

Doc 10013



Operational Opportunities to Reduce Fuel Burn and Emissions

Approved by the Secretary General
and published under his authority

First Edition — 2014

International Civil Aviation Organization

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Published in separate English, Arabic, Chinese, French, Russian
and Spanish editions by the
INTERNATIONAL CIVIL AVIATION ORGANIZATION
999 University Street, Montréal, Quebec, Canada H3C 5H7

For ordering information and for a complete listing of sales agents
and booksellers, please go to the ICAO website at www.icao.int.

First edition 2014

**Doc 10013, *Operational Opportunities to Reduce
Fuel Burn and Emissions***
Order Number: 10013
ISBN 978-92-9249-412-4

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AMENDMENTS

Amendments are announced in the supplements to the *Catalogue of ICAO Publications*; the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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FOREWORD

This manual 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. This manual was developed by the ICAO Committee on Aviation Environmental Protection (CAEP) and updates and replaces information previously provided in ICAO Circular 303 — *Operational Opportunities to Minimize Fuel Use and Reduce Emissions*, published in 2004.

This document contains information on current practices that are followed by aircraft operators, airport operators, air navigation services providers (ANSPs), other industry organizations and States, which are intended to minimize fuel use and reduce emissions from civil air transport. The manual is therefore aimed at airlines, airport operators, air traffic management and air traffic control service providers, airworthiness authorities, environmental agencies and other government bodies and interested parties.

It should be noted that this manual 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.

The objectives of this manual are to:

- a) document industry experience and the benefits, in terms of emissions, resulting from optimizing the use of current aircraft and infrastructure, and the related benefits of infrastructure improvements;
- b) identify improvements that could result in measurable fuel savings; and
- c) demonstrate that a more efficient use of infrastructure is an effective means of reducing civil aviation emissions and therefore promote enhanced use of the capabilities inherent in existing aircraft, ground service equipment and infrastructure.

The issues are addressed in a generic way or with the use of practical examples, and wherever possible, a general order of magnitude of the benefits is given.

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 manual examines some of the primary considerations associated with operational opportunities. Some of the usual considerations are that:

- a) appropriate safety criteria are met;
- b) operational and other environmental consequences are acceptable;
- c) the impact on customer service is realistic;
- d) priorities are judged on a case-by-case basis; and
- e) each operation is part of a complex and worldwide system.

Collaborative efforts are paramount in any operational improvement initiative. Before specific changes to aircraft operations are introduced, it is necessary for operators to consult with aircraft and engine manufacturers, and/or ANSPs, about the potential benefits and technical limitations of such changes. Before contemplating any changes to infrastructure, general consultation with the major aviation stakeholders is advisable.

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

Comments on this manual, 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

This manual, developed by the ICAO Committee on Aviation Environmental Protection (CAEP), identifies and reviews various operational opportunities and techniques for reducing 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. The manual updates and replaces ICAO Circular 303, *Operational Opportunities to Minimize Fuel Use and Reduce Emissions*, published in 2004.

This manual identifies specific actions that might be taken by the major stakeholders in civil air transport in order to reduce fuel consumption, together with practical examples. It also describes the conditions and limitations associated with these actions. It is not intended as a 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.

KEY CONSIDERATIONS

For economic and efficiency reasons, the commercial aviation industry has already developed and implemented many techniques to reduce fuel usage. There has been steady progress in making aircraft and airline operations more fuel-efficient, but it takes time to introduce technological improvements in aircraft/engine design and for those improvements to spread through the fleet. Changes to operating procedures or improvements to infrastructure may therefore offer significant and more immediate ways of improving efficiency.

Operational opportunities and techniques can be considered only in the context of airport and air traffic constraints, operational requirements, and individual operator circumstances on a given flight. While this manual is focused on reducing fuel and emissions, the primary concern for all operations is safety. Safety standards must not be compromised by any of the changes made in the interest of fuel conservation. 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.

