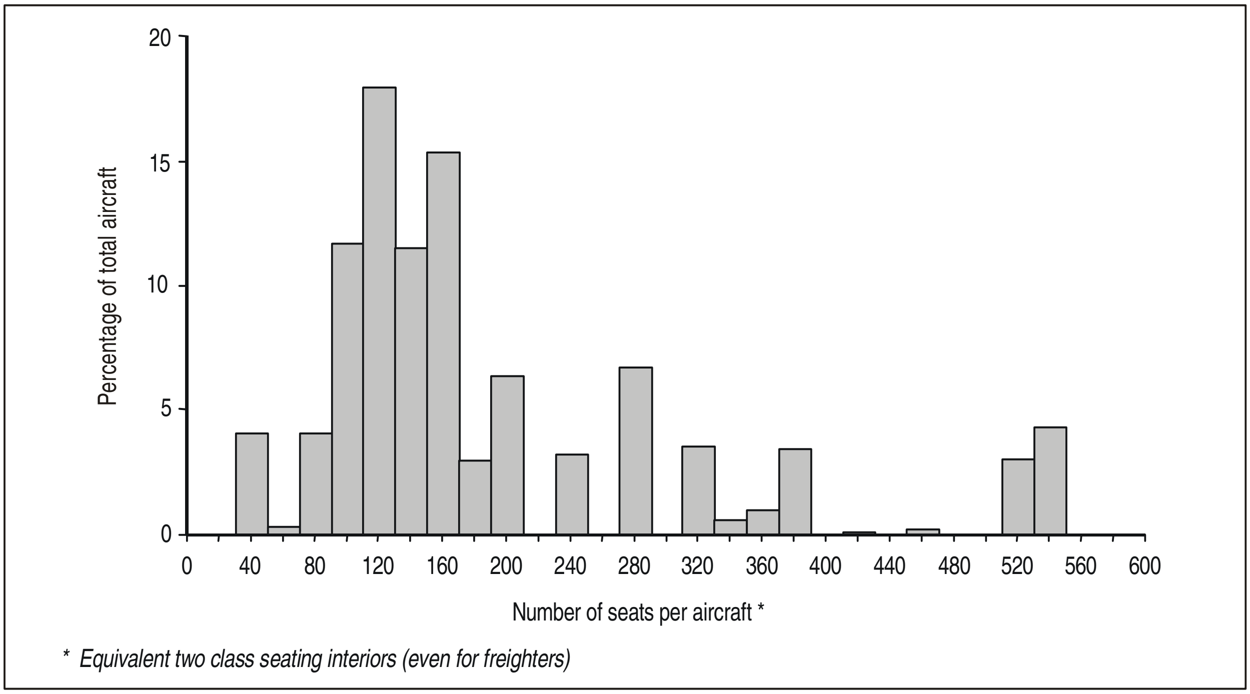


Figure 3-2. 1999 worldwide commercial jet transport fleet (including freighters)

3.5 The demand for air transport services is driven by worldwide economic activity and by the desire for an improved quality of life by many people of all nationalities. The very wide spectrum of sizes, ranges and usage of commercial jet transport is the direct result of cooperative efforts by air transport designers, manufacturers, financiers and airlines to efficiently match the supply of air transport services to the demand for passenger and cargo air transport. Such demands are very time-sensitive and depend on the needs of each individual origin and destination transport marketplace. Year-to-year growth, seasonal variations, the day of the week, and even the time of day are important time parameters that affect demand. Therefore, the efficient offering of a supply of air transport services is not sufficient. The success of supply-demand matching is a major factor in determining the total economic and energy efficiency of the air transport system. Since air transport services are offered in response to demand, geographical concentrations of air services exist primarily where people live and where business activities are highest. The resultant air traffic is especially dense in Western Europe, centred in the Benelux region; in the north-eastern metropolitan corridor of the United States; and over much of Japan. There are also several connecting hub airports around which air traffic is very dense. Major intercontinental traffic flows exist over the North Atlantic, the North Pacific, and between Europe and Asia. These regional concentrations and intercontinental flows dictate that the vast majority of all air transport services occur in the mid-to-high latitudes of the northern hemisphere. Although providing important transport services to people and business activity everywhere, air traffic to, from and within the southern hemisphere is relatively sparse.

TRENDS

3.6 The sheer size and the maturing technological and economic realities of the air transport industry mean that the time required to replace all existing aircraft with newer, improved types is quite long.

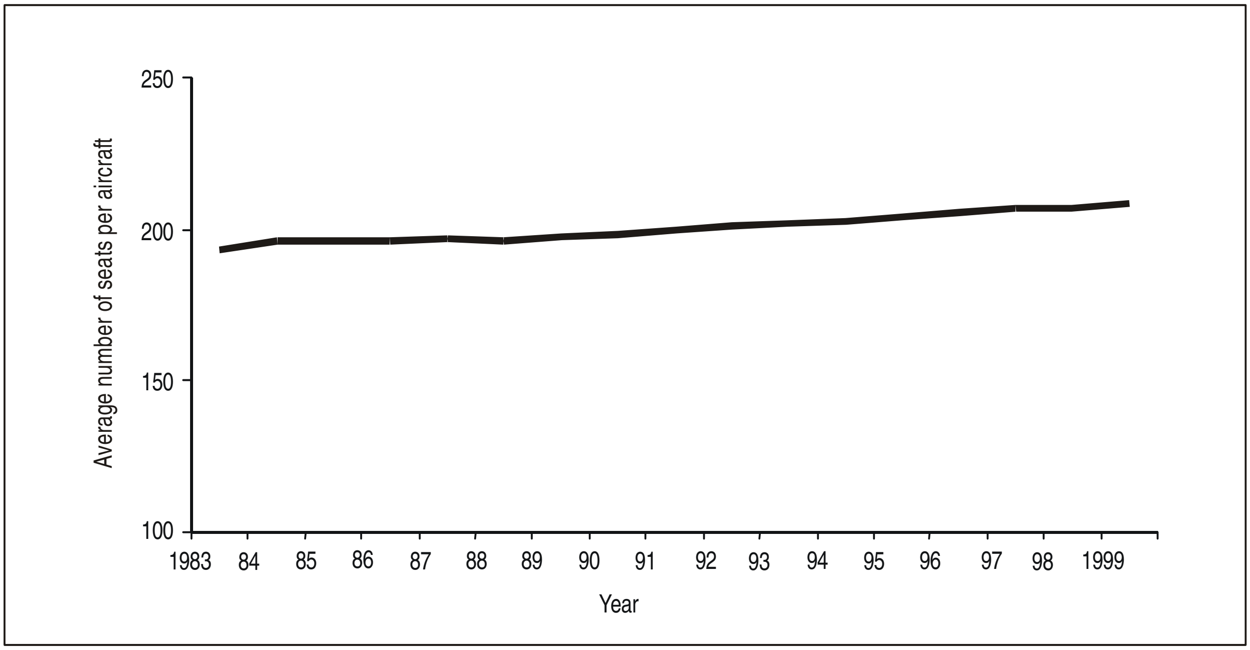


Figure 3-3. Average number of seats per aircraft over the last two decades

3.7 The combined time to:

a) research and develop new, economically effective technologies;

b) design and incorporate new technologies into efficient, new aircraft designs;

c) sell, purchase and manufacture thousands of newer technology aircraft; and

d) operate newer technology aircraft in airline service for their economic lives;

can total sixty years or more.

3.8 Nevertheless, there are many continuing opportunities for technology research and development aimed at improvements in the economics of the air transport system and in the energy efficiency thereof. As discussed elsewhere in this circular, not all efforts are being focussed on the aircraft themselves. Improvements in airline reservation systems, aimed at operating aircraft with a higher load factor, are an important trend. New developments and procedures in air traffic management (en-route as well as around airports) also aim at improved safety capacity and efficiency. Operation of airports themselves offer opportunities for better energy efficiency.

3.9 There is an economy of scale in the art and science of commercial aircraft design. That is, for the same technology level, a larger aircraft will usually be able to offer a lower cost per seat and be more fuel-efficient per seat than a smaller aircraft. However, as discussed above and in Chapter 12, the more relevant measure of air transport efficiency is how well the offer of a seat is matched with the demand for that seat. This matching challenge is a reality of air transport history that is very likely to continue to be a robust, repetitive reality. Therefore, the future of air transport will continue to demand a wide variety of sizes and ranges of efficient aircraft types in order to achieve a truly efficient total air transport system.

3.10 The historical growth in average number of seats per aircraft over the last two decades (shown in Figure 3-3) is the combined result of several industry trends, some of which are:

a) an air travel growth average of about 5.5 per cent annually from 1983 through 1999;

b) the consolidation of airlines into fewer and larger companies and alliances;

c) increasing congestion in the air and at certain important airports;

d) increased use of "hub-and-spoke" route patterns;

e) additional services by newly-formed niche airlines;

f) the development and use of longer-range, smaller-sized aircraft;

g) the introduction of more frequent services on existing routes; and

h) the introduction of services on new routes.

3.11 The next few decades will probably see the continuation of these industry trends. Anticipated overall market growth and infrastructure limitations will tend to result in an increase in average aircraft size. Fragmentation of markets, liberalization of governmental restrictions, and privatization of airlines, as well as other service providers, will tend to encourage the use of smaller aircraft. The anticipated expansion of regional jet fleets with less than one hundred seats will definitely tend to slow the growth in average aircraft size. Nevertheless, the sum of all factors will still likely result in some continued growth in average aircraft size.

3.12 There are a very large number of commercial jets in the worldwide fleet. Therefore, the improvement in fleet-wide fuel efficiency will be relatively slow as new aircraft are introduced to accommodate growth and replacement. On average, every year about 7 per cent of the seats in the fleet are new, 4 to 5 per cent are for growth and 2 to 3 per cent are for replacement of retired aircraft. As modern, more fuel-efficient aircraft are introduced and older, less efficient aircraft are retired, the fuel efficiency per seat-kilometre of the total fleet is forecast to improve at about 1 per cent per year for the next two decades; see Figure 3-1.

3.13 The study, research and development of new technologies aimed at reducing airline emissions are complex tasks. Everyone involved needs to be diligent in avoiding unintended negative consequences. This is especially true in the cases of conflicting environmental objectives (i.e. aircraft noise reduction versus the reduction of various engine emissions). For example, operating engines at higher combustor temperatures can have benefits in reducing fuel burn (and therefore CO_2), but also tends to increase the generation of NO_x. It is clearly feasible to consider improvements that meet only one, or a few, environmental objectives, but which work against others. Conflicts between noise reduction and improved fuel efficiency are addressed in Chapter 8.

FUTURE TECHNOLOGICAL IMPROVEMENTS

3.14 There have been many advances in avionics and flight deck automation that are not being fully utilized. Most modern jets, and almost all those being produced today, have on-board avionics and flight deck capabilities that could be used to improve the capacity and the efficiency of the air traffic management system. What is currently missing is a uniform, compatible, ground-based infrastructure and acceptable air traffic operating procedures to take advantage of the technical capabilities inherent in many aircraft. There are several studies and initiatives under way around the world to remedy these shortfalls, and much progress is anticipated during the next several years (see Chapter 6).

3.15 The aircraft and engine manufacturers' representatives on CAEP support the IPCC projection of a 20 per cent improvement in aircraft fuel efficiency between 1997 and 2015. Although results of the ongoing research effort are promising, manufacturers have expressed concerns relative to the rate of future progress due to uncertain research funding and increasing difficulty in translating NO_x reduction technology into production hardware. These problems are aggravated by the fact that with the significant progress that has been made to date, it is becoming increasingly difficult and expensive to improve on current technology.

3.16 In the IPCC Special Report, an engine fuel efficiency improvement of 10 per cent was projected for the 1997 to 2015 time period. Individual engine manufacturers have indicated to CAEP that they are generally in agreement with this projection:

a) Pratt and Whitney projects a 19 per cent reduction in fuel consumption per passenger-kilometre for a B777-200 aircraft relative to today's PW4084 engine;

b) Snecma predicts fuel efficiency improvements of 4 to 7 per cent by 2010 and 8 to10 per cent by 2020;

c) General Electric expects to improve fuel efficiency by 10 per cent by 2010. This projected improvement depends on thermal and propulsive efficiency improvements of 4.5 per cent, with the remaining 5.5 per cent improvement from an improved thrust/weight ratio; and

d) Rolls-Royce has a target of a 10 per cent fuel efficiency improvement by 2010.

3.17 CO_2 targets presented by Snecma in Table 3-1 are typical of the goals presented by each of the manufacturers. The research targets assume that government initiatives, such as the European Commission's 5th Framework Programme, and the Three Pillars for Success Programme of the United States National Aeronautics and Space Administration (NASA), are fully supported and that no fundamental technical barriers are encountered. Production targets assume that the potential gap between initial technology demonstration and product introduction, as discussed below, is addressed. All of the targets assume continued use of current jet fuels. It should be noted that the CO_2 targets beyond the year 2020 will be strongly influenced by the needs of new aircraft designs that are evolved in that time period. Also, the ability to meet NO_x targets will be reduced by the increased combustion pressure and temperature levels that will likely result from attempting to achieve the CO_2 targets in future engines.

Table 3-1. CO_2 targets

	1990	2010	2020
Research targets	Base	−7/−10%	−12/−20%
New production engine targets	+3/+5%	−4/−7%	−8/−10%

3.18 Translating technology into production hardware can occur only if several key conditions are met. The technology must be ready, market requirements must be clear and the new aircraft must be financially viable. Engine and airframe manufacturers advance technology separately, but coordinate to advance the airframe and engine integration technology together. Advances have been introduced both incrementally and as large-scale improvements. When viewed over several decades, they portray a relatively steady and continuous rate of improvement. Due to uncertainties in future market demands, it is not possible to accurately predict the details of any specific aircraft that might be introduced in the 2010 time frame. However, the assumption of continued efficiency improvement for average new production aircraft is reasonable.

3.19 There are two parts to the process of introducing new technology into production. The first part is to develop the technology concept to the point that it can be demonstrated in a realistic environment. The second is to transition the concept from the demonstration phase into a viable product with acceptable risks.

3.20 The difficulty of translating technology into production hardware has increased in recent years because the time available to design and certificate a new engine has been reduced, while at the same time, new products are expected to meet exceptional standards of efficiency, reliability and durability from the start of production. In the past, an engine development cycle lasting several years provided time to finish technology development in parallel with the engine development process. In recent years, the time available to design and build the first certification engine under a new engine development programme has been reduced to twelve to sixteen months. The engine development cycle is driven by the airframe development cycle that allows as little as two and a half years from aircraft go-ahead until entry into service. In order to meet such a schedule, it is necessary to develop an engine technology to a very high level of readiness before the aircraft development cycle is initiated.

SUMMARY

3.21 The record of the air transport system in making improvements in jet transport fuel consumption has been impressive. Technical advances have been achieved in engines and airframes and in the systems for both. The economic success of the air transport industry is reflected in the current use of about 14 000 jet aircraft worldwide.

3.22 Future growth needs to continue to be accomplished in an environmentally responsible manner. Careful attention is needed in order to focus improvements in areas with the potential for the most environmental benefit. The prospects for research and application of new technologies hold great promise for advances that will continue to improve the environmental performance of air transport. However, the rate of introduction of that technology into airline fleets will be slower.

3.23 It is generally agreed that fuel efficiency improvements of about one per cent per year will be achieved between the present and 2015.

Chapter 4
MAINTENANCE

INTRODUCTION

4.1 This chapter is divided into two main parts:

a) airframe maintenance and aerodynamic deterioration; and

b) engine maintenance and performance deterioration.

4.2 Examples are given of fuel penalties for deviations from the baseline aircraft. These assume the example aircraft is flown for 3 500 hours per year over an average stage length of 1 000 nautical miles (NM). The examples which follow are for an A300 aircraft. Actual fuel penalties will, of course, depend on many factors, including aircraft type, the way the aircraft is operated and the actual maintenance discrepancy. Aircraft manufacturers produce guidance material for specific aircraft types and models.

AIRFRAME MAINTENANCE AND AERODYNAMIC DETERIORATION

Critical airframe areas

4.3 Some of the largest penalties in terms of excess fuel consumption are caused by increased drag resulting from poor airframe condition. Excessive gap tolerances, badly fitting hatches and covers, fairing deterioration and the incomplete retraction of moving surfaces are all potential fuel wasters. Bumps, dents and scratches must also be taken into account when considering aerodynamic cleanliness. Even surface dirt, on all parts of the airframe, can considerably increase drag. The fuel-burn penalty incurred from drag-inducing items is largely dependent upon their location and extent, different areas of the airframe being more sensitive to alterations in their optimum aerodynamic smoothness. An example of a zonal classification for drag sensitivity divides the whole aircraft into three zones:

a) *Zone 1: High aerodynamic smoothness required.* This zone includes the forward fuselage, the engine cowl and pylon, the upper wing surface from leading edge to spoiler (approximately half chord) and the lower wing over the whole slat surface, and both surfaces of the vertical and horizontal stabilizers, extending to the rudder and elevators respectively. Deviations in surface profile and rigging tolerance deviations in this zone result not only in significant drag increases but can also adversely affect the stability, controllability and safety margin of the aircraft.

b) *Zone 2: Good aerodynamic smoothness required.* This zone consists of the centre fuselage, and the areas of the wings, empennage and engines not included in Zone 1.

c) *Zone 3: Normal aerodynamic smoothness required.* This zone covers the aft fuselage. Deviations in surface profile in this zone do increase drag and, subsequently, fuel consumption, but the actual increments are less significant.

Doors

4.4 Attention must be given to the rigging and sealing of doors since substantial fuel penalties can occur. A misrigged door will not only give rise to a step on the airframe surface which spoils clean airflow, but may also imply badly fitting pressure seals and consequent air leakage. In both cases, turbulence will cause increased drag.

4.5 Table 4-1 shows examples of the consequences of mismatched doors. It is worth noting that one hour of corrective action represents an average economy equivalent to 500 litres of fuel per aircraft per year. Passenger comfort will also be enhanced since air leaks increase cabin noise levels and can cause local cold temperature areas inside the cabin near the doors. Table 4-2 shows the effect of missing or damaged door seals.

Control surfaces

4.6 Although control-surface rigging is probably more carefully monitored than that of inspection hatches and cover plates, there is still likely to be room for improvement in most fleets. Quite apart from affecting the aircraft handling characteristics, the degree of accuracy with which control surfaces are rigged can contribute considerably to the final efficiency of the aircraft. Some examples of control-surface misrigging and the consequences thereof are shown in Table 4-3.

Skin dents and surface roughness

4.7 A certain amount of deterioration of the airframe surface comes about during normal operational use. Such things as bird strikes, grit abrasion, servicing and minor baggage-handling mishaps all leave their marks. Such damage, particularly on the engine nacelle, can have serious consequences on fuel burn. It should be emphasized that paint blisters should also be taken into account when considering scratches and surface roughness. Each defect alone does not represent very much, but collectively they can add up to a considerable amount. See Tables 4-4 and 4-5 for sample effects.

Parts missing from the airframe

4.8 The sort of items that tend to be missing from the aircraft structure include rubber seals and fairings, cover plates and small inspection hatches. However, sometimes larger items may not be installed at all. Aircraft minimum equipment lists and configuration deviation lists allow the aircraft to be dispatched without these parts installed since they do not affect the aircraft's safety. However, their absence will contribute to increased fuel burn in the same way as misrigged control surfaces. Table 4-6 gives examples of the related penalties.

