

**Cir 303
AN/176**



Operational Opportunities to Minimize Fuel Use and Reduce Emissions

Approved by the Secretary General
and published under his authority

February 2003

International Civil Aviation Organization

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Egypt. ICAO Regional Director, Middle East Office, Egyptian Civil Aviation Complex, Cairo Airport Road, Heliopolis, Cairo 11776

Telephone: +20 (2) 267-4840; Facsimile: +20 (2) 267-4843; Sitatex: CAICAYA

France. Directeur régional de l'OACI, Bureau Europe et Atlantique Nord, 3 bis, villa Émile-Bergerat, 92522 Neuilly-sur-Seine (Cedex)

Téléphone: +33 (1) 46 41 85 85; Fax: +33 (1) 46 41 85 00; Sitatex: PAREUYA

India. Oxford Book and Stationery Co., Scindia House, New Delhi 110001 or 17 Park Street, Calcutta 700016

Telephone: +91 (11) 331-5896; Facsimile: +91 (11) 332-2639

Japan. Japan Civil Aviation Promotion Foundation, 15-12, 1-chome, Toranomon, Minato-Ku, Tokyo

Telephone: +81 (3) 3503-2686; Facsimile: +81 (3) 3503-2689

Kenya. ICAO Regional Director, Eastern and Southern African Office, United Nations Accommodation, P.O. Box 46294, Nairobi

Telephone: +254 (20) 622 395/6; Facsimile: +254 (20) 623028 / +254 (20) 520135; Sitatex: NBOCAYA

Mexico. Director Regional de la OACI, Oficina Norteamérica, Centroamérica y Caribe,

Av. Presidente Masaryk No. 29, 3er. Piso, Col. Chapultepec Morales, C.P. 11570, México D.F.

Teléfono: +52 (55) 52 50 32 11; Facsimile: +52 (55) 52 03 27 57

Nigeria. Landover Company, P.O. Box 3165, Ikeja, Lagos

Telephone: +234 (1) 4979780; Facsimile: +234 (1) 4979788; Sitatex: LOSLORK

Peru. Director Regional de la OACI, Oficina Sudamérica, Apartado 4127, Lima 100

Teléfono: +51 (1) 302260; Facsimile: +51 (1) 640393; Sitatex: LIMCAYA

Russian Federation. Aviaizdat, 48, 1. Franko Street, Moscow 121351

Telephone: +7 (095) 417-0405; Facsimile: +7 (095) 417-0254

Senegal. Directeur régional de l'OACI, Bureau Afrique occidentale et centrale, Boîte postale 2356, Dakar

Téléphone: +221 8-23-54-52; Fax: +221 8-23-69-26; Sitatex: DKRCAYA

Slovakia. Air Traffic Services of the Slovak Republic, Letové prevádzkové služby Slovenskej Republiky,

State Enterprise, Letisko M.R. Štefánika, 823 07 Bratislava 21, Slovak Republic

Telephone: +421 (7) 4857 1111; Facsimile: +421 (7) 4857 2105

South Africa. Avex Air Training (Pty) Ltd., Private Bag X102, Halfway House, 1685, Johannesburg, Republic of South Africa

Telephone: +27 (11) 315-0003/4; Facsimile: +27 (11) 805-3649; E-mail: avex@iafrica.com

Spain. A.E.N.A. — Aeropuertos Españoles y Navegación Aérea, Calle Juan Ignacio Luca de Tena, 14,

Planta Tercera, Despacho 3. 11, 28027 Madrid

Teléfono: +34 (91) 321-3148; Facsimile: +34 (91) 321-3157; Correo-e: sccc.ventasoci@aena.es

Thailand. ICAO Regional Director, Asia and Pacific Office, P.O. Box 11, Samyack Ladprao, Bangkok 10901

Telephone: +66 (2) 537-8189; Facsimile: +66 (2) 537-8199; Sitatex: BKKCAYA

United Kingdom. Airplan Flight Equipment Ltd. (AFE), 1a Ringway Trading Estate, Shadowmoss Road, Manchester M22 5LH