Another consideration is the management of potential interdependencies (both trade-offs and synergies) that can exist between noise and emissions goals in the vicinity of airports as well as non-environmental interdependencies such as capacity and maintenance costs.

Many operational opportunities require collaboration and cooperation among all 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.

STRUCTURE

The manual begins with some background information with respect to global emissions and climate change issues, including an overview of ICAO actions in this area, and an introduction to operational opportunities and collaborative action (Chapter 1). The subsequent chapters then explore the range of opportunities for operational improvements:

- a) Chapter 2 covers the opportunities at airports to minimize fuel consumption and emissions from aircraft and airport-related sources.
- b) Chapter 3 focuses on opportunities relating to maintenance.
- c) Chapter 4 presents an overview of opportunities to reduce the aircraft dry operating weight.
- d) Chapter 5 discusses the effect of payload on fuel efficiency.
- e) Chapter 6 describes the current opportunities and the strategic work under way to improve the efficiency of the global air traffic management (ATM) system, with the aim of reducing fuel consumption and emissions.
- f) Chapter 7 reviews some flight planning and related issues from the aircraft operator's point of view.
- g) Chapter 8 covers opportunities to reduce fuel burn and emissions across the various phases of a flight.

FINDINGS

The principal findings from each chapter of the manual are outlined below:

- a) At airports, ground service equipment and surface access transport account for a significant proportion of emissions, depending on the area included in the assessment and the characteristics of the airport. Therefore, in addition to reducing aircraft fuel usage, it can be worthwhile implementing measures to reduce emissions from ramp equipment and from ground transport to and from the airport. Airports vary greatly in terms of their 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.
- b) Good engine and airframe maintenance practices will minimize costs and unnecessary fuel consumption. Over a period of 5 years, engine and airframe deterioration may increase the drag of the aircraft by up to 2 per cent. Engine wear and airframe imperfections, such as missing fairings and other small non-essential parts, all contribute to increased fuel consumption. Continuous monitoring and regular line maintenance activities are very important in detecting and correcting performance deterioration.
- c) Carrying unnecessary extra weight will increase the quantity of fuel burned in flight. The extra fuel burn attributable to additional weight carried on-board an aircraft is typically on the order of 2.5 to 4.5 per cent of the additional weight, per hour of flight, depending on the characteristics of the aircraft. Aircraft and component manufacturers are making great strides towards reducing the weight of equipment through the use of lighter materials and less complex assemblies. Opportunities exist for aircraft operators to review the carriage of non-essential on-board items and to install lighter equipment and fittings.
- d) The payload carried on a flight can also affect fuel efficiency because the efficiency of an individual flight can be related to the amount of revenue-generating payload carried, i.e. passengers or cargo. Sophisticated computer tools enable airlines to optimize the load factor on individual flights and across their networks. Because an operator's ability to achieve the most fuel-efficient load factor can be reduced by factors such as performance limitations, noise abatement constraints and the practicalities of managing operations across a network, it is important that a holistic perspective covering interdependencies is maintained when evaluating load-factor efficiency performance.

- e) Operational measures for fuel efficiency are in general influenced by applicable air regulations, safety considerations, good operating practices, ATM, and noise restrictions. Within these constraints, aircraft operations can be optimized for fuel efficiency and reduced emissions.
 - f) Significant fuel and emissions savings can be realized by an efficient ATM system. New and established technologies and concepts of operations in communications, navigation and surveillance (CNS) can provide opportunities to improve the efficiency of ATM. CNS/ATM can permit more direct routings and the use of more efficient flight conditions such as optimum altitude and speed. Airspace structure should be optimized to avoid creating impediments to effective route planning; non-optimized airspace structure can result in increased miles flown or restrict the availability of optimum flight levels.
 - g) There are many potential opportunities for improving efficiency through the planning and execution of a flight. Flights can be planned and operated more safely and efficiently if more accurate, comprehensive and timely information is available regarding operational factors and individual aircraft performance. Factors such as non-optimal altitude and airspeed due to the need to avoid severe meteorological conditions and conflicting traffic, and/or lack of flight planning optimization, can contribute significantly to less-than-optimal fuel consumption. Likewise, scheduling constraints, punctuality considerations, noise abatement measures or the need to plan flights around special-use airspace can also result in additional fuel consumption. Effective management of the centre of gravity of an aircraft can also yield appreciable savings in fuel consumption.
 - h) Opportunities to increase efficiency and reduce fuel consumption may exist across the phases of a flight, including taxi, climb, cruise and descent. Ideally, when planning and operating a flight, the trajectory should be considered as a whole, since changes to one segment of the trajectory can affect performance in other parts of the same trajectory, or limit the trajectories of other flights. In general, the optimization of one flight or phase of flight should not produce a disproportionate disbenefit elsewhere.
-