Table 4-1. Examples of the estimated fuel penalty in litres per year per aircraft for a given step and per millimetre of mismatch

Item	5 mm step	10 mm step
Passenger front door	9 100	21 100
Passenger rear door	2 950	6 750
Emergency exit, aft of wing	3 800	8 900
Cargo door forward	8 900	20 800
Cargo door aft	4 850	11 300
Main landing gear door	5 200	14 000
Nose landing gear door	8 450	19 200

Table 4-2. Examples of the estimated fuel penalty in litres per year per aircraft for missing door seals

	Values for each 5 cm missing	
Item	Sides	Top or bottom
Passenger front door	1 550	800
Passenger rear door	1 000	550
Cargo door forward	1 500	800
Cargo door aft	1 100	550

Table 4-3. Examples of the estimated fuel penalty in litres per year per aircraft for control surface misrigging

	Height		
Control surface	5 mm	10 mm	15 mm
Slat	12 300	28 200	40 500
Flap	6 050	10 500	13 500
Spoiler	14 000	32 300	50 200
Aileron	6 050	10 500	13 700
Rudder	7 450	12 900	16 700

Table 4-4. Examples of the estimated penalty in litres per year per aircraft for single dents or blisters in Zone 1 areas

Item	Surface area damaged	Depth	
		5 mm	10 mm
Fuselage	20 cm^2	72	72
	80 cm^2	274	304
Wing	20 cm^2	87	95
	80 cm^2	372	407
Tail	20 cm^2	46	99
	80 cm^2	95	186

Table 4-5. Examples of the estimated fuel penalty in litres per year per aircraft for 0.3 mm of skin roughness over 1 m^2

Affected area	Fuel penalty
Fuselage	3 350
Wing skin (upper)	12 400
Wing skin (lower)	5 950
Tail	5 800

Table 4-6. Examples of the estimated fuel penalty for parts missing from the airframe

Type of deterioration	Fuel penalty (litres per year)
Absence of seal on movable surfaces:	(per metre of missing seal)
Slats (span-wise seal)	14 000
Flaps and ailerons (chord-wise seal)	9 500
Elevator	6 300
Engine cowl: One pressure relief door missing	134 000
	269 000
	364 000
Spoiler or airbrake: Trailing edge missing from one	5 950
Cargo door: Lock cover plate missing	1 000
Fin/fuselage junction: Fairing and rubber seal missing	39 500
Elevator: Bearing access cover missing	19 700

Skin joints

4.9 Wherever skin panels join, there is a potential interruption in aerodynamic smoothness. The gaps between these skin joints should be smoothed out or faired with filling compound. Failure to do so will cause small fuel penalties when the air flows over the joint.

4.10 The penalties incurred by lap joints where the air flows parallel to the step are negligible. However, when the lap joint is at right angles to the airstream, the penalties are multiplied by a factor of 100 to 200.

Instrument accuracy

4.11 Inaccurate instruments can be another source of increased fuel consumption. False readings, however small, may mean that the aircraft is not achieving its optimum performance. In terms of fuel conservation, the two most important instruments are the machmeter and the altimeter. A single machmeter under-reading of 0.01 can cost 170 000 litres per year in unnecessary fuel burn. An altimeter error of only 100 ft can cost 100 000 litres per year in unnecessary fuel burn.

ENGINE MAINTENANCE AND PERFORMANCE DETERIORATION

General

4.12 Design features that provide for long-term clearance control, leakage control and erosion resistance are included in modern engines.

4.13 The major cause of deterioration of specific fuel consumption (SFC) in modern turbofan engines is erosion, which can change airfoil contours and surface finishes. Increases in radial clearances between blades and vanes and their respective sealing surfaces, as well as increases in radial clearances of rotating/stationary seals, also contribute to loss of performance. The contribution of each of these factors to engine deterioration is shown in Figure 4-1.

4.14 For guidance, a one per cent deterioration in SFC costs approximately U.S.$10 per engine flight hour (assuming fuel costs of U.S.$0.26 per litre). Engine design varies considerably so the examples given are not applicable to all engine types.

Engine gas path

4.15 The engine gas path is the major area in which engine performance retention or improvement can be affected. This is the area in which the most significant aerodynamic and thermodynamic deterioration occurs and where the largest performance restorations can be made. Degradations in the fan section, which can cause performance deterioration, are often not recognized. There are several of these that can be recovered by routine maintenance actions without removing the engine from the aircraft. Table 4-7 lists examples of these for a particular engine, with the corresponding estimated penalties if not recovered.

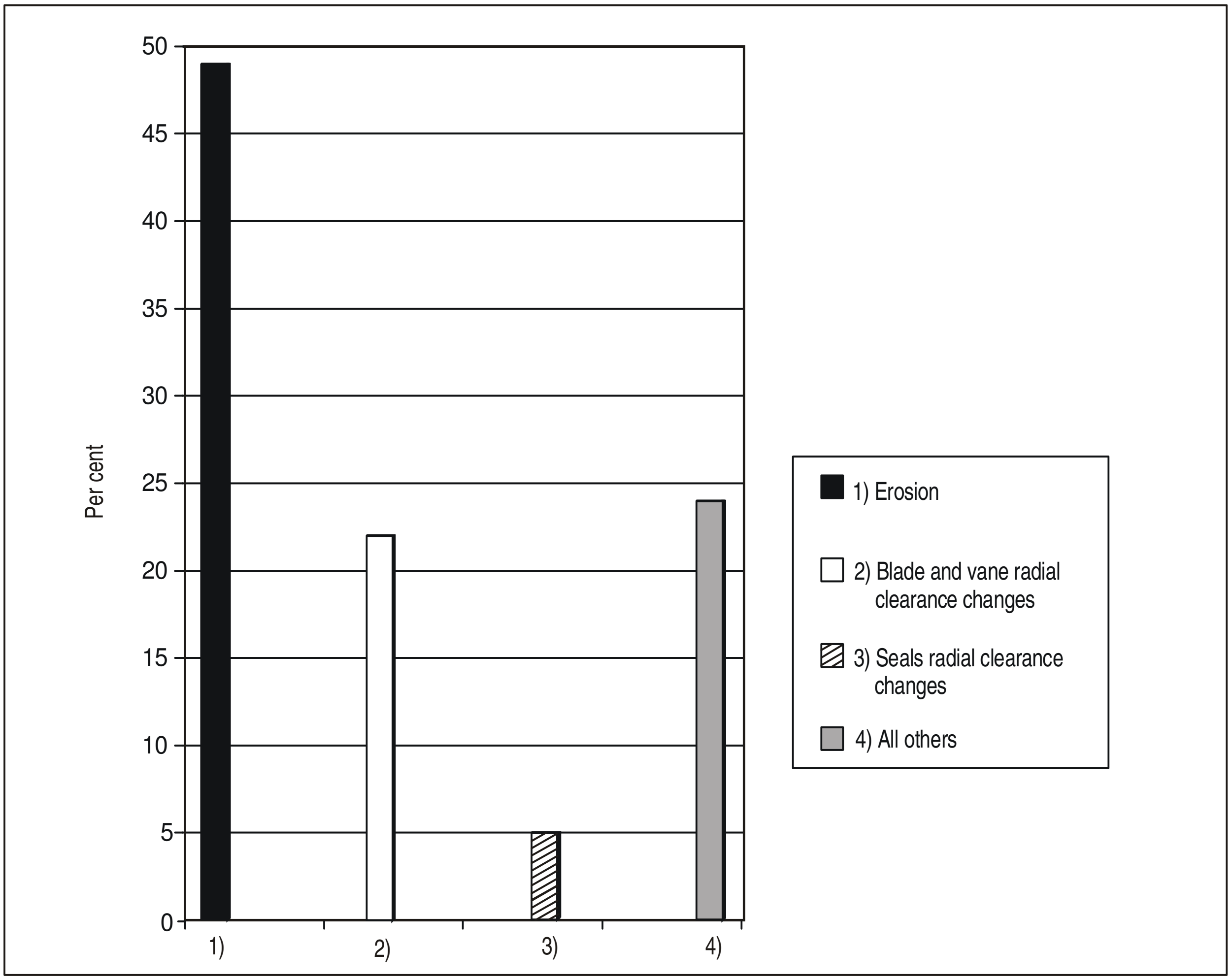


Figure 4-1. Example of primary causes of SFC deterioration in a modern turbofan engine

4.16 An accumulation of dirt and rubstrip debris will cause performance losses that increase with the amount of contamination. Some of this loss can be recovered by periodic fuel nozzle cleaning (some engines only) or water washing. Periodic engine water wash serves to retain performance and can readily be accomplished without engine removal. Although the resulting improvement in performance varies depending on the degree and type of gas path contamination, a substantial improvement is usually realized. The part of the engine gas path that is most accessible and which has a heavy impact on fuel consumption is the fan. Fan blade leading-edge erosion, deterioration of the fan rubstrip and damage to the fan blades, rubstrip or low-pressure compressor inlet are easily detected by visual inspection. Many of these components can be repaired or replaced, if necessary, without engine removal.

Engine systems

4.17 Engine systems such as the fuel control system, the surge bleed system, the pneumatic system and the turbine case cooling system can have an adverse impact on fuel consumption if out of trim or malfunctioning. In certain cases, high exhaust gas temperature (EGT) and/or throttle stagger will indicate

Table 4-7. Examples of engine deterioration

Item	Condition	Cruise TSFC	Estimated fuel penalty (litres per engine per year)
Fan blades	Leading edge erosion Foreign object damaged/blended blades	Up to 0.6 per cent Up to 0.3 per cent	86 500 43 300
Fan rubstrip	Wear resulting in increased tip clearance	0.2 per cent for a 12.5 mm increment	30 000
Fan flow path fairing	Leading edge erosion	Up to 0.7 per cent	11 700
Fan/compressor airfoils	Accumulation of dirt	Up to 1.0 per cent	146 000
Compressor airfoils	Foreign object damage observed at low compressor inlet guide vanes	Up to 0.3 per cent	43 000
Engine core	High time/cycles	Up to 2 per cent	293 000
First stator	Anti-ice failed "on"	1.7 per cent	246 000
Idle trim	Trim 1 per cent high		7 200

the need for immediate maintenance action. However, other more subtle deficiencies may go undetected for a period of time. An indicator in the cockpit will accompany certain system malfunctions. Others may require a visual inspection, a trim run or a troubleshooting procedure to verify their existence. Table 4-8 lists examples of those systems which are most likely to have an adverse impact on fuel consumption.

4.18 For those engines with a high pressure compressor (HPC) variable stator vane system, tests by the engine manufacturers have demonstrated that its scheduling is important from both a stall and a specific fuel consumption (SFC) standpoint. Generally, stators that operate further open than the optimum result in increased SFC and decreased stall margin. This can result, for example, in an SFC deterioration of about 0.3 per cent in cruise.

4.19 Significant performance losses can occur due to leakage of high-pressure air from engine pneumatic ducts and/or aircraft environmental control system ducts. High undercowl nacelle temperatures may indicate such leakage, and potential penalties can be as high as a one per cent SFC deterioration, as well as a reduction in the life of other components located in the nacelle.

Nacelle and cowling

4.20 The engine nacelle and cowling require careful attention to prevent them from causing performance deterioration. Table 4-9 gives examples of these potentially detrimental effects.

4.21 Cowl load-sharing reduces bending of the engine due to thrust and/or g-loading and serves to maintain tighter running clearances. Seal deterioration that allows fan air to enter the nacelle or allows air

Table 4-8. Examples of engine system deterioration

Item	Condition	Cruise TSFC	Estimated fuel penalty (litres per engine per year)
Turbine case cooling system	Fully or partially inoperative (mechanical system)	0.9 to 1.9 per cent (penalty depends on engine configuration and altitude)	133 000 279 000
	Fan air leakage (supply system)	Up to 0.5 per cent	73 200
	Turbine cooling air supply leakage	Up to 1.4 per cent	206 000
Buffer air supply	Air leakage	Up to 0.3 per cent	43 300
Stator anti-ice plumbing	Air leakage	Up to 1.7 per cent	246 000

Table 4-9. Nacelle and cowling — Examples of deterioration penalties

Item	Condition	Cruise TSFC	Estimated fuel penalty (litres per engine per year)
Fan duct and thrust reverser seals	Deteriorated seals due to age and door opening and closing	Up to 0.2 per cent	30 000
Cowl load sharing system	Misadjustment/wear in thrust reverser cowl load sharing system	Up to 1 per cent	146 000
Pre-cooler system	Fan air leakage	Up to 0.5 per cent	73 200
Service bleed system	Bleed air leakage	Up to 1.3 per cent	193 000
Service bleed system/ reverser activator air supply	Bleed air leakage	Up to 1.8 per cent	266 000
Translating cowl seals	Poor fit	Up to 0.35 per cent	58 200
Fan reverser static structure seals	Poor fit	Up to 0.28 per cent	46 600
ECS duct	Poor bellow fit	Up to 0.13 per cent	21 700
Fan frame	Deteriorated seals and strut end leaks	Up to 0.04 per cent	6 650
Fan frame to reverser seals	Deteriorated seals	Up to 0.05 per cent	8 350

in the nacelle to be exhausted normal to the fan airstream will result in increased fuel consumption. A less-than-optimum nacelle surface condition, i.e. surface roughness, dents and mismatched panels, will have an adverse impact due to increased drag, as on other Zone 1 parts of the airframe.

4.22 Leakage of fan airstream from the nacelle/reverser system can occur and can result in an SFC loss. Tests by engine manufacturers have shown that a 65-sq-cm leak area can result in a cruise SFC loss of 0.6 per cent. Tests also showed that leak areas as large as 135 sq cm can occur in service.

Ground-run practices

4.23 The practices that maintenance crews follow when operating engines during ground runs can have a very large impact on performance retention. Maintenance manuals give specific warnings against rapid throttle movements. The most damaging throttle movements are those that reduce the engine thrust from prolonged high power to speeds near idle, then hold the low speed for insufficient time to allow adequate cooldown, and then return once again to a high power. Calculations and engine experience demonstrate that, on some engines, such a throttle sequence with, for example, only a two-minute cooldown at idle can result in a significant rub between the high pressure turbine (HPT) blade and shroud of such a magnitude as to cause a change of 12°C in EGT at take-off and a deterioration of 0.5 per cent in cruise SFC.

4.24 As discussed earlier, erosion is a cause of some of the performance loss which engines experience. While much of the erosion probably occurs during flight operations, some of it can happen during ground runs for propulsion system maintenance. This portion of the loss can be reduced if reasonable care is taken to avoid engine run-up on or near surfaces that have loose or flaking material.

4.25 Maintenance crews are in a good position to detect unusual performance conditions and to take corrective action. Ingestion of large quantities of sheet ice may cause the loss of unusually large amounts of abradable material from the fan stator rub surface and a correspondingly large performance loss. There are many other possible unusual conditions that can be detected and appropriately acted upon by alert maintenance personnel.

SUMMARY

4.26 Although performance retention is largely designed into the engine and airframe, and original performance is largely restored during overhauls, line maintenance activity is very important in detecting performance deterioration.

4.27 Careful attention to the items highlighted will prevent unwarranted increases in fuel consumption. Periodic visual inspection of the airframe and engines, flight crew reports, engine condition monitoring and aircraft performance trend monitoring aid in the identification of components which require maintenance action. Often, a small investment of time on a repair will result in a substantial fuel saving. Good maintenance practices minimize costs and unnecessary fuel consumption.

Chapter 5
MASS REDUCTION

INTRODUCTION

5.1 Mass reduction can be divided into two main areas:

a) reducing the empty aircraft mass; and

b) minimizing the carriage of fuel not used on the flight.

5.2 Examples of the benefits of mass reduction are shown in Table 5-1.

EMPTY AIRCRAFT MASS

5.3 Two major areas in which there is scope to reduce empty aircraft mass are addressed briefly here. These are safety and commercial equipment, such as in-flight entertainment systems. The need for certain items of safety equipment is generally standardized worldwide (see Annex 6 — *Operation of Aircraft*), but there are a few items where there may be scope for discussion with State regulatory authorities about their possible reduction. This is especially so if they are very unusual or unique to a particular State, such as the

Table 5-1. Impact of a reduced mass of 2 250 kg

	Fuel saving	
Aircraft type	**Litres per year per aircraft**	**Percentage**
B707	614 000	0.5
B727	422 000	2.4
B737	198 000	5.0
B747	1 310 000	0.6
DC-9	243 000	3.5
DC-10	272 000	0.9
MD-11	253 000	0.8

amount of emergency oxygen required. It is worthwhile to occasionally review the items carried for commercial or safety reasons to ensure they are still needed and also to consider removing them from flights where they are not needed, e.g. safety equipment required only for overwater flights. This example illustrates a difficult decision which has to be made since a significant proportion of emergency landings on water have been made very close to land, on flights where overwater equipment is not legally required.

5.4 Specific examples of mass reduction include:

a) *Reduction in the amount of drinking water.* Rather than always filling up the tanks to the maximum, it may be possible to vary the amount loaded to suit the flight.

b) *Removal of water coolers.* For example, a reduction of 18 kg resulted from the removal of a water cooler that was not being used.

c) *Aircraft painting.* Painting is mostly a marketing issue, but paint is also used for corrosion protection and to preserve a good surface finish. Minimizing the amount of paint used can significantly reduce the mass.

d) *Installation of "zone dryers".* Installation of zone dryers in some aircraft may reduce moisture accumulation between the airframe and the side-wall panels.

e) *Reduction in the contents of the fly-away-kits.* The contents of the fly-away kits carried on-board for supporting the aircraft when it is away from base should be reviewed.

f) *Removal of the brake cooling fan.* This may, however, increase minimum turnaround times.

g) *Removal of windshield rain repellent system.* No longer used.

h) *Removal of the second APU generator.* For example, one generator was sufficient for domestic operations, resulting in a 45 kg reduction in mass.

i) *Lighter cargo containers.* Lighter aluminium containers are being used, and containers made from carbon fibre are also available.

j) *Lighter safety equipment.* Lighter types of items such as life rafts and life jackets may be available.

CENTRE OF GRAVITY

5.5 A mass-related issue is the position of the centre of gravity, which varies according to the distribution of the load on each flight. The further the centre of gravity is from its optimum position, the less aerodynamic the aircraft will be, with increased trim drag, which means more fuel being burned for a given flight condition. The available centre of gravity range is limited by stability considerations, but it is sometimes possible to redistribute cargo or passengers in order to move the centre of gravity nearer the optimum position. Some aircraft have a fuel tank in the tail which facilitates achieving a more efficient centre of gravity position.

5.6 The fuel saving can be as much as 0.05 per cent for each one per cent that the position of the centre of gravity is moved, but this varies with flight condition and aircraft type.

FUEL TANKERING

5.7 Fuel tankering — the carrying of fuel for subsequent flights — is done for a number of reasons. There is some potential for reducing the amount of tankering; however, significant differences in fuel prices between airports, some of which are set or controlled by national governments, encourages tankering. Even within States, fuel prices can vary greatly. For example, in one European State there are fuel price differences of up to 15 per cent. The cost of the fuel consumed in carrying extra fuel, and any loss in payload, can be more than offset by the difference between the price of fuel at the departure point and a destination where fuel could be loaded. Airlines need to check frequently on fuel prices to ensure that tankering is still justified by the fuel cost differential. Factors that can affect fuel cost and decisions on tankering include:

a) fuel quality is not assured at the destination airport;

b) appropriate fuel is not available; and

c) rapid turnaround is required (to minimize the risk of losing slots, tankering is an option; limited turnaround time, allowing insufficient time for refuelling, is a particular concern for airlines at airports that are heavily congested).

5.8 Smaller aircraft on short routes often carry sufficient fuel to complete several flight segments without refuelling in order to minimize time spent at intermediate airports (e.g. shuttle-service operations, operations with critical schedule and curfew problems and/or operations at remote airports with minimal or unreliable ground support services).

5.9 The additional fuel required to carry the extra, tankered fuel is dependent on the aircraft's characteristics and other factors but is of the order of 2 to 4 per cent of the total fuel uplift per flight hour. Clearly, the possibility of fuel tankering may be limited on longer flights where too much extra fuel could reduce payload. One airline has established a threshold for tankering of a fuel cost differential of U.S.$12 to $15 per tonne for short-range flights and up to U.S.$25 per tonne for long-range flights. In Europe, there are many examples of fuel price differences, including as much as U.S.$120 per tonne between major airports. One airline tankers 90 000 tonnes of fuel per year, which increases fuel consumption by 6 500 tonnes per year but saves U.S.$4 million.

EXTRA FUEL

5.10 Another possible reason for carrying excess fuel is overestimation of payload. For example, increasing the assumed average passenger mass from 95 kg to 105 kg could increase the planned block fuel by one per cent.

5.11 See Chapter 8 for comments on fuel reserve policy.

SUMMARY

5.12 The issue of mass reduction often centres on a trade-off between safety and fuel efficiency. Some safety equipment is not needed on all flights, and it may sometimes be practical to remove it. All flights should land with a significant amount of reserve fuel on-board, but reducing this to the amount required for safety purposes is an obvious focus for mass reduction.

5.13 A review of non-essential on-board items may present opportunities to reduce their quantities or eliminate them altogether, at least from some flights.

5.14 Fuel tankering is another example of carrying excess fuel for safety, financial or operational reasons. Tankering can be minimized by improving fuel quality and supply where needed and harmonizing fuel prices.

Chapter 6
AIR TRAFFIC MANAGEMENT

INTRODUCTION

6.1 Communications, navigation, surveillance and air traffic management (CNS/ATM) systems are used by air navigation services to improve flight safety and to optimize the use of available worldwide airspace and airport capacity. These systems enhance communications between aircraft and air traffic managers, improve the navigation of aircraft and increase air traffic management's ability to monitor and control flights more efficiently. These systems have the potential to reduce delays by providing more direct and efficient aircraft routing. Optimizing the use of airspace and airport capacity reduces flight, holding and taxi times, distance flown and associated fuel consumption by flying more direct routes.