Telephone: +44 161 499 0023; Facsimile: +44 161 499 0298; E-mail: enquiries@afeonline.com;

World Wide Web: <http://www.afeonline.com>

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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:

The Secretary General
International Civil Aviation Organization
999 University Street
Montréal, Québec
CANADA H3C 5H7

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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 up 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 CO₂. 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	DSR	Display system replacement
ADS-A	Automatic dependent surveillance — addressable	EATCHIP	European Air Traffic Control Harmonization and Integration Programme
aFAST	Active final approach spacing tool	EATMP	European Air Traffic Management Programme
AMAN	Arrivals management	ECAC	European Civil Aviation Conference
APU	Auxiliary power unit	E/DA	En-route/descent adviser
ASK	Available seat-kilometres	EDP	Expedite departure path
ASM	Airspace management	EGT	Exhaust gas temperature
ATA	Air traffic management programme	ETOPS	Extended range operations by twin-engined aeroplanes
ATAG	Air Transport Action Group	EU	European Union
ATC	Air traffic control	FAA	Federal Aviation Administration
ATFM	Air traffic flow management	FANS	Future air navigation systems
ATM	Air traffic management	FFP1	Free Flight Phase 1
ATN	Aeronautical telecommunication network	FFP2	Free Flight Phase 2
ATP	Air traffic planning and procedures	FMS	Flight management system
ATS	Air traffic services	FRA	Free route airspace
AVOSS	Advance vortex spacing system	FUA	Flexible use of airspace
CAASD	Centre for Advanced Aviation System Development	GPS	Global positioning system
CAEP	Committee on Aviation Environmental Protection	GPU	Ground power unit
CDA	Continuous descent approach	GSE	Ground support equipment
CDM	Collaborative decision making	HC	Unburned hydrocarbons
CDTI	Cockpit display of traffic information	HPC	High pressure compressor
CFMU	Central Flow Management Unit	HPT	High pressure turbine
CNG	Compressed natural gas	IAS	Indicated airspeed
CNS	Communications, navigation and surveillance	ICAO	International Civil Aviation Organization
CO	Carbon monoxide	ICR	Initial collaborative routing
CO ₂	Carbon dioxide	IPCC	Intergovernmental Panel on Climate Change
CRCT	Collaborative routing and coordination tools	LPG	Liquefied petroleum gas
CTAS	Centre-TRACON Automation System	LTO	Landing and take-off
CTOT	Calculated take-off time	MEL	Minimum equipment list
D2	Direct-to		
DMAN	Departure management		

NAS	National airspace system	SFC	Specific fuel consumption
NAT	North Atlantic	SMA	Surface movement adviser
NAVAID	Navigation aid	SMAN	Surface management
NEPA	National Environmental Policy Act	SMS	Surface management system
NEXRAD	Next generation weather radar	SO _x	Oxides of sulphur
NLR	National Aerospace Laboratory	SUA	Special use airspace
NONPREF	Non-preferential route	TCAS	Traffic Alert and Collision Avoidance System
NO _x	Oxides of nitrogen	TFM	Traffic flow management
NRP	National route programme	TKP	Tonne-kilometres performed
PAC	Pacific	TMA	Traffic management adviser
PARR	Problem analysis, resolution and ranking	TMA-MC	Traffic management adviser — multi-centre
pFAST	Passive final approach spacing tool	TMA-SC	Traffic management adviser — single centre
PM	Particulate matter	TRACON	Terminal radar approach control
RHSM	Reduced horizontal separation minima	TSFC	Thrust specific fuel consumption
RNAV	Area navigation	UNFCCC	United Nations Framework Convention on Climate Change
RNP	Required navigation performance	UPR	User-preferred route
RPK	Revenue passenger-kilometre	URET	User request evaluation tool
RTA	Required time of arrival	VKT	Vehicle-kilometres travelled
RVSM	Reduced vertical separation minima	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 CO₂ and H₂O 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂. 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 (CO₂).

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 (CO₂).

** 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 to 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 (CO₂).

** 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 (CO₂).

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.