ACRONYMS AND ABBREVIATIONS

ACARS	Aircraft communications addressing and reporting system
ACAS	Airborne collision avoidance system
A-CDM	Airport collaborative decision making
ADS	Automatic dependent surveillance
ADS-B	Automatic dependent surveillance — broadcast
AMAN	Arrival management
ANP	Air navigation plan
ANSP	Air navigation services provider
APM	Aircraft performance monitoring
APU	Auxiliary power unit
ASBU	Aviation system block upgrade
ASPIRE	Asia and Pacific Initiative to Reduce Emissions
ATC	Air traffic control
ATM	Air traffic management
ATS	Air traffic services
CAEP	Committee on Aviation Environmental Protection
CANSO	Civil Air Navigation Services Organization
CCO	Continuous climb operation
CDL	Configuration deviation list
CDM	Collaborative decision making
CDO	Continuous descent operation
CFMU	Central Flow Management Unit
CG	Centre of gravity
CNG	Compressed natural gas
CNS	Communications, navigation and surveillance
CO	Carbon monoxide
CO ₂	Carbon dioxide
CRT	Cathode ray tube
DARP	Dynamic airborne re-route procedure
DMAN	Departure management
DOW	Dry operating weight
ECAC	European Civil Aviation Conference
ECS	Environment control system
EDTO	Extended diversion time operation
EGT	Exhaust gas temperature
EMF	Environmental management framework
EMS	Environmental management system
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration (United States)
FEGP	Fixed electrical ground power
FF	Flight and flow
FMS	Flight management system
FPA	Flight path angle
FPFM	Flight planning and fuel management
FUA	Flexible use of airspace
GHG	Greenhouse gas

GIACC	Group on International Aviation and Climate Change
GPU	Ground power unit
GSE	Ground support equipment
HC	Hydrocarbons
HPC	High-pressure compressor
HPT	High-pressure turbine
IAS	Indicated airspeed
IATA	International Air Transport Association
ICE	Information for a collaborative environment
IPCC	Intergovernmental Panel on Climate Change
ISA	International standard atmosphere
ITCZ	Intertropical convergence zone
ITP	In-trail procedures
KPA	Key performance area
KPI	Key performance indicator
LED	Light-emitting diode
LPG	Liquefied petroleum gas
MEL	Minimum equipment list
MNPS	Minimum navigation performance specification
NAS	National Airspace System
NextGen	Next generation air transportation system
NO _x	Oxides of nitrogen
NPR	Noise-preferential route
PBN	Performance-based navigation
PCA	Pre-conditioned air
PIRG	Planning and implementation regional group
PM	Particulate matter
RNAV	Required navigation
RNP	Required navigation performance
RTA	Required time of arrival
RVSM	Reduced vertical separation minimum
SESAR	Single European Sky Air Traffic Management Research Programme
SFC	Specific fuel consumption
SID	Standard instrument departure
SMAN	Surface management
SMM	Safety management manual
SO _x	Sulphur oxides
STAR	Standard instrument arrival
SWIM	System-wide information management
TMA	Terminal area
TSFC	Thrust specific fuel consumption
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UPR	User-preferred route
VKT	Vehicle-kilometres travelled
VNAV	Vertical navigation
VOC	Volatile organic compound
WMO	World Meteorological Organization
ZEV	Zero-emissions vehicle

Chapter 1

BACKGROUND

1.1 GLOBAL EMISSIONS AND CLIMATE CHANGE ISSUES

United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol

1.1.1 The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 to seek 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.