6.2 This chapter describes, in global terms, the conventional ATM system in the context of the operational phases of flight and highlights current constraints and limitations and the adverse effects they have on airport and aircraft operations, including unnecessary fuel burn and excessive emissions. This chapter also addresses the limitations of current ATM systems and changes anticipated in the future, based on new technologies and improved procedures, that will to lead to the creation of a more efficient and integrated ATM system. In addition, it provides a list of ATM concepts and measures which could be considered as potential opportunities to reduce fuel burn and associated emissions.

6.3 The subject is addressed, initially, in a general way, highlighting the major global ATM issues. Aspects of current regional situations in, and future plans for, Europe, the United States and other parts of the world are then summarized.

CNS/ATM COMPONENTS

6.4 Implementation of CNS/ATM systems will affect six stages of flight: taxi, take-off, climb, cruise, descent and landing. Various programmes involving ICAO, the United States Federal Aviation Administration (FAA), and the European Union's European Organisation for the Safety of Air Navigation (EUROCONTOL) are under way to assess the benefits of the new CNS/ATM systems regarding the safe, orderly and efficient movement of aircraft from the departure gate to the arrival gate. The ultimate goal is to develop and implement a seamless global air transportation management system that promotes the safe, orderly and efficient movement of commercial aircraft while providing reductions in fuel usage and associated emissions.

6.5 The ATM system is the combination of the air traffic control (ATC) function, which is responsible for ensuring proper separation between taxiing and airborne aircraft, and the traffic flow management (TFM) function, which is responsible for the oversight of airspace management and may reroute aircraft, assign departure times and routes, and delay departures and arrivals.

6.6 The Air Transport Action Group (ATAG) in their publication *The Economic Benefits of Air Transport* states: "Another priority for increasing the capacity of the world's airspace and airports is the timely and cost effective introduction of aircraft communications, navigation, surveillance and air traffic management (CNS/ATM) systems which utilize satellite based technologies."

6.7 The new data communications systems improve the information exchange between pilots, airline operations centres, and controllers and enable airborne and ground systems to communicate directly with each other concerning traffic and route conditions. Having better information enables the pilot to make a better choice about the preferred route, and the controller to manage the airspace and airport capacity more efficiently.

6.8 The introduction of satellite navigation provides not only a more accurate means of navigation but also permits routes to be chosen independently of the location of ground facilities. It improves flexibility in the terminal area and increases the availability of runways during poor weather conditions. Currently, only one global positioning system (GPS), provided by the United States, is operational and available to airlines. It is expected that other satellite navigation systems, such as the Russian Global Orbiting Navigation Satellite System (GLONASS) and the European Galileo System will be offered for use by civil aviation in the future.

6.9 The surveillance component of the CNS system — automatic dependent surveillance (ADS) — takes advantage of the improved navigation capabilities of modern aircraft and systems. Through an aircraft-to-ground data link, it provides the air traffic controller with more information on each aircraft flight path than is presently available in order to monitor aircraft flying over populated areas of the world. For aircraft operating in areas of the world that are sparsely populated, or flying over large bodies of water, it will replace pilot voice position reporting. This system is intended to allow air traffic control to monitor the aircraft at all times and provide the ATM system with an up-to-date picture of all air traffic.

LIMITATIONS OF THE CURRENT ATM SYSTEM

Airport and terminal control area operations and capacity

6.10 Limited airport capacity is recognized as one of the main constraints on continued growth in air transport, and this limited capacity results in congestion and delays. There is also a lack of adequate awareness and shared decision making in the ATC, ramp and taxi areas. In low-visibility conditions, movements are severely restricted, and there is increased risk of runway incursion. Insufficiently developed taxiways and aprons also limit runway usage and consequently affect airport capacity. Operational measures and limitations for noise control may have an adverse effect on accessing key airports. Automated ground-based systems for managing departures and arrivals efficiently are not available in most cases, and on-board aircraft automation is therefore underutilized.

6.11 Existing arrival and departure routes are often designed in a less-than-optimum manner. This is due, in many cases, to the fact that many terminal airspace structures have evolved slowly with time and were originally based upon the performance requirements of a previous generation of aircraft. In addition, the position and availability of ground-based navigation aids dictate the routes. These routes have become entrenched in the airport operating practices, and in some States changes to these routes are restricted by legislation. This has led to an often inflexible system that increases track distance flown and results in climb and descent restrictions, which, in turn, impact adversely on the environment.

En-route operations

6.12 The existing route structure sometimes imposes distance penalties compared with the most economic routes (generally great-circle routes), taking into account wind, temperature and other factors such as aircraft mass, charges and safety. Use of a fixed-route network results in concentration of air traffic flows at major intersections, which can lead to a reduction in the number of routes and available flight levels. Studies on penalties to air traffic associated with the European ATS Route Network suggest that, in 1999, ATM-related problems added an average of about 9 per cent to the flight track distance of all European flights en route and in the terminal control area. Insufficient international coordination in developing ground ATC systems and maximizing airport and airspace capacity exacerbates these problems.

Restricted and military airspace

6.13 The fundamental premise that every State has complete and exclusive sovereignty over the airspace above its territory can be traced to the ICAO *Convention on International Civil Aviation* (Doc 7300). States implement restrictions on the use of airspace for a variety of reasons, including technological limitations, political considerations and security and environmental concerns. However, by far the most important reason for restricting airspace is to accommodate the needs of States' military forces. Significant regions of airspace are still permanently reserved or restricted, thereby forcing civil air transport to circumnavigate these areas. Restricted airspace may prevent aircraft from minimizing fuel use and emissions by employing more direct routing between any two points.

6.14 The extent of the problem varies by region. In Europe, for example, a significant number of States apply the flexible use of airspace (FUA) concept. The basis for FUA is that airspace should no longer be considered as either specifically military or civil but should be considered as a continuum, shared in accordance with user needs and used flexibly on a day-to-day basis.

Regional variations

6.15 There are a number of differences between the air navigation infrastructure requirements of the various regions of the world. North America and Europe embody the differences between two complex and highly developed regions. However, these regions also share some similarities; increased capacity and efficiency, for example, are the primary drivers of implementation planning in both regions.

6.16 Integration and harmonization of various concepts and needs are required to achieve consistency in terms of safety and regularity and to attain the seamlessness required for efficient operations. Planning for the implementation of improved air navigation systems based on CNS/ATM therefore cannot be accomplished in isolation.

6.17 Regional air navigation plans are coordinated through the global mechanisms established by ICAO, and ICAO Standards and Recommended Practices provide a common framework for the planning and implementation of systems. EUROCONTOL also provides a common platform for planning and implementation while ensuring commonality and coherency. Regional bodies establish relationships to address their unique and specific needs and to work more rapidly than traditional mechanisms allow.

DEVELOPMENTS IN EUROPE

Introduction

6.18 A EUROCONTOL study in 1997 indicated that, for current European fleet operations, improvements to the ATM system could help to reduce fuel burn by 7 per cent for an optimum, unconstrained scenario.

6.19 In order to address the serious congestion and delay problems in Europe, which occurred in the late 1980s, the Transport Ministers of the then twenty-three European Civil Aviation Conference (ECAC) States took a number of decisions:

a) in 1988, Transport Ministers commissioned a Central Flow Management Unit (CFMU) to optimize the use of available ATM capacity throughout Europe; and

b) in 1990, they adopted the en-route strategy for the 1990s "to provide increasing airspace and control capacity in order to handle the air traffic expeditiously while maintaining a high level of safety".

6.20 A programme to implement this strategy, known as the European Air Traffic Control Harmonization and Integration Programme (EATCHIP), was established in 1991. EATCHIP, which is a major collaborative effort between European States and EUROCONTOL, has resulted in a significant increase in flights, while maintaining the required level of safety, but the delay problems still persist and are now being addressed by the European Air Traffic Management Programme (EATMP).

Progress on institutional arrangements

6.21 At their fifth meeting on the air traffic system in Europe (MATSE/5), on 14 February 1997, ECAC Transport Ministers adopted the ECAC Institutional Strategy for Air Traffic Management in Europe. Furthermore, the Ministers requested, for consideration at their next meeting, a proposal for a comprehensive "gate-to-gate" oriented ATM Strategy for the years 2000+, as a follow-up to the current ECAC En-route and Airport Strategies for the 1990s.

6.22 On 7 June 1997, representatives of States signed a revised EUROCONTOL Convention. Article 1 of the Preamble to this revised Convention stipulates that "the need to minimize, where this is feasible, *inter alia*, in operational, technical and economic terms, any adverse environmental impact" of ATM activities must be taken into account.

6.23 Pending the entry into force of the revised Convention, a number of interim actions have been taken to secure the effective implementation of its key elements, including improvements to the decision-making processes, actions to optimize the use of existing ATM capacity and new multinational arrangements.

EUROCONTOL ATM Strategy 2000+

6.24 In the years 2000+, European ATM must simultaneously generate extra airspace capacity to meet a growing demand while reducing unit costs and increasing safety levels. The EUROCONTOL ATM Strategy 2000+ was developed through a comprehensive consultation process with the aviation community. It describes the processes and measures by which the forecast increasing demand for ATM and airspace capacity may be satisfied, while improving aviation safety.

6.25 In order to be compliant with the revised Convention, environmental objectives and goals have been fully integrated into the EUROCONTOL ATM Strategy 2000+.

EUROCONTOL's role regarding environmental issues

6.26 The revised EUROCONTOL Convention and the adopted ATM Strategy 2000+ give EUROCONTROL a clear mandate to work on ATM-related environmental issues. At MATSE/6, the ECAC

Transport Ministers and the European Commission stressed the growing importance of taking environmental considerations into account when considering future air traffic growth.

6.27 CNS/ATM systems play a significant role in accommodating the continuing growth in air traffic. In addition, improvements to CNS/ATM can produce environmental benefits such as a reduction in fuel burn and emissions.

ATM OPPORTUNITIES IN EUROPE

Introduction

6.28 An important way of reducing the impact of air traffic on the environment is to create a more efficient and environmentally sustainable ATM system. This section describes nine examples of ATM concepts and measures that can be considered as potential opportunities to reduce aviation fuel burn and emissions. These concepts and measures can also be applied to other regions of the world. However, it should be noted that the main drivers of CNS/ATM improvements are to reduce CNS/ATM system inefficiencies such as congestion and delays and to increase airspace and airport capacity.

Gate-to-gate concept

6.29 Gate-to-gate is a concept that involves considering and managing a flight as a continuous event, from planning, through execution, to the post-flight activities. Its scope extends from the first interaction of the flight with ATC, through the execution of the flight, to the calculation of charges for the services received after it has taken place.

6.30 This goes beyond the current scope of ATM and involves the coordination of ATM processes with those of the airport and aircraft operators to provide a seamless and coherent management approach. It also requires the clear definition of agreed boundaries of responsibilities between various participants in terms of how and when they interact with a flight in the planning and operational stages.

6.31 The overall objective of the gate-to-gate concept is to define, develop and implement an integrated system approach to flights based on common information and uniform principles that provides for their smooth and seamless management throughout. An essential factor in realizing this objective is the timely sharing of validated and up-to-date information about flights and their operating conditions among all those involved in their planning and execution (aircraft operators, en-route ATC, air traffic flow management (ATFM), airport ATC and airport operators, including handling agents). This in turn enables decisions about a particular flight to be made by those best placed, based on the latest information available at the time, thereby enabling the flight to be dynamically optimized to reflect near-term or real-time operational circumstances. For example, an aircraft operator who is advised that an airspace restriction will be removed earlier than previously anticipated can negotiate a shorter, more direct route.

6.32 This concept requires new attitudes, a willingness to share information and the use of modern communications to distribute data, the only condition being to respect information confidentiality and security. The basic philosophy of collaborative decision making (CDM) is that all relevant and required information should be shared in real time amongst all those who have an interest in the progression of a flight, using modern communication methods. This will enable decisions to be based on accurate data about actual events; preferences, constraints and responses to be more flexible; and better management of available resources. The use of CDM in a very decentralized and well-distributed system is an advantage for individual participants: they can understand decisions, influence them and obtain their preferences more easily.

6.33 The gate-to-gate concept adopted by EUROCONTOL and applied in the ATM Strategy 2000+ will help mitigate aviation's effect on the environment. Since they encompass the entire spectrum of flight activities, gate-to-gate processes can ensure that all these activities are carried out in the most effective way. The gate-to-gate concept will also ensure that the services provided by ATFM, ATC and airports are coordinated, correlated and synchronized.

Central Flow Management Unit (CFMU)

6.34 To combat the increasing air traffic delays experienced in the 1980s, the ECAC Ministers decided, in 1988, to implement a Europe-wide centralized Air Traffic Flow Management Unit (CFMU) within EUROCONTOL. The CFMU has been fully operational since 1996. By matching air traffic demand with the available airspace and airport capacity, the CFMU procedures have resulted in significantly reduced airborne holding times which, in turn, benefits the environment by reducing unnecessary fuel burn. The ATFM function is to regulate the flow of aircraft in cases where the air traffic demand exceeds the available capacity. The key objectives of the ATFM part of the CFMU are to:

a) protect ATC from overloads; and

b) provide an optimum flow of air traffic by the best use of available capacity.

6.35 In order to prevent ATC overloads, the ATFM process in Europe will keep departing flights on the ground. When a potential overload is detected, the EUROCONTOL Unit in charge of AFTM sends a message to the aircraft operator concerned and to the local aerodrome ATC indicating a take-off time to prevent the overload. The benefit is that there is then no need for ATC to delay flights, once they are airborne, by using en-route holding or speed restrictions. The same applies to arrivals. The CFMU tries to limit the number of flights that will be holding in the arrival phase. This process has a considerable positive impact on the environment because there is, in principle, no fuel consumption when the aircraft is waiting on the ground without engines running, instead of holding en route or during its approach.

6.36 In the case of problems due to aerodrome closures or bad weather, flights are prevented from taking off if they will not be able to land without delay. This prevents unnecessary holding and, subsequently, additional fuel burn and emissions.

6.37 ATFM informs ATC and the operator of the calculated take-off time (CTOT) well before the off-block time. The take-off time is calculated on the basis of an average taxi time per airport. In order to improve the process, trials are being made to provide more flexibility in the taxi-time values. This will avoid starting the engines before necessary. Further enhancements are under consideration, such as calculating, for each flight, an accurate taxi time between the gate and the runway.

6.38 Even if some modifications to the CTOT are made, the pilot will be aware, well in advance, of the take-off time and the time needed to taxi to the runway. This procedure will reduce the fuel consumption and emissions to the minimum because it will not be necessary to start the engines until the aircraft can taxi to the runway. In addition, waiting time at the holding point should also be reduced.

6.39 ATFM tries to reroute flights outside critical areas. However, by doing so, flight times may be increased. This clearly can be seen as a negative contribution, but it also has a positive impact because these flights will avoid the most critical areas.

6.40 It is current practice at some aerodromes to keep a “reservoir” of flights by using holding stacks. This optimizes the use of runways, but can also be considered as a negative contribution. The CFMU is enhancing its present ATFM system by receiving updates on a flight’s real position after take-off. The benefit will be increased accuracy in the ATM management process, which should help to keep the flight times inside the stacks to a minimum.

ATS route network developments

6.41 The ATS route network development process incorporates a number of key elements:

a) a Europe-wide (top-down) approach;

b) integration of national and regional plans;

c) cooperative planning;

d) use of agreed principles; and

e) validation by specialized groups.

6.42 Enhancing airspace capacity in the ECAC region provides a unique challenge because of:

a) the number of interests involved (thirty-eight States with civil and military participants);

b) the intense demand on the network;

c) an increasing demand of 4 to 5 per cent per annum;

d) a core area problem (80 per cent of the traffic in 10 per cent of the airspace); and

e) the short journeys in European airspace (60 per cent fly less than 400 NM).

The solutions must be applicable to the core area and must take into account the problem of short-haul traffic.

6.43 Route network development actions are key elements of the airspace optimization process and are primarily focussed on capacity and efficiency enhancement. This may conflict with fuel-burn reduction; for example, it may be necessary to slightly modify an ATS route to place a convergence or a crossing in a specific ATC sector. Nevertheless, it has been found that, in the process of optimizing the route network in Europe, the tendency has been towards a reduction in excess route length, with unnecessary segments being eliminated or shortened. This tendency is most noticeable where a radical airspace reorganization takes place. For example, reorganization of the Nordic airspace resulted in a reduction in route length of between 2 and 4 per cent and in some cases as high as 9 per cent. It should be noted that the larger percentage changes apply to the length of short routes. The scope for route length reduction is not great because, in general, the en-route extension component is of the order of 5 per cent. In fact, a radical reorganization in a non-complex area would probably reduce this to an average of 2 to 3 per cent.

6.44 In general, it can be stated that, subject to capacity implications, the aim of optimizing the route network in the ECAC area is to make it as efficient as possible. This would include the objective of reducing route length extension as far as practicable.

Terminal airspace developments

6.45 The main initiatives taken on terminal airspace developments, which will have an impact upon noise, fuel use and emissions, include the redesign of terminal airspace to better recognize the improved performance of modern aircraft. The aim of this redesign is to shorten the distance flown in the terminal area, where possible, to remove conflict between arrival and departure routes (thus allowing for the possibility of preferred climb and descent profiles), and to provide revised sectorization options which avoid staged climb and descent due to transfer of control from one approach sector to another. To date this is being carried out utilizing existing navigation facilities, but the use of area navigation equipment to achieve these goals is also being evaluated and implemented.

6.46 A high percentage of the air traffic in Europe is climbing or descending due to the relatively short stage lengths. This fact, together with the number of airports in close proximity to each other, results in a complex interaction of routes. This is further exacerbated by the fact that, at the majority of locations, routes are designed on an individual basis and not as an integrated system. This results in non-optimum routings which, in some extreme cases within the terminal area, may be up to twice as long as necessary. Even if routes are not extended significantly, the climb performance characteristics of modern jet aircraft may not be utilized to the full extent. Since many routes were designed for a previous generation of aircraft, the climb and descent profiles of modern aircraft have had their enhanced performance penalized to a large degree. This results in aircraft being restricted to levels that are not efficient in terms of fuel burn or noise reduction.

6.47 The development of advanced ground support tools to help controllers offer more efficient routings and profiles is being actively pursued.

6.48 To sum up, an integrated terminal airspace design policy, together with the use of enhanced aircraft climb/descent performance and advanced navigation aids, should provide significant environmental benefits within the terminal airspace. Added to this, the development of support tools should also ensure that the existing capacity of the system is maintained, or enhanced, while environmental benefits are gained.

Air traffic control and data processing

6.49 In the ATC and data processing domain, the European Air Traffic Management Programme (EATMP), in the 1999 strategy, aimed at achieving quantified improvements in the following areas:

a) safety;

b) capacity;

c) cost; and

d) environment.

All four areas are supported by objectives identified in the ATM Strategy 2000+. The first three areas have always been of concern, but the environment criterion is new to ATC and requires development.

6.50 EATMP's ATC and data processing will, in particular, contribute to environmental improvements through increased automation support for arrival, departure and surface movement management. These improvements will mainly bring about a reduction of noise, but will also have a positive effect on fuel burn and fuel consumption. Better organization of arrivals, departures and ground movements will prevent unnecessary holding, both in the air and on the ground, and thus greatly reduce exhaust emissions.

6.51 Indirectly, ATC decision support tools, such as automated conflict detection and conflict resolution, will also contribute to environmental improvements. Conflict detection and resolution are important for allowing more direct routes, which have the potential to considerably reduce the distance flown by individual aircraft and, as a consequence, reduce pollution.

6.52 Quantification of the environmental impact of ATC systems is addressed in EUROCONTROL's cooperative Advanced ATM Tool Integration Project (INTEGRA). This project aims at defining metrics and methodologies suitable for use in ATC simulations to provide measures of safety, capacity, cost and environmental impact in simulated, new ATC systems.

6.53 Methodologies have also been specified for calculating the total emission of carbon dioxide, nitrogen oxides, sulphur dioxide, carbon monoxide, hydrocarbons and particulate matter. The emissions are determined for the flight path actually taken and are compared with the emissions that would result from the most efficient flight path.

RNAV with automated ATM tools

6.54 An additional EATMP activity, involving the use of RNAV with automated ATM tools, aims at the optimization of traffic flows in and out of major airports and directly addresses six of the eight objectives detailed in the ATM Strategy 2000+. This activity is also expected to provide opportunities for significant environmental benefits. Three EATMP units (airport operations, airspace management and navigation, and ATC and data processing) are involved.

6.55 The on-board flight management system (FMS) provides a "preferred" flight profile based upon optimization criteria which may include, *inter alia*, the shortest feasible route, the optimum cruise level and a speed profile in accordance with a company-defined "cost index" parameter. The latter represents an indication of the trade-off that the operator makes between flight time and costs.