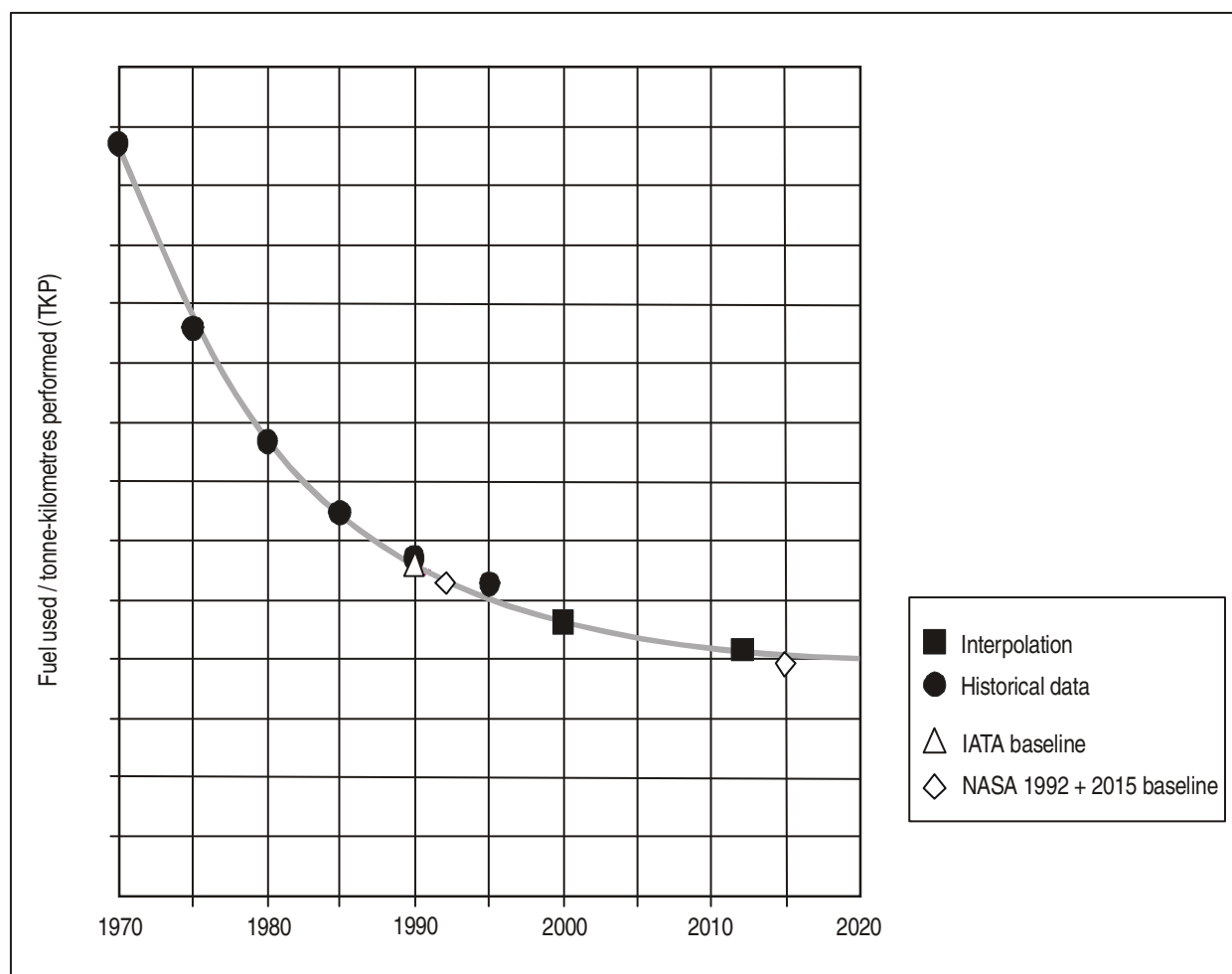
FUEL EFFICIENCY IMPROVEMENTS AND ADVANCES IN AIRCRAFT AND ENGINE DESIGN

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