1.1.2 One of the commitments in the Convention is that parties compile national inventories of their emissions sources. For domestic aviation, emissions are considered to be part of the national inventory of each country within which the flights occur. For international flights, the challenge is how to equitably allocate the emissions to national inventories. Emissions from international aviation differ from those from domestic aviation because they are not contained within a single country and may occur within the territory of other countries or in areas outside of recognized national boundaries such as over the high seas. Actions on international air transport taken by a country might have a direct impact on the operations in another country. 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.

1.1.3 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, from the 1990 levels, their collective emissions of greenhouse gases by approximately 5 per cent by the 2008 to 2012 period with the reduction varying from country to country. The agreed targets apply to national totals of greenhouse gases. Consequently, each Annex I country can determine how the various emissions-producing sectors in its economy should be called upon to assist in achieving the country's national target.

1.1.4 Emissions from domestic aviation are included in the total inventories reported and subject to the above targets. Emissions from international aviation, due to the allocation and legal issues involved (including provisions under the Chicago Convention), are included under Article 2.2 of the Kyoto Protocol: "The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively".

Post-Kyoto Protocol

1.1.5 The treaty succeeding the Kyoto Protocol was expected to be adopted at the United Nations (UN) Climate Change Conference in Copenhagen (COP15) in December 2009. No binding agreement on global emissions reduction targets was reached at COP15. However the Copenhagen Accord that was "noted" recognized that deep cuts in global emissions are required, as documented by the IPCC Fourth Assessment Report (see next section), with a view to reducing global emissions so as to limit the increase in global temperature below 2°C.

1.1.6 One of the outcomes of the UN Climate Change Conference in Durban (COP17) in December 2011 included a decision by Parties to adopt a universal legal agreement on climate change as soon as possible and no later than 2015.

Intergovernmental Panel on Climate Change (IPCC)

1.1.7 The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of knowledge of climate change and its potential environmental and socio-economic impacts. The Panel reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change.

1.1.8 Since 1996, ICAO has been actively contributing to the IPCC's activities, in particular to the IPCC Special Report on Aviation and the Global Atmosphere, issued in 1999, laying the foundations for aviation global emissions assessments.

1.1.9 The 2007 IPCC Fourth Assessment Report (AR4) included an update of the main findings of the Special Report as well as new findings related to aviation emissions, including influence of contrails and aerosols on cirrus clouds and the climate impact of oxides of nitrogen and methane. The IPCC has initiated the preparation of its Fifth Assessment Report (AR5), which is scheduled to be completed in 2014. ICAO is involved in the IPCC process to ensure that issues related to aviation and climate change are covered in the AR5.

The impact of aviation emissions on global climate

1.1.10 The main findings related to aviation emissions in AR4, published in 2007, are the following:

- a) total aviation CO₂ emissions (domestic and international) are approximately 2 per cent of the world's anthropogenic (human-made) CO₂ emissions (see Figure 1-1);
- b) the amount of CO₂ emissions from aviation is projected to grow around 3 to 4 per cent per year; and
- c) medium-term mitigation of CO₂ emissions from the aviation sector potentially can come from improved fuel efficiency. However, such improvements are expected to only partially offset the growth of aviation CO₂ emissions.