6.56 Due to potential conflicts with other flights, individual flights can often not be given their "preferred" flight profiles. Once airborne, tactical ATC optimizes the progress of individual flights on a sector basis. This can easily lead to a sequence of events whereby in one sector an aircraft is offered a direct route to reduce flight time, and then, in the next sector, the flight is required to enter a holding pattern.

6.57 For constrained flights, arrivals management (AMAN) tools should ensure a consistent ATC strategy over subsequent sectors, providing a flight profile that results in minimum deviation from the preferred profile. The three-dimensional navigation capability of modern FMS facilitates the use of RNAV procedures in the TMA. The combined use of airborne RNAV capabilities and ground-based AMAN functions (very advanced level) makes the use of continuous descent approaches, from cruise level down to the runway, feasible. Research has indicated that this can lead to a 30 per cent reduction in the fuel consumed over the last 150 NM of the flight.

6.58 AMAN tools can effectively increase airport capacity. Thanks to the increased delivery accuracy, the runway separation criteria may possibly be reduced. The resulting reduction in flight time can be directly translated into reduced fuel consumption. Moreover, the RNAV procedures offer a high degree of flexibility in creating flight patterns that avoid noise-sensitive areas without increasing controller or pilot workload.

6.59 Integration of departure management (DMAN) tools with AMAN facilitates the optimum use of runway capacity in the case of mixed operations. Once DMAN has established well-defined target take-off times, surface management tools (SMAN) can optimize the movement of the aircraft from engine start-up to take-off. Ultimately, the interoperability of DMAN at the airport of departure with AMAN at the airport of arrival will allow global flight optimization in terms of flight time, fuel consumption (and emissions production) and noise.

6.60 This project is phased such that implementation risks are minimized. Technical feasibility was proved in real-time simulations at the end of the 1980s. The operational functionality will be gradually built up through field trials at airports of participating ATS providers. The development of human-machine interfaces that are compatible with older and advanced ATC systems is under way and will be validated in simulations and pre-operational trials. This approach aims to minimize the time taken from prototype to operational implementation. The project is now in a preparatory phase during which a detailed business case is being developed and stakeholder commitment is being sought.

The flexible use of airspace (FUA) concept

6.61 The FUA concept is primarily concerned with the more efficient sharing of airspace among different groups of airspace users. The fundamental principle of the FUA concept is that airspace is a continuum to be allocated day by day to accommodate the needs of the different types of users, primarily military and civil.

6.62 In the past, blocks of airspace were designated for military use, either continuously or for specified time periods. Access to this airspace was denied to other airspace users even though it may not have been actively used by the military throughout all of the designated hours of operation. Local coordination procedures whereby military staff notified their civil colleagues when the airspace was temporarily available to civil flights, or no longer required for military operations, were only partially successful. This was because of the lead times needed to rearrange civil aircraft routings by the ATM system, and these procedures were only applied by some States and to some airspace. The net result was that scarce airspace resources were not always shared to the best effect.

6.63 FUA, through a number of strategic planning and real-time coordination processes at varying levels, provides the means to make more efficient use of airspace. Military authorities are able to reserve sufficient airspace to meet their defence and national security obligations, while outside of periods of military activity, the airspace is made available to other airspace users. In addition, it also contains several measures to overcome past airspace limitations.

6.64 At present, FUA deals only with military and civil coordination, and it has not yet been fully adopted by all ECAC States. The intention is to expand the concept in the future to encompass all aspects of airspace management and to move to a fully collaborative and cooperative planning process to optimize the use of all ECAC airspace.

Reduced vertical separation minimum (RVSM)

6.65 The RVSM concept adds six additional flight levels for use between FL 290 and FL 410 by spacing flight levels above FL 290 at 1 000 ft intervals instead of the traditional 2 000 ft. The introduction of RVSM will provide:

a) better flight profiles and thus increased fuel consumption efficiency; and

b) an increased airspace capacity, which will reduce delays.

6.66 RVSM was implemented in the North Atlantic in 1997. In Europe, the introduction of RVSM on 24 January 2002 presented the opportunity to revise the European airspace structure. In initial ATC real-time simulations, the reduced air traffic controller workload as a result of RVSM translated into a potential capacity increase of some 20 per cent. It is also considered that there is potential for further growth in a revised airspace structure, which could be achieved through resectorization and/or the introduction of additional sectors. According to the latest EUROCONTROL Performance Review Report, most en-route ATFM delays (about 50 per cent) originate in the upper airspace sectors. RVSM is being used in the development of ATS Route Network Version 4, which will contribute to a more effective route network.

6.67 A major evaluation of the cost-benefits of the introduction of RVSM was carried out in 1999. During that process, an analysis was made of the fuel cost and increased efficiency of flights at optimum levels. However, this was balanced by the exclusion from RVSM airspace of those aircraft which would incur a fuel penalty for their operations.

6.68 The analysis suggests that the vast majority of the benefits derive from a reduction in aircraft delays, even after the delay cost per minute has been reduced. The reduced cost of aircraft delays accounts for 94 per cent of the overall benefits from RVSM. The remaining 6 per cent of the benefits arise from increased fuel efficiency. RVSM is a major means by which EUROCONTROL will provide additional airspace in the medium term.

The free route airspace (FRA) concept

6.69 The FRA concept consists of defined airspace in which users freely plan their routes between entry and exit points without reference to an ATS route network. While the responsibility for safe separation in the FRA rests with the ground-based ATS system, the concept is concerned with how the airspace is managed and used, and not with responsibilities for separation.

6.70 The concept exploits the existing basic area navigation requirement and does not require additional avionics. A first evaluation of the FRA concept in Europe is planned to start in the upper airspace of eight ECAC States in 2003. These States are Belgium, Denmark, Finland, Germany, Luxembourg, (including Maastricht Upper Area Control Centre (UAC)), the Netherlands, Norway and Sweden. The result of that first evaluation could be the basis for possible wider adoption.

6.71 FRA is expected to provide benefits in terms of:

a) increased capacity with a reduction in operator costs through shorter and more fuel-efficient trajectories;

b) increased capacity through a reduction in potential conflicts; and

c) enhanced flexibility through the ability to react dynamically to real-time events.

DEVELOPMENTS IN THE UNITED STATES

The role of ATS in environmental issues

6.72 Federal agencies in the United States adhere to the National Environmental Policy Act of 1969 (NEPA) and its implementing regulations promulgated by the Council on Environmental Quality in accordance with Executive Order (EO) 11514, Protection and Enhancement of Environmental Quality, 5 March 1970, as amended by EO 11991 (sections 2(g) and 3(h)), 24 May 1977. NEPA establishes a broad national policy to protect the quality of the human environment and provide policies and goals to ensure that environmental considerations are given careful attention and appropriate weight in all decisions of the federal government. NEPA provides specific direction to federal agencies, sometimes called "action-forcing" provisions, on how to implement the goals of NEPA. NEPA, as amended, requires that any agency proposing a major federal action identify and develop methods and procedures, in consultation with the Council on Environmental Quality, that will ensure appropriate consideration in decision making will be given to the environment together with economic and technical considerations.

6.73 The ATS environmental strategy is to use an interdisciplinary approach to ensure that NEPA provisions are incorporated early into the planning and decision-making stages. This strategy requires forward thinking about potential concerns and issues impacting the quality of the environment. This includes identification and avoidance of environmentally sensitive areas whenever practicable. Mitigation and outreach plans must be used to minimize negative impacts.

6.74 The FAA must analyse the environmental impact of proposed air traffic actions in order to avoid or minimize negative impacts that might occur from these actions. Environmental consideration is accomplished in ways that are consistent with the FAA's principal mission of promoting a safe and efficient aviation system.

Evolution of the United States National Airspace System

6.75 The assumption for the future planning of the United States air traffic management system is that traffic demand will increase significantly without a corresponding increase in the controller workforce. Controller workload under peak traffic conditions should remain equivalent to the workload controllers absorbed in the 1990s under lighter traffic demand. This increased ATC efficiency has been achieved through the implementation of decision support systems for traffic management and control, dynamic alteration of airspace boundaries, separation minima consistent with technology enhancements, improved air/ground communications and coordination, and enhanced ground/ground coordination. Evolution of the national airspace system (NAS) exhibits the following characteristics:

a) incremental implementation of new technologies. This approach maintains safety as the first priority, while also increasing capacity, efficiency and flexibility in a balance with environmental considerations;

b) distribution of timely and consistent information across the NAS for both user and service provider planning;

c) improved surveillance in all phases of flight to enhance airborne and ground situation awareness. This is especially significant for allowing positive control in present non-radar environments;

d) use of the global positioning system (GPS) to enhance navigation, resulting in the eventual decommissioning of ground-based navigation aids (NAVAIDs);

e) increasingly accurate weather information available to the service provider and user, including automatic simultaneous broadcast of hazardous weather alerts for wind shear, microbursts, gust fronts and areas of precipitation, icing, and low visibility;

f) decision support systems that provide both information and procedures to support the providers in their tasks. This increases productivity and provides greater flexibility to user operations, which is especially important given the potential for reduced separation minima consistent with technology enhancements;

g) allocated capacity for users at the affected airport in the form of an arrival interval, and the designated number of flights that may arrive in that interval, to reduce ground delays;

h) increased collaboration among users and service providers. Collaboration includes information exchange, plus shared and active user participation in decision making. For situations such as demand-capacity imbalances or severe weather, this capability allows a determination of when, where and how transitional route structures are established to meet a short-term problem;

i) expansion of terminal-area route structures, including those flown automatically by the on-board flight management system (FMS). When the projected demand for volumes of airspace is at or near capacity, and after collaboration between users and national traffic flow management (TFM), a temporary route structure with transition points for moving to and from user trajectories is identified;

j) static route structures exist only in places of continuous high density or to provide for avoidance of terrain and active special use airspace (SUA) in the en-route phase of flight;

k) the oceanic environment closely resembles the en-route environment in terms of waypoints, surveillance, airspace structure, and communications;

l) airspace allows operators to use preferred profiles from entry into cruise to final exit. Entry to, and exit from, the airspace are based on preferred profiles for climb and descent and are not restricted to the 200 NM in-out requirements of the national route programme (NRP). Within this airspace, aircraft may be able to operate closer to their optimum altitudes by increasing the available flight levels using 1 000 rather than 2 000 ft separation (see RVSM section);

m) spaceports have been established at numerous coastal, inland and sea-based locations. As a result, a variety of space vehicles are operating in the NAS, ranging from traditional rocket-types to those with conventional aircraft capabilities;

n) airspace design and underlying sector configurations are no longer constrained by the current geographic boundaries, particularly in high altitudes. Upon completion of the national airspace redesign, tools and procedures will be in place for frequent evaluation (up to several times a day) of the airspace structure and anticipated traffic flows, with adjustments made accordingly; and

o) seamless communications and coordination, coupled with the NAS-wide information system, allow for the real-time dynamic reassignment of airspace between facilities to meet contingencies such as equipment failures.

Limitations of the current ATM system

6.76 Despite the existence of more than 4 300 ground-based aviation navigation systems, whose signals are used by aircraft avionics for en-route navigation and landing guidance, not all airports and airspace are covered. Over the next ten years, the navigation system is expected to use satellites, augmented by ground monitoring stations, to provide navigation signal coverage throughout the NAS. Reliance on ground-based navigation aids is expected to decline as satellite navigation provides equivalent, or better, levels of service.

6.77 The transition to satellite navigation will significantly expand navigation and landing capabilities, improving safety and making for a more efficient use of airspace. In addition, it will reduce the FAA's need to replace many aging ground systems, decrease the amount of avionics required to be carried on aircraft and simplify navigation and landing procedures. The FAA continues to change the NAS from a ground-based infrastructure to one that encompasses both ground and airborne systems.

6.78 The participation of FAA organizations demonstrates recognition of the need to engage the acquisition components of the FAA early in the concept formulation process. Participation of the Department of Defence as well as industry also recognizes the need for early involvement of these stakeholders to facilitate development of a coherent strategy across the entire NAS.

En-route operations

6.79 In today's domestic airspace, aircraft are radar-monitored and typically follow the fixed-route structure of airways, preventing pilots from flying the most direct route or taking advantage of favourable winds.

6.80 The current en-route airspace structure consists of sectors with a specific lateral and vertical dimension. Designs are compromises based on the constraints of traditional traffic flows, ATC-preferred routes, automation, and communications systems. However, the current structures do not permit the flexibility users desire because user-preferred routes often traverse small portions of sectors. The evolution of the "free flight" concept involves reduced restrictions on instrument flight rule (IFR) traffic to enable system users to choose their own flight paths and altitudes to maximize efficiency with minimum constraints, maintaining the highest level of safety. Managing free flight traffic within the existing structure could increase the required coordination between controllers and between controllers and pilots.

6.81 Evolution to a free flight environment requires significant improvements in en-route and oceanic computer systems and controller decision support tools. The aging automation infrastructure must be replaced before new applications and improved services can be provided.

Oceanic operations

6.82 Currently, en-route and oceanic facilities are collocated but do not share common systems, primarily because of the lack of surveillance and direct communications services over the ocean. The addition of oceanic surveillance and real-time direct communications would enable oceanic services to gradually become comparable with en-route services, and oceanic and en-route systems would evolve to a common hardware and software environment.

6.83 In oceanic airspace, aircraft follow "tracks" that are aligned each day with prevailing winds. Lack of radar surveillance and direct controller-pilot communications requires oceanic separation distances to be twenty times greater than in domestic airspace. The large separations limit the number of available tracks. Because of this, some flights are assigned a less-than-optimum altitude, and there is insufficient opportunity to adjust altitudes to conserve fuel. Additional tracks, and access to optimum altitudes, would reduce fuel consumption and costs substantially.

6.84 These current limitations can be overcome by the implementation of improved aircraft navigational performance, automatic dependent surveillance (ADS) in oceanic airspace, data link communications and better automation.

Restricted and military airspace

6.85 Special use airspace (SUA) throughout the United States is designated to confine activities because of their nature, and non-participants may be excluded from entry.

6.86 SUA presents a potential impediment to operations in the higher altitude airspace because there may be situations where an optimum user routing would traverse such airspace. Although the organization responsible for each SUA publishes an airspace schedule, the airspace may be scheduled for use but be free of operations. In this situation, users have to plan their flights to avoid the airspace even if it will be vacant. Improvements in communicating SUA schedules and status through the deployment of advanced collaborative SUA utilization tools would increase access to inactive/unscheduled airspace.

Developments in the United States since 1995

6.87 RTCA approach to FAA/industry partnership. RTCA, Inc. is a private, not-for-profit corporation that functions as a federal advisory committee to develop consensus-based recommendations regarding communications, navigation, surveillance, and air traffic management system issues. RTCA's recommendations are used by the FAA as the basis for policy, programme and regulatory decisions and by the private sector as the basis for development, investment and other business decisions.

6.88 During October 1994, the Chairman of RTCA, Inc. formed an RTCA Board of Directors Select Committee on Free Flight tasked to reach consensus on a free flight concept. Free flight is an innovative idea intended to achieve these industry-recommended goals:

a) achieve early benefits by deploying known technology while maintaining or exceeding current levels of safety;

b) provide operational availability of the core capabilities by the end of 2002;

c) achieve and maintain consensus within the United States aviation community regarding Free Flight Phase 1 (FFP1) operational requirements;

d) extend early benefits to national airspace system users and to service providers;

e) employ an evolutionary development paradigm; and

f) make leveraged use of proven technologies.

6.89 The concept moves the NAS from a centralized command-and-control system between pilots and air traffic controllers to a distributed system that allows NAS users, whenever practical, to choose their own route and file a flight plan that follows the most efficient and economical route. New technologies permit the FAA to move forward with incremental, beneficial changes. Nevertheless, the full implementation of free flight requires major alterations to the NAS infrastructure, decision support systems (automation), airspace design, avionics and procedures, all of which will take considerable time.

6.90 The FAA has undertaken initiatives that will allow a free flight NAS. Perhaps the most publicized is the national route programme (NRP), which allows NAS users to file user-preferred routes, rather than ATC-preferred routes, that begin 200 NM from the departure airport and end 200 NM from the arrival airport. NRP has been beneficial but many restrictions reducing user efficiency continue to exist. For example, NRP requires users to file flight plans to existing navigation aids or fixes. This precludes the flexibility users desire, which is to plan their flights to random points defined by latitude and longitude.

6.91 The existing NAS continues to reflect its origins as a system in which aircraft flew directly from NAVAID to NAVAID along a set of FAA-defined routes. The airspace structure and boundary restrictions strongly reflect the constraints that the communications and computational systems imposed when the NAS was developed. For further progress toward meeting user needs and requirements, there must be changes in procedures, roles and responsibilities, equipment, and automation functions to allow the system to evolve into a structure accommodating greater user flexibility in planning and conducting flights.

Progress on collaborative partnerships

6.92 Since 1995, RTCA and the FAA, working with a broad cross section of NAS user groups, have collaborated on the development of the *Government/Industry Operational Concept for the Evolution of Free Flight*. RTCA provides the forum for broad FAA and industry discussion and consensus building for the free flight initiative. The Select Committee spearheaded the development of the final set of recommendations for Free Flight Phase 1 (FFP1).

6.93 The Air Traffic Service Plan issued by ATS in the fall of 1996 facilitated an ongoing dialogue between the air traffic service organizations and airspace users. This dialogue is intended to develop a clear understanding of user needs and to provide the air traffic services necessary to meet them. Its primary purpose is to highlight the aviation community's views, focussing on necessary changes to combine increased user flexibility with operating efficiencies under increased levels of system capacity and safety.

6.94 The final version of the RTCA's *Government/Industry Operational Concept for the Evolution of Free Flight*, Addendum 1, published on 20 August 1998, forms the basis for understanding the direction and description of the elements of FFP1.

6.95 A number of boards and working groups have been established to facilitate rapid identification and response to issues, to promote communication and to provide focussed attention to specific topics. Collaborative groups include the Human Factors Review Board, the Metrics Working Group, and the Risk Review Board.

United States ATS strategy for 1998 to 2002

6.96 The FAA established Free Flight Phase 1 in 1998. This followed nearly four years of study by RTCA and the Administrator's Equipment Modernization Task Force regarding overall improvements to NAS operations and preparations for free flight.

6.97 In accordance with industry recommendations, FFP1 was charged with achieving the limited deployment of the following tools by the end of December 2002:

a) collaborative decision making;

b) user request evaluation tool;

c) surface movement adviser;

d) traffic management adviser; and

e) passive final approach spacing tool.

Collaborative decision making (CDM)

6.98 CDM provides operators and the FAA with real-time access to NAS status information including weather, equipment and delays. This collaboration helps manage the airspace more efficiently. In 2000, the use of CDM had already prevented over nine million minutes of delay since September 1998. RTCA recommended CDM to the FAA for incorporation into Free Flight Phase 1. Over thirty airlines and NavCanada are enrolled as users of this programme.

6.99 Three components comprise the CDM programme:

a) ground delay programme enhancements;

b) initial collaborative routing (ICR); and

c) NAS status information.

6.100 *Ground delay programme enhancements*. This enables the FAA's Air Traffic Control System Command Centre and participating operators to share their latest information on airline schedules and projected airport demand and capacity rates at times when airport capacity is expected to be reduced, such as during prolonged severe weather periods. This collaboration helps participating operators to optimize their operations through enhanced rationing and scheduling techniques.

6.101 *Real-time schedule updates.* The operators provide the flight schedule monitor with real-time schedule updates, enabling the service providers at the command centre to determine needs, time and duration of ground delay programmes.

6.102 *Initial collaborative routing*. This enables traffic management specialists at the command centre and traffic management coordinators at the various high altitude centres to share real-time traffic flow information among themselves and with the operators. This capability will improve the overall national airspace system operational efficiency through the making of mutually acceptable, more efficient decisions in times of constrained traffic flow. The most common use of ICR is to create and assess rerouting strategies around areas of hazardous weather. The ICR data conferencing infrastructure was completed in November 1998. As of 2000, ICR technical capabilities existed at the Boston, Cleveland, Indianapolis, New York and Washington high altitude centres, and New York Terminal Radar Approach Control (TRACON).

6.103 *NAS status information*. This provides the real-time sharing of a wide variety of information about the operational status of the national airspace system. Much of this information, previously unavailable to, or unusable by, most national airspace system users and service providers, is now available on the Internet at www.fly.faa.gov/ois.

User request evaluation tool (URET)

6.104 URET is a conflict probe that enables controllers to manage user requests in en-route airspace by identifying potential aircraft-to-aircraft conflicts up to twenty minutes ahead and aircraft-to-airspace conflicts up to forty minutes ahead. Use of URET has reduced altitude restrictions and increased direct routings.