1.2 ICAO AND CLIMATE CHANGE

ICAO Programme of Action on International Aviation and Climate Change

1.2.1 Approximately 62 per cent of aviation emissions are attributed to international aviation operations. This amount is projected to grow at around 3 to 4 per cent per year, and ICAO has been actively developing a comprehensive mitigation strategy to limit or reduce greenhouse gas (GHG) emissions from international aviation.¹

1. ICAO, "Aviation Outlook," ICAO Environmental Report 2010: Aviation and Climate Change.

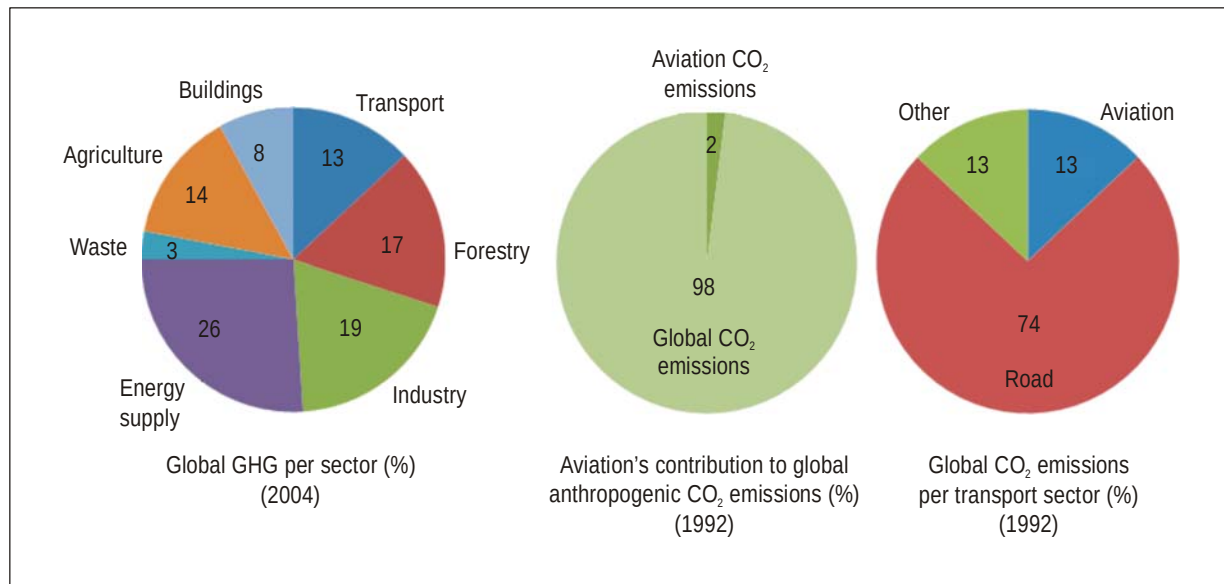


Figure 1-1. Aviation's contribution to global emissions²

1.2.2 A milestone in this strategy was achieved by the High-level Meeting on International Aviation and Climate Change in October 2009 (HLM-ENV/09). The meeting agreed on a set of comprehensive measures known as the ICAO Programme of Action on International Aviation and Climate Change.

1.2.3 In particular, the Programme of Action encompasses a basket of measures developed by the Group on International Aviation and Climate Change (GIACC),³ covering aircraft-related technology development, improved use of air traffic management and infrastructure, more efficient operations, economic/market-based measures and regulatory measures.

1.2.4 The Programme of Action also included the agreement on a global aspirational goal of 2 per cent annual improvement in fuel efficiency until the year 2050, which made international aviation the first sector with a shared global commitment to environmental goals of increasing fuel efficiency and stabilizing its global CO₂ emissions in the medium term.

Alternative fuels

1.2.5 Development and deployment of sustainable alternative fuels is an important element of ICAO's comprehensive mitigation strategy that includes technological, operational and market-based measures to address aviation greenhouse gas emissions. The ICAO Conference on Aviation and Alternative Fuels was held in November 2009 (CAAF/09). The Conference adopted a global framework on the development and deployment of such fuels for aviation as an important means of reducing aviation emissions.

2. Source: IPCC, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007, and IPCC Special Report, *Aviation and the Global Atmosphere*, 1999.