6.105 The FAA developed URET as a decision support tool for use by pilots and the ATC to detect potential conflicts well in advance of their occurrence, alert the air traffic controller of these conflicts and evaluate the various possible countermeasures by the use of a trial planning programme. URET works by combining real-time flight plan and track data with site adaptation, aircraft performance characteristics and winds and temperatures aloft to construct four-dimensional profiles for pre-departure and active flights. URET, the basis for the FFP1 conflict probe, was deployed in 1997 for large-scale national trials in the Indianapolis and Memphis Air Route Traffic Control Centres.

6.106 Using URET, a fuel saving of up to 150 000 tonnes per year has been estimated by the Centre for Advanced Aviation System Development (CAASD) in its two studies conducted for the United States Air Transportation Association. This saving is expected as a result of the ATC system allowing aircraft to be operated on more fuel-efficient trajectories and to remain at the preferred altitude until their optimal top-of-descent point, instead of beginning the descent earlier.

6.107 CAASD and the FAA have estimated that a potential saving in user operating costs of up to U.S.$620 million annually are possible if the FAA can eliminate route and arrival descent restrictions due to air traffic management control. Air traffic controllers state that up to 60 per cent of the current flight restriction in the ATM system could be eliminated with the use of URET. "The Advanced Automation System: A Benefit/Cost and Risk Analysis", conducted by the MITRE Corporation, projected an incremental benefit for the complete automated conflict resolution of U.S.$2.5 billion to $3.5 billion for a twenty-year life cycle implementation of URET and a benefit potential in fuel saving of U.S.$150 million to $400 million annually.

6.108 US Airways, in a test of URET, found that the removal of the Falmouth sector crossing restriction for Pittsburgh arrivals allows arrivals from the south-west to remain at 33 000 ft for 88 additional miles. This equated to a saving of 170 kg of fuel per flight or 495 000 kg per year.

6.109 URET has exceeded over 500 000 sector hours of controller use at Indianapolis and Memphis. The tool has shortened air routes by nearly one mile per flight in the Indianapolis airspace, which saves airlines about U.S.$1 million per month.

6.110 The URET prototype is used on a daily basis at Indianapolis and Memphis centres. On 1 February 2000, at the request of the controller workforce, URET availability was increased to twenty-two hours per day, seven days per week. The FFP1 URET Core Capacity Limited Deployment System is planned for installation at Atlanta, Chicago, Cleveland, Indianapolis, Kansas City, Memphis and Washington high altitude centres, beginning in November 2001.

6.111 The URET daily use prototypes have been incorporated into the new display system replacement control rooms at both Indianapolis and Memphis. This permits continued early evaluation of user benefits in support of FFP1 objectives.

Surface movement adviser (SMA)

6.112 SMA provides aircraft arrival information to airline ramp towers to assist operators in better managing ground assets (gates, baggage operations, refuelling, food service, etc.). The functions provided by the FFP1 SMA differ from those of the one-time prototype in use at Hartsfield Atlanta International Airport. Airline ramp tower personnel at participating FFP1 SMA airports, and other operators with an interest in these airports, receive a one-way feed of automated radar terminal system data, previously unavailable to them, regarding current traffic information. Specifically, airline ramp control operators are provided with updated information from which they can accurately estimate the actual touchdown time of aircraft.

6.113 Airline ramp control operators remain informed of aircraft identification and position in terminal airspace. This information enhances airline gate and ramp operations, prevents congestion and reduces taxi delays. Early feedback from Northwest Airlines in Detroit is very positive. As a result of the enhanced situational awareness, Northwest estimates that it is able to prevent four to five costly flight diversions weekly during inclement weather.

6.114 SMA information became available at Philadelphia International and Detroit Metropolitan Airports on 18 December 1998, several weeks ahead of schedule. On 21 December 1999, SMA information became available at Chicago O'Hare, Dallas/Fort Worth, Newark and Teterboro Airports, again ahead of schedule. The FFP1 segment of SMA has been completed.

Traffic management adviser (TMA)

6.115 TMA is a strategic planning tool that provides en-route controllers and traffic management specialists with the ability to develop arrival sequence plans for selected airports. It provides computer automation to enhance arrival sequence planning and the efficiency of air traffic operations in the extended terminal airspace surrounding major airports. Use of TMA neither decreases safety nor increases controller workload. RTCA recommended the TMA capability to the FAA for incorporation into FFP1.

6.116 TMA and the passive final approach spacing tool (pFAST) form part of the NASA-developed Centre-TRACON Automation System (CTAS). TMA affects traffic flow and planning of aircraft operating in en-route airspace, and pFAST affects the management of aircraft that have entered terminal airspace. TMA is operational at the Fort Worth very high altitude centre and at the Minneapolis centre. It enables en-route controllers and traffic management specialists to develop complete arrival-scheduling plans ("meter lists") of properly separated aircraft. These plans allow early runway assignments that can maximize an airport's use of its available capacity. A significant fuel saving and reduced passenger delays will result from efficiencies achieved through the use of TMA. Early indications from Fort Worth show that it has been possible to increase the arrival rate into Dallas/Fort Worth Airport by 5 per cent.

6.117 Early TMA prototypes have been deployed at air route traffic control centres in Denver, Miami, Los Angeles and Fort Worth. Eight TMA systems are to be deployed at Fort Worth, Minneapolis/St. Paul, Denver, Los Angeles, Atlanta, Miami, Oakland and Chicago. Remote TMA displays (with no processing or TMA interactive capability) will be deployed to TRACONs and adapted airport towers associated with each TMA site.

pFAST

6.118 pFAST maximizes runway utilization by providing controllers with aircraft sequence numbers and runway assignments according to user preferences and system constraints.

6.119 Both pFAST and TMA form the CTAS. pFAST affects traffic flow and planning of aircraft operating in terminal airspace; it provides TRACON controllers with aircraft runway preferences and sequence numbers. The CTAS suite of tools increases arrival acceptance and the efficiency of air traffic operations in the extended terminal airspace surrounding major airports, without decreasing safety or increasing controller workload. pFAST does this by providing automation aids to assist controllers in optimizing:

a) the flow of traffic to adapted airports within the Air Route Traffic Control Centre/TRACON; and

b) the use of available runways and surrounding airspace.

6.120 Airline benefits in terms of fuel saving and reduced delays are attributable to the efficiencies achieved through the use of pFAST. Early indications from Dallas/Fort Worth show that an extra two aircraft per rush (thirty-minute period of heavy traffic — nine rushes daily) are able to land at the airport.

6.121 The pFAST prototype was deployed at the Dallas/Fort Worth TRACON. The former prototype is now operational at Dallas/Fort Worth. Additional FFP1 systems will be deployed in the Southern California (for Los Angeles arrivals), Atlanta, Minneapolis, St. Louis and Chicago TRACONs.

6.122 The high level of cooperation achieved during FFP1 between the FAA and the aviation user community has been unprecedented. Building on this collaborative momentum, the RTCA Free Flight Steering Committee formed its government/industry working group to study and recommend how best to preserve and build upon FFP1 successes.

United States ATS strategy for 2003 to 2005

6.123 *Free Flight Phase 2 (FFP2).* RTCA, in its role as Federal Advisory Committee to the FAA, submitted industry recommendations regarding the continuation of free flight activities, known as "Documentation of 2003–2005 Capabilities Working Group Deliberations and Recommendations," August 2000 (referred to herein as the RTCA Steering Committee Recommendations).

6.124 *TCA Recommendations for FFP2.* The RTCA Steering Committee focussed on how to determine where additional FFP1 and other capabilities should be implemented. After much deliberation, the group agreed to utilize a problem-based method for determining capability need and location. This type of analysis provided an analytical justification for recommendations and helped the group identify needs for which there were no available solutions. Identifying this type of need enabled the group to define areas for priority research and development.

6.125 In addition to defining capabilities for implementation and identifying areas for priority research and development, RTCA recommended certain airspace and procedural initiatives that would accommodate free flight operations.

6.126 The recommendations are:

a) continue implementation of certain FFP1 capabilities at prioritized sites: conflict probe (based on URET), traffic management adviser — single centre (TMA-SC), pFAST and CDM (enhanced). RTCA additionally recommended the implementation of a new capability called collaborative routing and coordination tools (CRCT), a suite of tools that uses the monitor alert threshold to evaluate the impact of traffic flow management (TFM) rerouting strategies. In addition, it will predict airspace traffic density, provide for the rerouting of aircraft to prevent exceeding the monitor-alert threshold and provide an impact assessment of the proposed solutions;

b) facilitate certain airspace and procedural initiatives that will alleviate congestion and provide greater access to the NAS: a uniform national ultra-high altitude service, domestic RVSM in ultra-high sectors and the use of more area navigation and required navigation procedures (RNAV/RNP) to improve general aviation access to congested airspace; and

c) conduct selected, prioritized research activities: direct-to (D2), problem analysis, resolution and ranking (PARR), traffic management adviser — multi centre (TMA-MC), surface management system (SMS), the equitable allocation of limited resources, advance vortex spacing system (AVOSS), active final approach spacing tool (aFAST), en-route descent adviser (E/DA) and expedite departure path (EDP).

6.127 The FAA has implemented FFP2 to expand the availability of FFP1 capabilities to additional sites and to provide new FFP2 capabilities, beginning on 1 October 2000 and ending on 31 December 2005. Geographical expansion will allow a broader portion of the aviation community and the general public to benefit from the synergism that has developed among the FFP1 tools. The interaction of additional and widely spaced URET and TMA sites, for example, will allow more aircraft to fly fuel-efficient paths over longer distances, and arrivals of more aircraft to be more efficiently scheduled. As was the case with the FFP1 capabilities, new FFP2 tools have been recommended by an interested and knowledgeable cross section of the aviation community. Assessing the benefits of these new tools remains to be done, but it is reasonable to anticipate that these benefits will be compounded through interaction with the existing FFP1 tools.

FFP2 programme scope

6.128 *Geographical expansion of FFP1 capabilities.* Geographical expansion of FFP1 capabilities includes the implementation of URET, pFAST, TMA-SC and CDM (enhanced) to additional facilities beyond FFP1 sites. It also provides for implementation of the new capabilities, called CRCT and CPDLC, at all appropriate facilities.

6.129 *Airspace initiatives.* The FAA will continue to pursue aggressively the RTCA-recommended airspace initiatives through the agency's air traffic management programme (ATA) for national ultra-high altitude service and through the air traffic planning and procedures (ATP) organization for domestic RVSM in ultra-high sectors and RNAV/RNP capability in en-route airspace. Both ATA and ATP will develop and implement national plans to fulfil the committee's recommendations and report progress to the aviation community through the appropriate RTCA Committee.

6.130 *FFP2 research and development.* The RTCA 2003–2005 Capabilities Working Group recognized ongoing research that should be accelerated and merged to facilitate the development and implementation of an integrated set of capabilities.

6.131 FFP2 has selected a number of these research and development initiatives to pursue, based on capability, maturity and the ability to deliver user benefits quickly. The following research and development projects are expected to mature and may be deployed during the 2003–2005 time frame:

a) *Direct-to (D2).* A tool designed to assist en-route controllers in identifying aircraft that could have their time en route reduced by flying "direct to" a downstream point closer to the destination airport. D2 builds on the NASA-developed Centre TRACON Automation System (CTAS) TMA to provide a tool able to identify aircraft that could save at least one minute of flying time by flying direct to a downstream fix.

b) *Equitable allocation of limited resources.* This capability will assist the FAA in more fairly responding to individual user demands while still managing overall density across the NAS. This capability, more than likely, will be a component of the MITRE/CAASD-developed CRCT.

c) *Problem analysis resolution and ranking (PARR).* PARR is a set of tools that will assist the en-route D-position controller in the management of flight data derived from the MITRE/CAASD-developed URET. It will also assist the controller in developing strategic resolution of aircraft-to-aircraft and aircraft-to-airspace conflicts, responding to hazardous weather conditions, and complying with TFM metering times and flow instructions. The integration of these tools will allow the entire sector team to have access to the full range of tactical and strategic tools and displays at each position.

d) *Traffic management adviser — multi centre (TMA-MC).* TMA-MC is an en-route component of NASA-developed CTAS. Multi-centre TMA builds on the single-centre TMA to enable efficient management and metering of traffic in complex airspace. Complex airspace is defined as airspace in which multiple facilities (multiple centres and/or multiple TRACONs) with interdependent traffic flows are responsible for delivering arrivals to a congested airport.

e) *Surface management system (SMS).* SMS will reduce arrival and departure delays and inefficiencies that occur on the airport surface due to surface events and downstream restrictions. The resulting capability needs to be flexible in order to cooperate with other established capabilities. In addition to the ongoing NASA SMS research project, RTCA suggested that the agency should continue with the research while implementing other user initiatives to provide more efficient airport surface operations.

6.132 The following research and development projects will be monitored and accelerated to the extent possible, but are not expected to mature during the 2003–2005 time frame:

a) *Expedite departure path (EDP).* EDP is a decision support system designed to assist controllers in TRACONs and ARTCCs with departure-related situations. It provides controllers with active advisories (speed, heading and altitude) via the NASA-developed CTAS, for managing the complexities of unrestricted climbs into the en-route system.

b) *Advance vortex spacing system (AVOSS).* AVOSS is a ground-based system that dynamically provides safe spacing for aircraft in trail to a single runway. It uses current and estimated weather conditions to determine when the vortices from an aircraft have left the approach corridor.

c) *En-route descent adviser (E/DA).* E/DA is another capability of the NASA-developed CTAS, which will be able to assist radar-side controllers in handling arrival aircraft in the descent phase of the sequencing process. The E/DA tool will provide controllers with speed, heading and altitude/top-of-descent advisories that depict the results of the planning and trajectory calculations.

d) *Active final approach spacing tool (aFAST).* aFAST is a terminal component of the NASA-developed CTAS and a follow-on to pFAST. It is a decision support tool that will provide TRACON controllers with accurate, conflict-free aircraft speed and vector advisories. These advisories will optimize the safe delivery of aircraft to the runway threshold.

United States ATS strategy for 2006 and beyond

6.133 Recommendations for 2006 and beyond include continued implementation of certain FFP1 capabilities at selected prioritized sites, including CRCT. Future efforts also include facilitation of certain airspace and procedural initiatives that will alleviate congestion and provide greater access to the NAS. Consideration will be given to establishing a uniform national ultra-high altitude service, domestic RVSM in ultra-high sectors, and the use of more RNAV/RNP to improve general aviation access to congested airspace.

Gate-to-gate concept

6.134 Each day, approximately 100 000 flights use the NAS, requiring many decisions in the management of the traffic. The NAS architecture provides tools to help users and service providers make collaborative decisions to prioritize and schedule flights and better organize air traffic locally and nationally.

6.135 During flight planning, improved tools will be used to predict the location and impact of traffic demand and weather along planned routes and at the destination. As the flight progresses, additional updates on weather, NAS status and other user-specific data will be provided to the airline and other operational centres as appropriate. New tools will eventually help plan direct flight paths, sequence departures and arrivals, change routes and balance capacity and demand throughout the NAS.

6.136 To improve flight planning, the NAS architecture contains new and improved information services in the areas of traffic flow management and flight services that enable collaboration — service providers and users sharing the same data and negotiating to find the best solutions to operational needs.

6.137 The NAS-wide information service will evolve from today's current array of independent systems and varying standards to a shared environment connecting users and providers of traffic flow management, flight services and aviation weather information.

Oceanic operations

6.138 A study is currently under way to investigate a number of innovative alternative ways to meet oceanic user's needs and FAA commitments to reducing lateral separation to 50 NM. This effort anticipates that an FAA/industry partnership will deliver benefits earlier than is currently affordable with FAA funding alone.

6.139 Automatic dependent surveillance — addressable (ADS-A) will provide surveillance of flights in oceanic airspace through a satellite data link. ADS-A will enable longitudinal separation between FANS-1/A-equipped aircraft to be reduced to 50 NM. Oceanic data link for controller-pilot communications and ADS-A surveillance will evolve to provide services to aeronautical telecommunication network (ATN)-equipped aircraft. The oceanic automation infrastructure will be upgraded to process and display ADS-A information.

Reduced vertical and horizontal separation

6.140 These are programmes used by the airline industry on oceanic routes and are aimed at reduced longitudinal, vertical and horizontal separation between aircraft. Current restrictions require a lateral separation of 60 to 100 NM, a vertical separation below the 29 000 ft flight level of 1 000 ft and a vertical separation of 2 000 ft for aircraft above 29 000 ft, and a longitudinal separation of fifteen minutes.

6.141 In 1997, the FAA initiated the RVSM programme in an effort to increase available flights and to reduce flight time over the North Atlantic. The RVSM programme has reduced the vertical separation between flight levels 29 000 and 41 000 to 1 000 ft, resulting in a projected doubling of the available oceanic tracks and a reduction of between 50 000 and 68 000 tonnes of fuel annually. MITRE, in its study for the ATA, projected a fuel saving in the North Atlantic of 50 000 tonnes per year. MITRE also projects a fuel saving of 1.08 million tonnes from the implementation of RSVM worldwide. The FAA, in its study "Strategic Plan for Oceanic Airspace Enhancements and Separation Reductions," identified an average fuel saving per aircraft movement in 1996 of approximately 200 kg and projected the average fuel saving per aircraft movement in 2015 to be approximately 165 kg.

6.142 The increased use of improved navigational technology, including GPS, traffic alert and collision avoidance system (TCAS) and data link have enabled the reduction of lateral and longitudinal separation on routes over the Pacific. On these routes, lateral separation has been reduced from between 60 and 100 NM to 50 NM in certain cases. Additionally, longitudinal separation on these same Pacific routes has also been reduced from 15 minutes to the time required (at various air speeds) to fly 50 NM. In the Oakland flight information region, which is responsible for 65 per cent of the Pacific routes, a saving of 94 000 tonnes of fuel per year can be realized. The Pacific saving, combined with the potential Atlantic saving of 39 000 tonnes, provides a potential oceanic fuel reduction opportunity of 133 000 tonnes of fuel annually.

Oceanic step climb

6.143 The FAA, in its study "Strategic Plan for Oceanic Airspace Enhancements and Separation Reductions," provided an overview of near-term (1998–2000), mid-term (2001–2005) and far-term (beyond 2005) oceanic initiatives, commitments and plans of the oceanic step climb programme. Initially, the aircraft flies at a lower altitude, but as fuel is burned and the mass of the aircraft decreases, it can climb to a higher altitude where fuel is burned more efficiently. In the near term, the FAA's initiatives include the continued expansion of RVSM in the North Atlantic (NAT) airspace, the initiation of 50 NM lateral separation in the Pacific (PAC) airspace, the implementation of RVSM in PAC airspace and the introduction of dynamic aircraft route planning in the South Pacific. The FAA's mid-term programme calls for 50 NM longitudinal separation in the PAC airspace, 30 NM lateral separation in the NAT and PAC airspace, and a five-minute longitudinal separation in the NAT airspace. RVSM is also planned for the Western Atlantic route system. Among the far-term initiatives are further reductions in separation and increased flexibility, leading to a free flight oceanic airspace environment. These benefits are summarized in Table 6-1.

Air traffic control and data automation

6.144 During the later stages of NAS modernization, the TFM infrastructure will become part of the NAS-wide information service, and the flight object structure will be in place. Airlines and other users will begin providing four-dimensional (longitudinal, lateral, vertical and time) trajectory information for in-flight planning. The flight object will be updated as the aircraft operates through the system.

6.145 Performance models will be developed as part of the NAS modernization to predict when traffic demand will exceed system capacity. These data will be available to the FAA, airlines and other users so that traffic flow can be adjusted. By Phase 3, an improved simulation capability will be developed to immediately assess proposed schedule changes, flight cancellations and other operational modifications.

Table 6-1. Oceanic step climb programme — Approximate fuel cost saving

Region	Minima	Fuel cost saving (in millions of dollars U.S.)	Notes
Pacific	50 NM lateral	357	For 1996 though 2015
	50/50	604	(Cumulative: 50, 50/50, 30/30) for 1996 through 2015
	30/30	835	(Cumulative: 50, 50/50, 30/30) for 1996 through 2015
Atlantic	RVSM	12.2	For 1996 (using medium traffic growth and the average of low and high fuel prices)
		48.9	For 2015 (using medium traffic growth and the average of low and high fuel prices)
		545.9	For 1996 through 2015 (using medium traffic growth and the average of low and high fuel prices)

6.146 En-route automation includes the display system replacement (DSR). DSR is able to show weather data from the next generation weather radar (NEXRAD) and, with near-term upgrades, will enable controllers to use FFP1 tools.

6.147 For oceanic automation, a multi-sector oceanic data link that uses satellite communications is being installed to provide reliable data communications between the pilot and controller for aircraft equipped with future air navigation systems. These data communications consist of internationally standardized pilot/controller messages for routine air traffic control, and free text messages. Satellite and high frequency (HF) voice communications will also be available.

6.148 In the 2008–2015 time period, the en-route and oceanic systems should evolve into a common hardware and software structure, although some applications may remain unique in each domain. This common architecture will promote a more efficient and seamless transition between the two domains.

6.149 The implementation of the flight object and the NAS-wide information service will allow data sharing across domains, facilities and NAS users. This sharing will benefit users by enhancing the airlines' planning for daily operations. Pilots will be able to file and modify the flight plan according to NAS conditions, monitor flight progress and identify the most advantageous route, landing runway, and gate.

Data link

6.150 Data link is used to communicate between the aircraft and various ground systems via the use of digital data networks. Data communicated via this link includes air traffic information, flight information, navigation information and surveillance data, all of which promote method safety and reduction of flight time. The programme also provides the ability to fly more direct routes using less vectoring, reduces the number of holds and the associated time, and reduces ground delays as well as communication errors.

6.151 The digital process used by data link sends information to the aircraft, via automated ground systems, where it is received by like automated systems and converted into usable information. The system provides a more efficient, reliable and friendly manner of transmitting information when compared with the former method of voice communication between ATC, pilots and airspace managers.

6.152 It is estimated that data link will provide a saving of up to 1.03 million tonnes of fuel annually when fully implemented.

Satellite-based navigation

6.153 A transition to satellite-based navigation provides significant operational and safety benefits. It meets the needs of growing operations because pilots will be able to navigate virtually anywhere in the NAS, including to airports that currently lack navigation and landing signal coverage. Satellite-based navigation will allow direct routes, and more runways will be served by precision approaches.

6.154 Radio frequency interference is an acknowledged risk associated with GPS-based navigation. The ionosphere and unintentional or intentional radio frequency interference can affect the GPS signal. To address this problem, a second civil frequency will be included on the replacement GPS satellites due to be launched starting in 2005.

6.155 From 2008 to 2015, NAS modernization calls for continued transition away from ground-based navigation. Whether all ground-based navigation systems can be phased out will be evaluated. Some ground-based navigation systems may need to be retained to support operations along principal air routes and at high-activity airports should there be a GPS/wide area augmentation system (WAAS) service outage or interference. The deployment of new GPS satellites with a second civil frequency (for improving navigation and landing performance and robustness) will be completed in this phase. In Phase 3 of NAS modernization, the terminal automation systems will be integrated into the NAS-wide information service. This will enable flight data to be exchanged between aircraft, air traffic control facilities, airports, airline ramp control and airline operations centres.

6.156 With the new capabilities inherent in advanced navigation and surveillance technology, departure and arrival procedures will change to reduce or eliminate speed and altitude restrictions and to allow aircraft to use a greater portion of the airspace around airports. New, direct general aviation routes will be established in highly congested terminal areas wherever possible.

National airspace redesign

6.157 The FAA is participating in the RTCA Special Committee 192, National Airspace Review Planning and Analysis. Current efforts are laying the groundwork for transitional phases prior to 2005 for airspace and sector design. Using an airspace liaison team concept, the FAA is providing oversight, at the national level, of numerous airspace study activities. The FAA is moving forward with the initial phases of the national airspace redesign.

6.158 Reduction of delays experienced by all aviation system users is always a key objective in redesign efforts. As airspace analyses are conducted within the context of the national airspace redesign, FAA will examine the impact that proposed changes will have on delays. By redesigning airspace to increase acceptance rates, volume-related delays will be reduced.

6.159 Airspace redesign objectives also include system flexibility. Airspace management is examining actions aimed at reducing the amount of extra flight distance associated with ATC-preferred routes, and at increasing the percentage of flight segments flown off ATC-preferred routes.

6.160 Many of the most heavily travelled routes in the system have published ATC-preferred routes, which are designed to minimize conflict in congested airspace. However, these routes often differ significantly from the routes that pilots or flight planners would normally propose between two cities. One feature of redesigned airspace is expected to be reduced dependence on ATC-preferred routes. Another key aspect of redesigned airspace will be to reduce the necessity for flow restrictions. This should further increase system flexibility.

6.161 The FAA is implementing two major procedural changes that will increase user operational flexibility. These are the elimination of undesirable ATC-preferred routes and the development of standard instrument departures and approaches to increase participation in the national route programme. Publication of these changes will help to ensure that users can take advantage of these new efficiencies and the increased flexibility.

6.162 In attaining the flexibility targets, the FAA is incorporating appropriate environmental considerations in the evaluation of airspace design alternatives. Integration of environmental considerations with airspace sector design is a key component to the FAA's provision of flexibility in air traffic services. This will ensure that issues related to the environment are properly considered in airspace studies, thus ensuring that new flexibility increases can be implemented as soon as possible.

National route programme, ultra-high (free route) concept

6.163 As a step towards mature free flight, the FAA is exploring the possibility of defining a high altitude airspace structure where it could begin to implement many of the free flight concepts. This airspace would allow properly equipped users to begin achieving the economic benefits of flying their preferred routes and altitudes with fewer restrictions than the present system imposes. The initial implementation is envisioned to be at the higher flight levels of the en-route structure and at additional levels as technology and procedures safely allow.

6.164 Operations conducted in ultra-high altitude airspace would be along user-preferred routes from airspace entry to exit. Entry and exit locations would be based on user preferences for climb and descent and not be restricted to the 200 NM in-out requirements of the NRP. This would permit aircraft operations that are closer to optimum altitudes by increasing available flight levels through a reduction in vertical separation from 2 000 to 1 000 ft. The increase in available flight levels would also give controllers more flexibility in managing conflicts rather than separating aircraft through structured route control. Reduced lateral separation standards would allow more aircraft to fly along beneficial routes while possibly decreasing the number of predicted conflicts a controller must manage. If efficient flow into a destination airport required an adjustment to arrival time, aircraft would receive the required time of arrival (RTA) for their planned exit points. Pilots would operate their aircraft in the most efficient manner to arrive at the exit point at the RTA.

6.165 Before the proposed high altitude airspace can be implemented, three major areas must be considered: the FAA infrastructure, special use airspace and aircraft equipment.

WORLDWIDE DEVELOPMENTS

6.166 Clearly, other parts of the world besides Europe and the United States can benefit from some of the techniques and procedures being applied in those areas. For example, there are plans to expand the application of RVSM in several parts of the world.

6.167 There are specific examples of major route and airspace improvements that are aimed at reducing flight time and fuel burn. For example in the Asia/Pacific Regions, there are major efforts to introduce RVSM together with RNP 10. The fuel-burn reductions so far have been estimated by some airlines as being between 1 per cent and 2 per cent en route over the Tasman Sea, North Pacific (NOPAC), Central Pacific (CENPAC) and Pacific Organized Track Systems (PACOTS). But there is also the uncalculated reduction in fuel burn on the ground because of the vast reduction in departure delays. The Japan Civil Aviation Bureau (JCAB) has reported that the RVSM/RNP 10 programme has effectively eliminated Narita Airport departure delays for entry into the Pacific. One estimate of the delay time eliminated is eight aircraft hours per day, based on previously reported statistics. Although unconfirmed, this must mean similar reductions in delays and fuel burn at other Asian and North American airports.

6.168 It is also hoped that in the South China Sea the new route structure approved long ago will be implemented. This is the busiest airspace in the region and suffers from extensive ATC delays and inefficient use of flight levels. This new air route structure was not aimed at reducing flight times because the routes are relatively direct already. The problem is ATS inefficiency which leads to significant excess fuel burn.

6.169 In the development of all the new routes that have been put in place over the past ten years, there are examples of a saving of forty or more minutes of flight time being offset by the added ATC cost of flying the improved route. The environmental result is that because the airlines now calculate the user charge element of route selection for each flight, they may forego the flight time and fuel-burn saving in the interest of obtaining the minimum overall flight cost, given that aircraft are not generally range/payload limited on those routes.

COCKPIT DISPLAY OF TRAFFIC INFORMATION (CDTI)

6.170 The air-to-air CDTI is the basic technology that enables the pilot to electronically "see and avoid" other aircraft in a largely passive mode. Each aircraft automatically broadcasts its position, and this information is visually depicted on a cockpit display in all suitably equipped aircraft in the surrounding area. Independent of ground-based radar, CDTI will greatly enhance a pilot's situational awareness and lead to safer and more efficient airspace operations. ADS-B techniques can also enhance traffic collision avoidance systems in the future.

6.171 Benefits from the use of CTDI, as identified by the FAA, include: reduced communication congestion, enhanced situational awareness and safety, use in remote oceanic areas, better position tracking, autonomous air-to-air surveillance, expanded surveillance capacity and reduced taxi and take-off delays.

6.172 In its study conducted for the ATA, MITRE estimated that CTDI used during the period of marginal visual meteorological conditions would provide a fuel saving of 68 000 tonnes annually.

FUEL SAVING AND EMISSIONS REDUCTION

6.173 A study was conducted to develop a refined estimate of the potential of CNS/ATM to reduce emissions. This study was initiated by the FAA's Office of Environment and Energy (AEE) and executed by the FAA's Office of System Architecture and Investment Analysis (ASD).

6.174 This study was based on the United States National Airspace System Performance Analysis Capability (NASPAC) Simulation Modelling System. NASPAC is an event step simulation that models the en-route and terminal traffic in the entire NAS and includes all en-route sectors and four hundred airports. The model computes throughput and delay at each airport and sector of airspace based on input capacity values representing the scenario under study. The study considered CNS/ATM enhancements planned for 1996 to 2015 in flights en route to the United States, in terminal airspace, in United States controlled oceanic airspace and on airport surfaces. The study also considered emissions by phase of flight, promoting CNS/ATM enhancements by allowing flights to follow optimal trajectories. Fuel saving and emissions reduction were computed from reductions in terminal delays and reductions in en-route flight times and distances. The results of this study calculated the approximate upper boundary of potential CNS/ATM benefits.

6.175 This study differed from the original "MITRE I" study in several ways in that it considered future demand and the implementation sequence of CNS/ATM enhancements using different baseline years. MITRE I used a simple method of converting fuel burn to emissions, while the FAA study used a more sophisticated method.

6.176 The results of the FAA study considered emissions reductions in 2005, 2010 and 2015 against the baseline year of 1996. The analysis found a reduction in fuel burn of 4 670 000 tonnes per year. The more sophisticated emissions conversion method used in this study compared to MITRE studies predicted a reduction of NO_x of 95 000 tonnes per year and 27 000 tonnes less HC.

6.177 Expressed as a percentage of baseline emissions, the FAA study found reductions of NO_x and HC of 9.9 per cent and 18 per cent respectively. Both the earlier MITRE I and the FM study support the conclusion that CNS/ATM enhancements, when fully implemented, have the potential to reduce aircraft emissions by 10 to 15 per cent (MITRE II 1998).

6.178 MITRE I assumed that emissions were produced at a constant rate per unit of fuel regardless of phase of flight. In the follow-up study, MITRE II, four aspects of the first study were analysed with the goal of determining whether the assumptions and approximations used in the original analysis were representative of the emissions saving derived from CNS/ATM.

6.179 The analysis was based on both CO_2 and H_2O emissions being directly related to fuel burn and not varying with the phase of flight, and NO_x emissions varying considerably with the phase of flight as well as the rate at which the fuel is burned. The recomputed emissions saving for NO_x found a reduced benefit from 70 000 tonnes saved per year to 51 000 tonnes saved per year (a 27 per cent benefit reduction).

6.180 The study was also based on HC emissions varying with the phase of flight, being higher at lower thrust settings where combustion is less efficient. The weighted average for HC emissions across all phases of flight led to an increased reduction of 14 000 tonnes per year compared to the 9 500 tonnes per year computed in the original study (a 45 per cent benefit increase). Table 6-2 provides an analysis, by CNS/ATM initiative, from the "MITRE II" study.

6.181 The National Aerospace Laboratory (NLR) of the Netherlands conducted a study of CNS/ATM, for IATA, to investigate operational measures that could improve aircraft fuel efficiency and reduce aircraft emissions. NLR concluded that "on a global basis every aspect of CNS/ATM, including optimization of flight procedures and techniques and in-flight performance (climb, cruise and descent phase), minimizing aircraft weight, optimizing ground-level operations and improving airframe and engine maintenance and instrument accuracy, will all contribute, albeit in a small way, to the total significant savings by the year 2010."

6.182 NLR fuel-saving projections for both CNS/ATM-related and non-CNS/ATM-related opportunities are presented in Table 6-3.

Table 6-2. Estimated fuel saving and emissions reduction from CNS/ATM implementation worldwide (thousands of tonnes)

CNS/ATM initiative	Fuel	NO_x	HC
CDTI benefits	69	0.8	0.2
Oceanic step climb	2	0.05	0
Planned VRP	597	6.6	1.8
Relax 200 NMI	139	1.5	0.4
Provide UPR to NONPREF	914	10.1	2.7
UPR to all flights	70	0.8	0.2
RVSM	1 056	11.8	3.2
Cruise climb	107	1.2	0.3
Data link	1 039	11.4	3.1
Oceanic RVSM/RHSM	137	1.5	0.4
URET	152	1.7	0.5
TATCA (CTAS and RHSM)	268	2.9	0.8
SMART	79	0.9	0.2
Total	**4 629**	**51.25**	**13.8**

Table 6-3. Operational opportunities to reduce aircraft-related emissions (as a percentage of current (1999) fuel use)

Measures	Region	Fuel	No_x	CO and HC
CNS/ATM related	Africa	−6	−6	−8.9
	Asia/Pacific	−6	−6	−17.19
	Europe	−10	−9	−14
	Latin America/Caribbean	−8	−8	−8
	Middle East	−4	−4	−4.5
	North America	−10	−9	−16
Non-CNS/ATM related		−5	−5	−5
All operations	Global	−14	−13	−20.21

SUMMARY

6.183 Improvements in the local, national and, above all, regional and international ATM infrastructure offer the greatest potential for significant fuel saving. This chapter has summarized specific actions which are planned to achieve this increase in efficiency, and refers to an associated ICAO document that analyses the value of some of the potential saving.

Chapter 7

NON-REVENUE FLYING

INTRODUCTION

7.1 Operators already tend to keep the amount of non-revenue flying to a minimum since it is a direct cost to the operation. However, some potential may exist to reduce fuel usage and emissions production by reducing non-revenue flying even further. Nevertheless, the complete elimination of these flights is unlikely for safety and legal reasons. Both local and international rules may dictate the minimum amount of flying required to carry out some functions (e.g. training), so not all of the reductions identified may be universally achievable.

7.2 It is very difficult to quantify the precise fuel saving that may be possible because each case tends to be very specific; however, an estimate has been given where possible.

TRAINING: FLYING VERSUS SIMULATION

7.3 The requirement for pilot training flights is gradually being reduced with the introduction of new technology in both aircraft and simulators. Advances in computing and graphics presentation now allow a more realistic representation of the aircraft in the simulator, in turn allowing more training to be done on the ground and less in the air.

7.4 Older aircraft types may require more airborne training than newer types because advances in simulator technology may not be available for older aircraft. Training flights can sometimes be reduced because, increasingly, conversion training between aircraft in the same family may be carried out using zero-flight-time simulators.

7.5 When training flights cannot be avoided, the use of suitable airfields close to commercial destinations will keep fuel used in positioning the aircraft to a minimum.

7.6 Fuel loading has a secondary effect on the amount of fuel burned during training, although it is usual to load sufficient fuel to ensure that aircraft handling is representative of commercial operations. The fuel consumption rate is higher during training flights than during normal flight operations due to flying at lower altitudes, and other factors.

POSITIONING FLIGHTS

7.7 Positioning flights tend to be relatively short, although they can involve flying longer distances if an aircraft has had to position back to base after an en-route diversion. It is possible to reduce, to some extent, the need for diversions because of adverse weather by equipping aircraft to operate to higher standards for all-weather operations (e.g. Category III). This will not eliminate weather diversions in the most extreme conditions, and furthermore not all aircraft types are Category III capable.

7.8 It is sometimes also necessary to reposition aircraft when an operator's fleet is split between two or more bases. This may be due to the differing nature of operations at certain periods (e.g. weekends) or as a result of the maintenance schedule of the fleet. Careful planning of the schedules and/or changing flight schedules to ensure that one type operates from only one base is not always possible but does serve to reduce this type of non-revenue operation.

7.9 Occasionally, when services have been guaranteed (e.g. some shuttle services, high profile flights), back-up aircraft have to be positioned at the airport where the flight originates.

7.10 Since positioning flights do not entail flying an aircraft with safety margins (for example due to a defect), it is sometimes possible to carry a commercial load, though not necessarily passengers, on a positioning flight. This will save fuel if the cargo in question would otherwise have had to be carried on a special flight.

7.11 It is difficult to quantify the fuel saving that could result from reducing positioning flights because they tend to be very specific in nature. Short distance flights may not entail much fuel burn, whilst longer sectors involve greater fuel and crew expense and so tend to be reduced to the minimum possible.

FERRY FLIGHTS

7.12 The improved reliability of modern aircraft and engines, coupled with the ability to accept defects or defer defect rectification in some cases, reduces the need for positioning aircraft for defect rectification or technical reasons (also known as ferry flying).

7.13 For some defects on some aircraft, and if certain conditions are met, the certificating authority may allow a flight to be carried out with a full or reduced commercial load and this will alleviate the need for a substitute flight. Ferry flights sometimes entail limited operations at lower altitudes/speeds, or with increased operating margins, often with a corresponding increase in fuel consumption. The restrictions are dependent on the defect and are to ensure that safety margins are not compromised.

7.14 Improved reliability remains the best way of reducing ferry flights for the purpose of defect rectification. Non-revenue ferry flying can also be reduced by carrying out maintenance close to, or at, the fleet's main operating base, though this may not be possible for a number of reasons. The ability to operate with acceptable defects for a limited period can also be key to reducing non-revenue flying. This requires full and sensible use of the minimum equipment list (MEL).

TEST FLIGHTS

7.15 Manufacturers, certificating authorities or airlines sometimes require test flights after certain maintenance work has been completed. Such flights are necessary when air loads or other conditions, required to verify the rectification work, cannot be reproduced on the ground.

7.16 Examples of the tests required include a check of the air-conditioning pack performance for altitude thresholds and a check of a "manual reversion" facility, following degradation of hydraulic control systems.

On some aircraft, correct rigging of the stall warning system is essential, and low speed handling and stick shaker/pusher speeds have to be verified in the air after certain maintenance work on the system.

7.17 Occasionally, tests of a non-safety related nature can, with the agreement of the regulating authorities, be carried out during line flying. One example is the checking of alternate flap operation on a particular aircraft type.

7.18 Newer aircraft have the ability to test certain items using built-in test equipment which uses the aircraft's own systems to identify problems. As a result, air tests may be reduced or shortened.

DEVELOPMENT — TRIAL INSTALLATION

7.19 Development of aircraft systems may be carried out by suitably approved design organizations and may be mandated by the airworthiness authority. These systems often have to be tested in the air before being allowed into commercial service.

7.20 Such tests can sometimes result in a number of lengthy development flights investigating specific functions throughout the whole of the flight envelope of the aircraft, and such flights can involve significant fuel burn. However, the end result may be the reduction of fuel burn or improvements in safety margins during commercial operations.

ENGINE TESTING

7.21 Ground running of engines is another part of normal airline maintenance operations, which should obviously be kept to a minimum.

SUMMARY

7.22 Modern aircraft help keep non-revenue flying to a minimum. Modern computer technology used in simulators and for route planning and scheduling also provides techniques for minimizing such flying. Regulatory authorities also need to balance the requirement for non-revenue flying, especially in view of the capabilities of modern aircraft, with the environmental degradation caused by the additional fuel consumption and emissions.

Chapter 8

FLIGHT/ROUTE PLANNING AND OTHER OPERATIONAL ISSUES

INTRODUCTION

8.1 This chapter reviews some flight planning and related issues from the operator's point of view. This includes aspects of the general infrastructure, applicable regulations, fuel characteristics and related issues that can affect the fuel efficiency of aircraft operations directly or indirectly.

ROUTES

8.2 Minimum route lengths (great circle) are not necessarily the optimum because aircraft operate in an atmosphere that is constantly moving. Consequently, the route that gives the least flying distance through the air (the least equivalent still air distance) may actually be longer over the ground than the great circle distance. Conversely, with a strong enough tailwind, an equivalent still air distance shorter than the great circle distance is sometimes possible.