3. The 36th Session of the ICAO Assembly (September 2007) requested the ICAO Council to form the Group on International Aviation and Climate Change (GIACC). The GIACC is composed of 15 senior government officials representing all ICAO regions, with technical support provided by the Committee on Aviation Environmental Protection (CAEP).

The 37th Session of the ICAO Assembly

1.2.6 With the solid basis of the Programme of Action on International Aviation and Climate Change, ICAO has strived to make further progress on the recommendations of HLM-ENV/09 and CAAF/09 toward the development of proposals for more ambitious policies on international aviation and climate change. This work is proceeding, in particular, in three areas:

- a) exploring the feasibility of more ambitious goals including carbon-neutral growth of the sector and long-term emissions reductions, moving beyond the global commitment of a 2 per cent annual fuel efficiency improvement up to 2050;
- b) developing a framework for market-based measures in international aviation; and
- c) elaborating on measures to assist developing States and to facilitate access to financial resources, technology transfer and capacity building.

1.2.7 In line with those three areas, the 37th Session of the ICAO Assembly, held in October 2010, adopted a new, robust set of policies on international aviation and climate change.⁴

Committee on Aviation Environmental Protection (CAEP)

1.2.8 The Organization, with the support of its Committee on Aviation Environmental Protection (CAEP), continued to actively pursue its technical work on measures to reduce the environmental effects of aviation. The committee is composed of leading technical experts in the environmental field from around the world. Its recommendations over the past 40 years have laid the basis for the remarkable progress of civil aviation in minimizing the impact of aircraft noise and aircraft engine emissions through technological, operational and market-based measures.

1.2.9 CAEP held its eighth meeting (CAEP/8) in February 2010. For climate change, among other measures, CAEP committed to a timetable for the development of a CO₂ standard for commercial aircraft, aiming at 2013.

1.3 OPERATIONAL OPPORTUNITIES

Introduction

1.3.1 CAEP has been pursuing three main approaches to addressing aviation emissions, namely technological innovation and certification standards, operational measures and the possible use of market-based options. On balance, the operational measures have the potential to provide substantial near-term reductions in fuel use and emissions.

1.3.2 In 2010, the CAEP work programme on operational measures focused on three key issues:

- a) recommendations for operational goals for noise and fuel burn in the medium term and the long term;
- b) quantification of the benefits of CNS/ATM measures, including increased liaison with ICAO's planning and implementation regional groups (PIRGs); and

4. Resolutions A37-18 and A37-19 are available at <http://www.icao.int/environmental-protection/Pages/Assembly.aspx>.

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

This manual addresses the key issue in 1.3.2 c) and is based on ICAO Circular 303 — *Operational Opportunities to Minimize Fuel Use and Reduce Emissions*, published in 2004.

1.3.3 The term “operations” in the context of aviation encompasses a very broad range of activities that can be divided into three main classes: aircraft operations, airport operations and air traffic management (ATM) operations. Aircraft operations include for example the scheduling process, loading of the aircraft, the flight operation itself and aircraft maintenance. Airport operations comprise activities in and around the airfield such as ground handling (runway, taxiway and ramp), use of ground-based systems, and ground movement management. ATM operations consist of activities having a direct impact on the aircraft flight, the flow of traffic and how the airspace is used.

1.3.4 All these activities are interlinked and therefore involve different stakeholders, namely the airspace users, maintenance engineers, airport operators, air navigation services providers and the regulatory authorities.

Collaborative action

1.3.5 In order to achieve optimal results and effectively implement operational measures, collaboration and coordination between different stakeholders are essential.⁵ This may be particularly important when resolving issues related to the interdependencies between the different effects of operational measures. Depending on the initiative, strong collaboration may be required between the following stakeholders:

- a) air navigation services providers (policy/decision makers, airspace and procedure designers, operational air traffic control staff);
- b) airspace users (policy/decision makers, senior pilots, technical staff);
- c) airport operators (operations and environment departments); and
- d) regulatory authorities (aviation regulators, local authorities).