8.3 Routing can be affected by constraints other than those related to the shortest distance and most beneficial winds, such as:

a) closed airspace areas, danger areas, etc., which have to be avoided for military, political or safety reasons;

b) congestion, which often necessitates a non-optimum route to avoid being held in a stack at the destination airport;

c) systematic variables as a result of airport runway usage and the effect on length of departure and arrival routes;

d) twin-engined aircraft without the appropriate extended range operations (ETOPS) capability may be constrained by the regulations to fly a longer-than-optimum route (see ETOPS discussion below); and

e) differences in overflight charges can make it more costly to fly optimum routes in some cases. Harmonization of charges would help reduce fuel usage in such cases, and one airline has estimated that this factor alone results in 2.3 per cent extra fuel being consumed.

8.4 In Europe, the average extra distance flown as a result of these factors is of the order of 9 to 11 per cent, and for the rest of the world it is estimated to be about 6 to 7 per cent, with corresponding excess fuel burn.

8.5 United States airlines encourage their flight crews to request a "direct route" to their destination once airborne. Such requests are often approved by ATC. This reduces the fuel used and makes more efficient use of the available airspace. More fuel could be saved if flight plans could be based on direct routes. This improvement depends on infrastructure upgrades and implementation of the CNS/ATM procedures; see Chapter 6.

ROUTE NETWORK STRUCTURE

8.6 One choice for some airlines is between a route structure that emphasizes direct connections between its main airports or one which concentrates on routing passengers and cargo through a limited series of major hubs (the "hub-and-spoke" concept). From an environmental point of view, it is hard to decide whether the hub-and-spoke route network structure is better or worse than a point-to-point network structure.

8.7 One view is that the hub-and-spoke concept will lead to a concentration of passenger movements at relatively large future hubs. The need for extra capacity will, as a result of this concentration, be very unequally distributed. Additional passenger movement growth resulting from network concentration may, however, exceed aircraft movement growth. Consequently, the implications of network concentration for runway and ATC capacity may be smaller than what would have been expected.

FUEL RESERVES

8.8 With fuel mass being up to ten times that of passenger mass, a reduction in the fuel carried has considerable potential for reducing fuel burn (see Chapter 6). Keeping the fuel reserves carried to a minimum is therefore one way of reducing fuel consumption. Annex 6, Part I, Chapter 4, 4.3.6, sets general guidelines for the minimum fuel reserves and should be the basis for national requirements. Minimum fuel required usually includes amounts to cover:

a) taxiing out;

b) flying to the destination airport and executing an approach and missed approach;

c) flying to an alternate airport;

d) holding at the alternate airport and then approaching and landing; and

e) a contingency.

8.9 The amount of contingency fuel takes account of several factors, including the following:

a) weather;

b) ATC routings and traffic delays;

c) loss of pressurization;

d) loss of an engine en route; and

e) other reasons for increased fuel consumption and/or delays.

8.10 In addition, discretionary fuel may be carried, but the amount is not based on any specific scenario. Boeing analysed the various elements of fuel carried and commented as follows:

a) *Trip fuel optimization*. There is a need for accuracy and adjustment for the individual aircraft.

b) *Alternate airport choice*. The selection of the closest appropriate airport was highlighted and the possibility of not specifying an alternate in some cases was also mentioned.

c) *Holding fuel.* Usually specified by time at a given altitude, so only very small variations are possible.

d) *Contingency allowance.* Has the scope for the largest possible fuel reduction.

e) *Discretionary fuel.* Added due to company policy or at the pilot's request; needs to be reviewed.

8.11 The contingency allowance is often specified as a function of the trip time or trip fuel. For example, US FAR 121.645(b) specifies an extra 10 per cent added on to the total trip time for operations outside the United States and does allow the possibility of a reduction. Other United States regulations on fuel reserves illustrate the possible choices for calculation of minimum fuel reserves, and there is a significant difference between those for domestic flights and other operations. For longer-range flights, a percentage fuel reserve can be excessive especially for aircraft equipped with modern communications and navigation systems. On certain flights there is a potential for reduction of flight plan fuel by utilizing what is known as "reclearance", "redispatch", "refile", or "island reserve" procedures for the reduction of diversion or contingency fuel.

8.12 The subject of fuel reserves is a complex combination of regulations, experience, knowledge of operational factors, and risk assessment. The issue of fuel reserves is one where legislation and safety considerations clearly limit reductions, and any change is subject to many variables.

NOISE CONSTRAINTS

8.13 Extra fuel burn and emissions are caused by various noise certification, operational and related regulations that are intended to reduce the inconvenience of aircraft noise to those who live, work and pursue recreational activities near airports.

8.14 These can be divided into several categories:

a) aircraft and engine design. In order to meet noise certification requirements, engines tend to be more powerful, heavier and less efficient;

b) larger aircraft are, in principle, more fuel-efficient but tend to be noisier per operation. Noise certification limits do not allow for an increase in noise with an increase in mass thus making it increasingly difficult to design new larger aircraft;

c) various arrangements have been made to reduce the noise impact of aircraft after they have been manufactured (e.g. hushkits), usually involving re-certification into a later, lower noise category.

Most of these schemes, except engine replacement or a paperwork re-certification (i.e. no physical change to the aircraft), cause inefficiencies, such as extra mass or decreased engine efficiency, with a resulting increase in fuel consumption;

d) routes and climb-out profiles intended to redistribute noise near airports result in longer routes and more inefficient climb and descent profiles and procedures. Other local operating limitations intended to reduce noise impact have similar results; and

e) night-time or other operational limits at airports of origin or destination, or both, can introduce inefficiencies into aircraft operations, such as extra landings and take-offs, flying slower and holding longer to prevent arriving too early, or flying faster to arrive before the start of a curfew. Also extra congestion can arise by forcing more flights into periods near the beginning and end of curfews.

EXTENDED RANGE OPERATIONS BY TWIN-ENGINED AEROPLANES (ETOPS)

8.15 Another limit on using the most efficient route can be the regulations governing aircraft with two engines. Most of the current jet air transport fleet is now composed of two-engined aircraft. Annex 6, Part I, defines ETOPS as any flight by a twin-engined aeroplane more than 60 minutes from an adequate and suitable en-route alternate airport. The basic extra limitations appropriate for ETOPS include:

a) the aircraft and engine type must be approved for operation at the required distance from an adequate suitable airport;

b) the flight crew must have the appropriate training;

c) the individual aircraft must have no component unserviceability that could compromise its ability to fly the designated distance to an airport where it could land in an emergency; and

d) the weather forecast at the alternate airport(s) available must be acceptable for landing.

8.16 Based on these requirements, national airworthiness regulations allow such operations up to 180 or more minutes from a suitable airport. These extended limits enable more direct routes to be flown and allow for greater flexibility to take advantage of any beneficial en-route conditions such as tailwinds. However, the more direct flights may not be allowed by ETOPS regulations, and much longer routes may have to be flown in the interest of safety.

8.17 Twin-engined aircraft inherently climb at a faster rate than three- or four-engined aircraft. This is due to the airworthiness certification requirements that specify minimum performance conditions with one engine failed, which means that more all-engine power will be available for a twin-engined aircraft. This ability to climb faster allows the aircraft to reach its initial cruise altitude earlier, which is more fuel-efficient overall. On busy routes such as the North Atlantic corridor, this may be a greater advantage because the lower cruise flight levels may be more congested.

8.18 In order to minimize fuel use, it is essential to minimize limitations due to ETOPS, thus permitting the most efficient route to be flown, and always ensuring the safety of the operation.

FUEL FREEZING POINT

8.19 The trend towards longer and higher altitude flights has highlighted one limitation that can occasionally prevent flying in the most fuel-efficient manner. This is the need to maintain the aircraft fuel above the fuel freezing point. The temperature of the fuel in an aircraft tank always remains well above the local ambient temperature. However, with typical atmospheric temperatures in the stratosphere of –55°C, but with fuel freezing points as high as –40°C, situations can arise where cold-soaked fuel could reach unacceptably low temperatures if precautions are not taken. This may occasionally result in the aircraft being flown at lower altitudes and/or faster speeds, which warms the fuel up but increases fuel consumption. Actual atmospheric temperatures of –70°C have been recorded in a recent airline survey, but fuel temperatures did not drop below –42°C which was also the actual freezing point of the Jet A fuel. The fuel available may have a maximum (i.e. not warmer than) freezing point between –47°C and –40°C. In practice, the actual fuel freezing point is almost always lower (i.e. colder) than the specification limits. On certain long-range routes involving flying at very high altitudes, some airlines test samples of fuel prior to departure to determine the actual freezing point of the on-board fuel. This information is given to the flight crew, and it allows them to fly at the highest possible altitudes in order to save fuel.

FUEL FORMULATION

8.20 Another environmental aspect of fuel is the amount of sulphur it contains. Other things being equal, such as the sulphur already in the atmosphere, a lower sulphur fuel will result in less sulphur in the engine exhaust. However, aviation kerosene generally has a low sulphur content already. The IATA *Guidance Material for Aviation Turbine Fuels Specifications*, and other fuel specifications, require a maximum total sulphur content by mass of 0.3 per cent for Jet A-1 type fuel, but most jet fuel has a much lower sulphur content than this.

8.21 Boeing has reviewed the impact of fuel density and specific fuel energy content and has concluded that there is no relevant fuel saving or other operational implications. The fuel energy level value does vary by a small amount, but there is no way to use the differences to obtain any practical fuel saving benefit.

WEATHER FORECASTING

8.22 Better weather forecasting can enable better flight planning because the full effect of winds can be taken into account. This is especially true on the ultra-long haul sectors when the weather can change significantly over a 12- to 18-hour flight. In some areas of the world, the current position (altitude and direction) of the jet stream is critical to the optimization of routings for fuel conservation.

8.23 It is also of great importance to be able to identify areas where icing conditions are prevalent. Operating in icing conditions, as well as being potentially hazardous, is not fuel-efficient because power bleeds from the engines necessary for the de/anti-icing systems result in additional fuel burn. Any ice accretion on the airframe and engines also reduces the aerodynamic efficiency of the aircraft by adding to its mass and drag, further increasing fuel burn.

8.24 For some operations, especially ETOPS, accurate forecasts for alternate airports are especially necessary to facilitate the most efficient flight planning.

8.25 For a given time, location and altitude, the meteorological forecast data need to be accurate, timely and delivered in an appropriate way. This permits more accurate fuel planning and avoids "extra" fuel being loaded as a contingency for perceived changes during the flight. Better data will reduce the fuel carried and the fuel used. Some airlines employ their own meteorologists to predict weather en route and at the destination.

AIRCRAFT AND ENGINE PERFORMANCE MONITORING

8.26 An essential tool in minimizing fuel consumption is accurate aircraft and engine performance monitoring. Monitoring and analysing aircraft and engine performance provides several benefits that all tend to reduce fuel carried and fuel used. This process can provide general fleet data or detailed data for a specific aircraft on a specific route. This enables specific aircraft performance criteria to be utilized for each individual aircraft in the planning stage so that a more accurate fuel figure, generally less conservative, can be used.

8.27 The effects of increased empty aircraft mass and performance deterioration, as well as the beneficial effect of some modifications, can be tracked and accounted for as the aircraft ages. It is appropriate to monitor notional mass (e.g. average passenger mass) to ensure it is consistent with reality. If notional mass is too high, unnecessary fuel will be uplifted.

8.28 On specific flights, fuel monitoring and reporting can be used to give flight crews confidence by presenting statistics on the performance of the flight plan. As an example, some airlines collect cruise performance data for every aircraft on every flight. The deviation from the nominal or "book" performance is determined and the result loaded into the flight planning system. An individual deviation is applied to every aircraft. This analysis is done monthly, which allows the airline to load the minimum amount of fuel necessary to operate every flight.

SUMMARY

8.29 The planning of a route structure and of individual routes is a complex and constantly changing challenge, but minimizing fuel consumption is one of the prime operational goals. A number of factors are listed above that are part of the planning process carried out on the ground before a flight is started.

8.30 One of the general principles is that flights can be better planned and operated more efficiently if more knowledge is available of actual specific aircraft performance and operational factors, such as weather conditions, congestion, other traffic, and airport conditions. Major factors in less-than-optimal fuel consumption are excessive fuel reserves and operational noise constraints.

Chapter 9
TAKE-OFF AND CLIMB

INTRODUCTION

9.1 Take-off and climb are critical safety-related phases of a flight, not only because of aircraft performance but also because of the congestion that is common at and near many airports. A relatively large proportion of the fuel consumed is during these phases of flight, especially on a short flight. There are many constraints on, and not many options for, varying the normal procedure, which is mostly prescribed by airworthiness and operational regulations.

DERATED AND REDUCED THRUST TAKE-OFFS

9.2 Derated and reduced thrust take-offs tend to increase fuel consumption compared to full thrust take-offs. However, the amount is very small, and the benefits of reduced engine wear, and therefore reduced engine deterioration, may outweigh this small effect. Derated and reduced thrust take-offs also reduce NO_x production.

OPTIMIZATION OF CLIMB PROFILES

9.3 Generally the fuel-saving benefits of optimizing the climb profile are small, less than one per cent of trip or block fuel. Many airlines already apply fuel-saving schedules, and there are no significant additional anticipated improvements. Generally the most efficient climb speed schedule is used and a 250-kt (IAS) speed limit below 10 000 ft is observed globally. The 250-kt limit, required by ATC, delays acceleration and, for heavier aircraft with a higher optimum speed, can cause a fuel penalty. For example, the extra fuel used can be up to 350 kg for delaying acceleration from 2 000 ft to 10 000 ft. Although this speed limit is a safety issue needed to help ATC maintain appropriate aircraft separation, and there may be bird strike implications, exceptions can be granted in certain situations.

9.4 Climb speed schedules vary by aircraft type. When on-time performance is of vital concern, high-speed climb schedules are sometimes used to meet scheduled arrival times.

NOISE CONSTRAINTS

9.5 Noise constraints often prevent the optimization of climb profiles (see Chapter 8).

SUMMARY

9.6 Take-off and climb procedures are generally optimized as much as possible within the many airport and ATM constraints. Potential savings are small. Noise-based constraints often have negative effects on the environment in the take-off and climb regimes. There are no viable changes that could be made in the take-off and climb regimes that would have a significant effect on fuel consumption.

Chapter 10
CRUISE

INTRODUCTION

10.1 Some limited opportunities exist for fuel and emissions reduction during the cruise portion of flight. For the most part, operators are well aware of these possibilities and are applying them already. They principally consist of flying as closely as possible to the most fuel-efficient speed and altitude for the aircraft mass and managing aircraft systems to minimize fuel usage.

SPEED AND ALTITUDE OPTIMIZATION

10.2 Aircraft are designed to operate at an optimum cruise speed and altitude, which depends on the aircraft mass. If it is not possible to fly at the optimum altitude, it is generally better to change the speed. For current aircraft designs, flying at speeds or altitudes other than the optimum can seriously increase fuel consumption and emissions.

10.3 There is generally very limited opportunity to optimize cruise speed because operators already tend to fly close to or at the long-range cruise speed. This is usually only one per cent worse in terms of fuel mileage than maximum-range cruise speed, and at this speed, speed stability problems tend to occur.

10.4 There is some potential for optimizing cruise altitudes using reduced vertical separation minima (RVSM). This may have more potential than optimizing cruise speeds since having to wait for the next available flight level without RVSM can increase fuel burn by 2.5 to 3.5 per cent. RVSM should allow this to be reduced to below one per cent above the absolute optimum.

SYSTEM MANAGEMENT

10.5 One aircraft system management issue is the use of cabin air recirculation fans. The purpose of recirculating cabin air is to maintain the desired level of passenger cabin ventilation while minimizing the use of engine bleed air. Recirculation fans draw air from the flight deck, passenger cabin and/or electrical equipment bay areas and return it to the mix manifold where it mixes with fresh conditioned air from the air-conditioning packs and is distributed again to the cabin. Usually 50 per cent of the air is recirculated.

10.6 Recirculation fans may, when desired, be switched off for several minutes to increase the flow of fresh air to the cabin. When one or more recirculation fans are switched off (or are inoperative), the air-conditioning pack(s) operates in the high-flow mode to maintain the airflow rate throughout the aeroplane. An air-conditioning pack operating in the high-flow mode draws more bleed air from the engine(s), and fuel burn is increased because of this additional bleed air requirement. Table 10-1, prepared by Boeing, lists the estimated fuel-burn increase with one or all packs in high-flow mode. One airline calculated the additional fuel burn to be 135 000 kg per aircraft.

Table 10-1. Estimated fuel-burn increase with air-conditioning packs operating in high-flow mode

Boeing model	Estimated fuel-burn increase	
	One pack in high flow (%)	All packs in high flow (%)
737-300/400/500	0.5	1
747-100/200/300/400	0.3	1
757	0.3	0.7
767	0.3	0.6

OTHER FACTORS

10.7 Boeing has also analysed several other possible factors that could affect fuel consumption such as:

a) lateral unbalance;

b) FMS cost index;

c) trim drag reduction; and

d) zero yaw/sideslip.

SUMMARY

10.8 Minimum fuel consumption in cruise is obtained by following the manufacturer's recommendations concerning cruise speed and altitude as closely as ATM and weather conditions allow. Fuel saving is also possible by judicious management of the air-conditioning system.

Chapter 11
DESCENT AND LANDING

INTRODUCTION

11.1 There are a number of potential ways to save fuel during the descent and landing portion of the flight which includes descent, holding (if necessary), approach and landing, and taxiing.

HOLDING

11.2 It should be recognized that any form of holding entails a fuel penalty, and avoidance of airborne delays is the most efficient solution; however, this is often not possible. Aircraft are least efficient holding at low levels in "racetrack" patterns. Early recognition that a holding delay is going to be experienced can enable operating crews to plan early and minimize this additional penalty.

11.3 If the holding delay is known about early enough, it may be possible to slow down during cruise. This is a form of en-route holding and can minimize additional fuel burn because the aircraft can be operated closer to optimum conditions. Holding can also be achieved by lengthening the route in order to fly a longer distance for a longer time, if notification is given early enough.

11.4 If a holding delay is necessary, the objective should be to fly in the cleanest possible configuration (least drag) for as long as possible. This results in the least fuel consumption. For example, for the Airbus A300, a 15-minute hold at 210 kt and 5 000 ft with slats extended expends 300 kg more fuel than flying for the same time in a clean configuration at minimum drag speed.

FUEL JETTISONING — OVERWEIGHT LANDINGS

11.5 The issue of whether to jettison fuel arises when a landing is required soon after take-off due to some unexpected event such as an aircraft problem or passenger health condition. If the aircraft mass still exceeds the maximum landing mass, the decision must then be taken whether to land overweight or to jettison fuel. Only some aircraft types have the option to dump fuel in flight. These are essentially the longer-range types where the difference between maximum take-off and maximum landing mass is relatively large.

11.6 The introduction of overweight landing policies by airlines in North America dates back to 1971. These policies and procedures necessitated a change in airline operating philosophy since authorization to exceed a certification limitation is involved. As a result, care is needed to ensure that safety is not compromised through the use of a procedure that is essentially designed to save money and reduce air pollution.

11.7 However, the reduction in fuel wastage is significant. One airline reported saving over 13 million U.S. litres of fuel during the first eight years of its overweight landing programme. Another operator has not dumped fuel for any reason since 1980.

11.8 It must be emphasized that the pilot-in-command always has the final responsibility and authority to decide whether to jettison fuel or to land overweight. It is the operator's responsibility, however, to provide the pilot with the tools necessary for making that decision. This includes the required regulatory relief to exceed the certification limitation together with clear and concise flight crew operating procedures. Crews must be provided with all the necessary data and training to create pilot confidence and lead to a safe operation.

11.9 Manufacturers design their aircraft with a margin to allow for landing over the maximum certificated landing mass. However, following an overweight landing, the flight crew must file a report, and an overweight landing inspection must be carried out to ensure that the structural integrity of the aircraft remains intact.

11.10 There are many reasons why a flight crew may choose to return to the airport of departure or divert to an airport other than the planned destination. Examples include smoke in the cabin, oxygen depletion or pneumatic system problems, unruly passengers, in-flight illness, and certain flight instrument failures. When determining whether or not to jettison fuel, the pilot has to consider the seriousness of the in-flight circumstances together with airport and runway conditions and aircraft performance limitations.

11.11 There are also times when a pilot may determine that it is safer to dump fuel than to land overweight. Go-around capability is a consideration during any approach, but it becomes more significant when landing above maximum landing mass. The overweight landing procedures of most airlines require that the pilot verify go-around capability prior to initiating the approach. This becomes more critical if the aircraft has an engine inoperative. Under these circumstances, it is highly likely that a pilot would jettison fuel to, at least, maximum landing mass. However, the vast majority of unscheduled landings are made with all engines operating.

11.12 The pilot must also evaluate destination weather, runway length and surface conditions in addition to aircraft systems and subsystems that affect the ability of the aircraft to stop at the higher landing speed associated with an overweight landing.

11.13 If time is of primary importance, such as in the case of a medical emergency, fire or certain structural failures, an overweight landing might be justified. If the situation is such that a return is imperative though not time-sensitive, then jettisoning fuel to ensure the safety of the aircraft may be a better option.

11.14 In general, fuel jettisoning represents a very low percentage of an airline's total fuel use, amounting to approximately 0.025 per cent, on average.

DESCENT PROFILE OPTIMIZATION

11.15 Recent data from operators show small fuel-saving benefits (less than one per cent of block fuel) from the optimization of descent profiles. Fuel-saving procedures are already applied by most airlines, and therefore there is very little additional potential for improvement. To the extent permitted by ATC, FMS descent is normally used and reduced/delayed flap settings for landing. A 250-kt (IAS) speed restriction below 10 000 ft is observed. Delayed gear extension is also used.

11.16 As an example, for an Airbus A300, a 20-kt reduction in descent speed (280 kt instead of 300 kt) would save about 15 000 kg or 0.1 per cent of fuel per aircraft per year. The fuel consumption during descent from FL 310, in ISA conditions, to 1 500 ft at M0.78/280 kt/250 kt, is approximately 360 kg compared with over 380 kg at M0.78/300 kt/250 kt. Whatever the flight conditions, the optimum descent speed would have been about 280 kt; however, a speed limit of 250 kt below 10 000 ft is used for normal ATC purposes. Increasing this speed would allow more efficient descent profiles.

APPROACH PROCEDURE

11.17 The basic principle is that minimizing drag minimizes fuel burn; this in turn implies delaying the extending of flaps, slats and landing gear until as late as possible. It has been demonstrated that a continuous descent approach (CDA) procedure offers the best potential for fuel saving on approach. This procedure, which involves a continuous descent from at least 6 000 ft to touchdown, minimizes the use of engine thrust during the descent, resulting in lower fuel burn. The actual fuel saving depends on the aircraft type and the nature of the descent; however, reductions of between 200 kg and 400 kg per flight, depending on aircraft size, are possible.

11.18 As an example, a fuel saving of 150 kg per approach for an Airbus A300 would mean an annual saving of more than 200 000 kg, or one per cent of total fuel, per aircraft per year. An additional benefit of CDA operations is the reduction of noise levels on the ground beneath the aircraft and inside the cabin.

11.19 It is necessary for the appropriate information to be available to the operating crew, in this case an accurate distance-to-go figure, to enable an accurate CDA to be flown. However, even if it is permitted by national regulations, restriction of this procedure to Category I weather conditions or better may apply. Any increase in go-arounds due to unstable landing configuration would reduce the fuel saving.

LANDING AND TAXIING

11.20 By landing without using reverse thrust, Boeing has calculated that a B747 could save 65 to 70 kg of fuel per landing for an annual average saving of 75 000 litres of fuel. However, the cost of the increased brake wear would be significantly greater than the cost of the fuel saved. Boeing did not comment on the safety implications of using brakes only instead of reverse thrust and brakes.

11.21 Taxiing with one or more engines shut down in order to save fuel is reviewed in Chapter 2, Airport Operations.

SUMMARY

11.22 Descent profile optimization and the use of continuous descent approaches can offer significant potential fuel-saving benefits for some aircraft types at certain airports. However, holding can still cause the greatest amount of unnecessary fuel burn.

Chapter 12
LOAD FACTOR IMPROVEMENT

HISTORY

12.1 Consumption of jet fuel began in international commercial aviation with the DH Comet in 1952. In 1958, the Boeing 707 began flying in the United States fleets, and by 1970 jet fuel consumption in the United States had risen to 10 billion U.S. gallons per year. Aviation gasoline consumption peaked in 1958 at 1.6 billion U.S. gallons, and by 1970 had diminished to 13 million U.S. gallons. Aviation gasoline consumption in 1970 was limited to a few local service air carriers still providing service with piston-powered aircraft, and to general aviation.

12.2 The new jet aircraft are much more productive than the piston-powered aircraft they replaced. They have larger cabins with more seats and are much faster. Instead of two or three flights per day, jets are capable of flying two or three times that many trips. Today, the average jet has almost two hundred seats and flies at an average speed of 365 kt or more compared with a 1950s vintage aircraft with an average of fifty seats and an average speed of slightly over 175 kt. With four times the number of seats and twice the speed, today's jet aircraft are eight times more productive than their 1950s counterparts.

12.3 The decade of the 1960s saw rapid growth in aviation capacity generated by these new aircraft. In the United States, the average annual growth rate for available seat miles in the 1960s was 15.6 per cent, which diminished to 5.3 per cent in the 1970s. The 1980s rate was 5.2 per cent, and by the 1990s the rate had fallen to 3.0 per cent.

SUPPLY AND DEMAND

12.4 Besides being more productive, jet aircraft are also much more efficient. Maintenance costs have decreased and aircraft dispatch reliability has increased. After the introduction of the first generation of jet aircraft, fuel efficiency also continued to improve. This improved efficiency was primarily due to continued improvements in jet engines, airframe structures and systems, and the introduction of larger aircraft that had lower fuel consumption per seat-mile. Greater efficiency allowed airlines to lower prices to stimulate demand and fill the vast quantity of additional capacity being produced.

12.5 The growth in passenger demand, however, did not keep pace with the growth in capacity; all through the 1950s and 1960s, the average load factor declined (see Figure 12-1). Immediately after World War II, the load factor of United States airlines ranged around 65 per cent. By 1971, the load factor had fallen to its lowest level — 48.5 per cent. During World War II, aviation capacity was rationed and dedicated in large part to the war effort. The load factor of United States airlines climbed to its highest level then, when it reached 88 per cent in 1944. Of course, the industry was much smaller than today. In 1944, the total number of available seat miles was 2.8 billion. By 1999, that number had grown to 917.8 billion. It would take fewer than twenty of today's B737 aircraft to produce the total capacity generated by the industry in 1944.

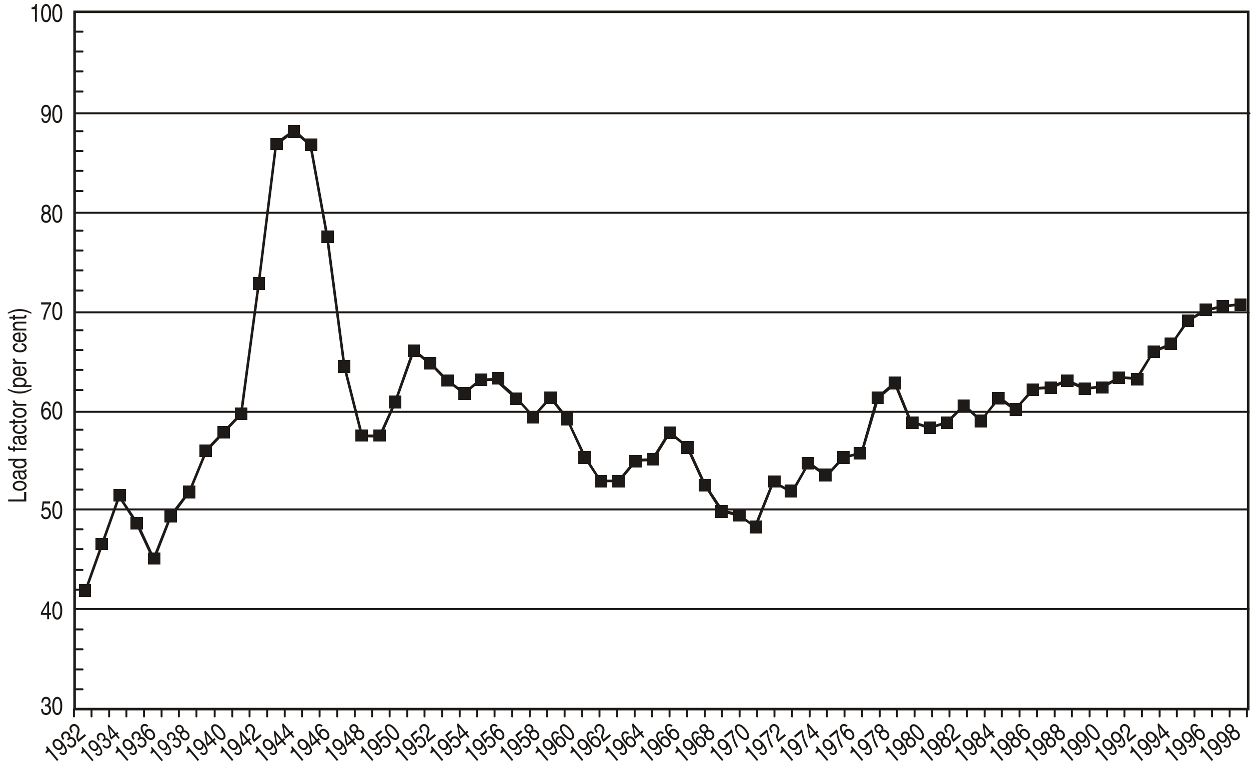


Figure 12-1. The average passenger load factor of U.S. airlines

12.6 After reaching a low in 1971, the average United States load factor grew steadily until reaching a post-war record of 71 per cent in 1999. After the initial rapid introduction of jet aircraft by the United States, subsequent additional capacity was introduced at a much slower pace. In addition, airlines began to use sophisticated computer techniques to better manage their inventory of available seats. These computer programmes, sometimes called yield management systems, and the pricing freedom introduced with deregulation, allowed carriers to offer off-peak pricing to fill seats that otherwise would have gone unsold. By filling more seats, carriers were able to reduce the average price of all seats, thereby continuing to stimulate demand.

12.7 Demand for air travel has a large seasonal component, peaking during July and August in most markets. In addition to seasonal peaks, there are also weekly and daily peaks that are driven by business travel demands. Business travellers increase the weekly demand on Monday through Friday and the daily demand on morning and early evening flights. The new inventory management computer packages allow airlines to reduce prices during low-demand periods in order to fill empty seats. The peak load factor during holiday and summer peaks can average 85 per cent, or even higher, on a daily basis. This high load factor would be difficult to maintain on a year-round basis because of the lack of demand during off-peak periods.

12.8 Carriers have also purchased more of the smaller- and medium-sized jets rather than the jumbos that can sometimes be difficult to fill while still maintaining regular daily service. The smaller jets can be scheduled to better match the level of demand throughout the day and throughout the week. A primary risk associated with a high load factor is that during peak periods of demand, airlines will not be able to accommodate all travellers. When the average load factor reaches 85 per cent, many flights are completely full. A traveller whose schedule is not flexible with respect to time may not be able to find a seat and may then choose not to travel. This unaccommodated demand, or "spill" factor, must be considered when setting prices and load factor goals. Airlines have addressed this issue with their inventory management systems by holding some seats available at full fare until the last minute. Prices for these seats are high and cause customer dissatisfaction. The risk of revenue loss to the airline is that the seat held until the last moment will not be sold at any price.

12.9 Another issue concerning load factor statistics is the difference between the actual load factor and that recorded in the statistics. Differences may be due to the following:

a) non-revenue passengers and cargo may not be taken into account;

b) cargo on passenger aircraft is not usually included in the load factor; and

c) due to aircraft performance limitations, the possible maximum payload may be less than the nominal maximum, but the load factor remains based on the latter.

Therefore, since flights may actually be more fuel-efficient than statistics show, there may be less room for increasing the load factor than there may appear to be.

EFFICIENCY

12.10 Increasing the load factor is an important way to increase airline efficiency, and airlines have generally vigorously pursued a higher load factor. Evidence of this is the steady increase in the load factor since the early 1970s (see Figure 12-2). Airlines have also pursued efficiency by investing in new aircraft technology. Since 1970, aircraft fuel efficiency, measured for passenger airlines by available seat miles per gallon of fuel, has increased by 85 per cent in the United States. In 1970, United States passenger airlines had achieved 28.5 available seat miles per U.S. gallon. By 1999, this figure had increased to 52.6 seat miles per U.S. gallon. The increase in the passenger load factor compounded the increase in aircraft efficiency. In 1970, United States passenger airlines had achieved 14.8 passenger miles per U.S. gallon. By 1999, the number of passenger miles per U.S. gallon had increased by 150 per cent from 1970 values to 37.4 miles per U.S. gallon. The 1999 fuel efficiency figure of 37.4 miles per U.S. gallon compares well with that actually achieved by even the most efficient automobiles travelling with a single passenger. And of course, the speed and safety of jet travel are a major benefit for the traveller as well.

FUTURE TRENDS

12.11 It is somewhat problematic whether the airlines will be able to continue to achieve these compounded benefits by further increasing the passenger load factor. It seems likely that the industry will be able to marginally increase the load factor from the present levels. A huge risk is that pricing differentials between peak and off-peak periods will grow even larger than those that exist today. One of the major complaints facing the industry is that pricing should be uniformly based on distance travelled. In order to do this, seats would have to be sold on a first-come, first-served basis, and the benefits of peak pricing strategies would disappear. On the other hand, if capacity were to be limited during peak demand times or if prices had to be increased to squelch demand during peak demand times, there would be an increase in “spill”. This unaccommodated demand would be an indication that the airline industry was no longer meeting the timely service needs of the travelling public.

SUMMARY

12.12 The various items that affect the load factor have been addressed, and the limitations on achieving the airline goal of a higher load factor have been reviewed. As more sophisticated techniques become available the load factor tends to increase, but there remain practical and physical limits to how much more improvement can be made.

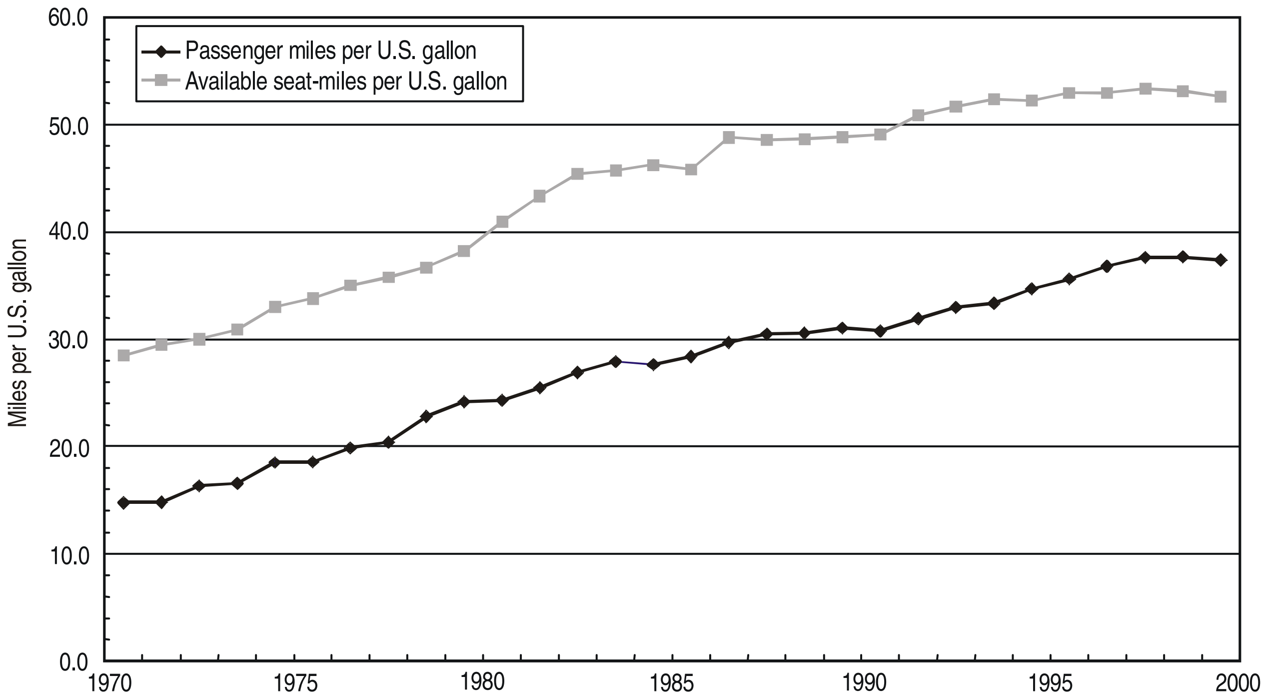


Figure 12-2. Fuel and efficiency trends of U.S. airlines

Chapter 13
IMPLEMENTATION

NEED FOR ACTION

13.1 To achieve significant reductions in emissions, action needs to be taken by all stakeholders involved in the operation of aircraft, airports and the air traffic management system.

13.2 Providers of the air traffic management infrastructure, usually governments, need to provide more opportunities to minimize flight distances as well as delays and fly at the most efficient altitude, speed and wind conditions. Improvements in these areas using the latest technology would provide the largest and most immediate benefits. Specific changes include implementation of:

a) reduced vertical separation minimum worldwide;

b) the gate-to-gate concept worldwide;

c) automatic dependent surveillance in oceanic airspace;

d) free flight worldwide;

e) flexible use of airspace in all ECAC States;

f) free route airspace in Europe; and

g) free route airspace in the United States.

13.3 Airlines need to review their current practices and continuously monitor their procedures and the condition of their aircraft to ensure the most efficient use of fuel.

13.4 One general issue is the availability of accurate, comprehensive and timely data. This includes the relative performance of individual aircraft, weather forecasting and actuals, and accurate information on the aircraft's mass, fuel and payload. This enables contingency fuel reserves and other precautions to be minimized.

13.5 Areas of potential inefficiency include maintenance, route planning, non-revenue flights, unnecessary drag and unnecessary mass.

13.6 Ways of reviewing current practices include the use of general checklists and checklists for specific aircraft and engine types, which are available from the manufacturers (for example, the Boeing Fuel Conservation and Operations Newsletters).

13.7 One airline developed a fuel-saving programme in 1998 that included three engineering and maintenance components: a drag reduction programme, a mass reduction programme and an engine wash programme.

13.8 Specific fuel-saving opportunities include:

a) reviewing all on-board safety equipment for necessity and possible mass reduction;

b) reviewing all on-board passenger comfort items for necessity and possible mass reduction;

c) evaluating fuel reserves to eliminate any excess; and

d) taxiing with one or more engines inoperative.

13.9 Government regulators should re-evaluate regulations that limit the most fuel-efficient use of aircraft and the infrastructure. These include:

a) ensuring that minimum permissible fuel reserves reflect current operating conditions and available data;

b) reviewing minimum required safety equipment to ensure the requirements are still appropriate; and

c) reviewing certification and continuing airworthiness testing requirements.

13.10 Airports need to evaluate practices that result in unnecessary fuel use. These include taxes and charges that encourage fuel tinkering, and limitations which cause congestion, such as curfews and other noise restrictions. Specific actions addressing operational opportunities for greater efficiency and/or reduced emissions include:

a) consider changing the energy source of ground support equipment to reduce adverse emissions;

b) consider ways of minimizing taxi time and distance, such as redesigning the airport layout;

c) install surface management systems; and

d) coordinate the introduction of procedure improvements with stakeholders.

13.11 Airframe and engine manufacturers need to support the above activities, providing analysis, information and assistance, as needed, to facilitate the most efficient use of their products and, in particular, providing estimates of the potential fuel saving resulting from improved operational opportunities.

13.12 Other stakeholders in air transport should also review the limitations that they impose on air transport, which cause extra fuel burn. Specific examples include:

a) surface access to airports;

b) noise limitations; and

c) land-use management.

SUMMARY

13.13 The benefits of minimizing fuel use can only be realized if the different sectors of the industry work separately and together, as necessary, to make the appropriate changes to save a significant amount of fuel.

— END —

ICAO TECHNICAL PUBLICATIONS

The following summary gives the status, and also describes in general terms the contents of the various series of technical publications issued by the International Civil Aviation Organization. It does not include specialized publications that do not fall specifically within one of the series, such as the Aeronautical Chart Catalogue *or the* Meteorological Tables for International Air Navigation.

International Standards and Recommended Practices are adopted by the Council in accordance with Articles 54, 37 and 90 of the Convention on International Civil Aviation and are designated, for convenience, as Annexes to the Convention. The uniform application by Contracting States of the specifications contained in the International Standards is recognized as necessary for the safety or regularity of international air navigation while the uniform application of the specifications in the Recommended Practices is regarded as desirable in the interest of safety, regularity or efficiency of international air navigation. Knowledge of any differences between the national regulations or practices of a State and those established by an International Standard is essential to the safety or regularity of international air navigation. In the event of non-compliance with an International Standard, a State has, in fact, an obligation, under Article 38 of the Convention, to notify the Council of any differences. Knowledge of differences from Recommended Practices may also be important for the safety of air navigation and, although the Convention does not impose any obligation with regard thereto, the Council has invited Contracting States to notify such differences in addition to those relating to International Standards.

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