1.3.6 Interdependencies can be positive (synergy) or negative (trade-offs). For example, there can be interdependencies (both trade-offs and synergies) between noise and emissions. Increases in ATM and airport capacity may temporarily ease congestion and hence make each flight more efficient, but such increases may also trigger trade-offs between per-flight efficiency and total absolute emissions, which may then become an issue for society and political decision makers. In addition, improvements that are undertaken for purely operational reasons can sometimes offer fuel and emissions reduction benefits that may be overlooked.

5. See also Part 1 of the *Manual on Global Performance of the Air Navigation System* (Doc 9883), section 1.3.3.

Chapter 2

AIRPORT OPERATIONS

2.1 INTRODUCTION

2.1.1 This chapter summarizes operational opportunities at airports to minimize fuel consumption and resulting emissions from aircraft and airport-related sources including ground support equipment (GSE) and ground transportation. Operational opportunities include measures such as minimizing fuel use, optimizing airport design, modifying current operating practices, modernizing GSE and consolidating ground transport. It must be appreciated that site-specific limitations or conditions may preclude the application of a given technology or operational measure.

2.1.2 Reductions in fuel consumption from airport sources will reduce CO₂ emissions, which affect global climate, as well as other emissions that affect local air quality (oxides of nitrogen (NO_x), sulphur oxides (SO_x), hydrocarbons (HC) which include volatile organic compounds (VOC), carbon monoxide (CO), and particulate matter (PM)). While there is a direct correlation between the fuel burn reduction and associated CO₂ reduction achieved by any measure, some measures have differing effects on other emissions.

2.1.3 Identification and selection of any operational measures to reduce fuel consumption and associated emissions at airports must be made in consultation with the airport operator, local/regional/national authorities, air navigation services providers, 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, fuel and therefore emissions reductions may be achieved through the collaborative management of all the operations of airside stakeholders. Operational measures may also result in improvements in system efficiency and reductions in system operating costs. Airport operations need to be integrated with flight operations, ground service operations and air traffic management for maximum fuel savings. Chapter 6 addresses air traffic management aspects.

2.2 PREVIOUS WORK BY ICAO

2.2.1 ICAO has been concerned with emissions at airports for many years. Previous studies have indicated that aircraft emissions may dominate on-airport emissions inventories, but ICAO's 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 indicate that pollutant levels will remain at present levels or be reduced at least until 2015. Although it will remain a small part of regional inventories, the relative contribution of aircraft to local air quality may change in the future.

2.2.2 ICAO periodically updates its *Airport Planning Manual* (Doc 9184), Part 2, *Land Use and Environmental Control*, which provides information on means of reducing emissions and improving fuel efficiency, and encourages the use of environmental management systems at airports.

2.2.3 ICAO's *Airport Air Quality Guidance Manual* (Doc 9889) provides detailed information on air quality standards, conducting airport emissions inventories, aircraft and other emissions calculations, dispersion modelling and monitoring and measuring air quality.

2.3 AIRPORT DESIGN AND FACILITIES

An effective airport design can minimize aircraft and ground equipment fuel use. The design might be improved or modified during expansion processes. This includes the layout of the buildings, service stations, runways, taxiways, rapid exit taxiways, pavement and other related facilities to provide additional capacity. Table 2-1 lists some examples of opportunities for minimizing fuel usage and resulting emissions.

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

<i>Measure</i>	<i>Description</i>	<i>Comments</i>
Airport layout	Provide an efficient runway, taxiway and apron layout.	Minimizes taxiing and congestion. Facilitates more efficient ground movements through an improved infrastructure (taxiway design, rapid exit taxiway location and design, aircraft passing/holding bays, etc.).
	Site selection (for new airports).	Allows for optimization of regional transit access, weather (low fog areas, etc.).
Airport facilities	Provide 400-Hz fixed electrical ground power (FEGP) and, where necessary, pre-conditioned air (PCA) at gates/maintenance areas and encourage their use.	Reduces or eliminates APU, GPU and air-conditioning unit usage. Typically requires substantial capital investment, but often realizes fuel/maintenance savings.
	Improve low visibility take-off and landing capabilities, supported by surface movement guidance and control systems, where necessary.	Reduces congestion and delay in bad weather and can reduce the need for diversions to other airfields.
	Use LED airfield lighting, where appropriate.	Directly reduces primary energy use.

2.4 AIRCRAFT OPERATIONS

2.4.1 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. Table 2-2 lists some examples.

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

2.4.3 Noise reduction measures implemented at some airports due to local community concerns or regulation can result in increased fuel burn and emissions. Examples include: noise abatement procedures and noise-sharing regimes that increase distances flown; preferential runways and flight tracks (e.g. noise-preferential routes (NPRs)) that require extra flying and taxi times; noise fines that can result in changes to procedures or take-off mass, reducing efficiency; curfews that can cause congestion leading to delays and holding; extra landings and take-offs and flying at

non-optimum speeds. Efforts to reduce fuel burn and emissions should consider these interdependencies and the feasibility of reducing the emissions penalties of noise-related measures. Also, initiatives by airports or other stakeholders that address aircraft noise and its impact, including land-use planning and community relationship development, may in the long term reduce the pressure for noise abatement procedures and their associated trade-offs affecting fuel burn and emissions, as will the ongoing process of fleet evolution.

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

<i>Measure</i>	<i>Description</i>	<i>Comments</i>
Aircraft procedures	Continuous descent operations (CDO)	Descending with engines at low power reduces fuel burn and noise under the flight path, but can be dependent on airspace management and capacity constraints.
	Continuous climb operations (CCO)	Continuously climbing to avoid the need for level flight at low altitudes reduces fuel burn and noise under the flight path, but can be dependent on airspace management and capacity issues.
Discretionary pilot actions	Minimizing the use of reverse thrust on landing	The pilot must retain full authority over the safe operation of the aircraft.
	Engine(s)-out taxi	The pilot must retain full authority over the safe operation of the aircraft. Emissions reductions are site- and aircraft-specific.
Other procedures	Reduced engine idling time	HC and CO emissions are greatest during engine idling. Reducing idling can also result in decreased engine operation, thereby reducing maintenance and improving engine life.
	Aircraft towing	Aircraft towing can significantly reduce aircraft engine use and emissions. Logistic problems may occur at airports with limited manoeuvring areas.

2.5 GROUND SUPPORT EQUIPMENT

2.5.1 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, providing electric power, fuel and other services to the aircraft.

2.5.2 Airports in different regions of the world have divergent responsibilities for the provision and operation of GSE services. For example, in North America and many parts of Europe responsibility for conversion or replacement of most GSE rests with individual aircraft operators, rather than with the airport authority.

2.5.3 The most common types of GSE are:

- a) *Aircraft tractors*. Aircraft tractors, also known as aircraft tugs, 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.
- b) *Air-conditioning units*. Air-conditioning units are trailer- or truck-mounted units used to supply pre-conditioned air to stationary aircraft at the terminal and also during maintenance. As mentioned in Section 2.3, gates are increasingly being modified to provide pre-conditioned air (PCA) from dedicated electricity-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. Air starts are typically used only when an aircraft is not equipped with an auxiliary power unit (APU) or when the APU is not operational. The APU is a small turbine generator that provides compressed air as well as electrical power and cabin air conditioning for on-board equipment such as lights, avionics, galleys and instrumentation.
- d) *Baggage tractors*. Baggage tractors are used to transport luggage or cargo between aircraft and terminal(s). 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/unloading over a 3 to 8-hour period, whereas baggage tractors typically require 13 500 to 27 000-kg ratings and operate sporadically over an 8-hour shift. Electric models are available for certain applications.
- 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 6 to 8 km per day depending on the airport layout. 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 widebody main deck loaders rated at 13 500-kg lift capacity that lift containerized cargo onto the main deck of widebody 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/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 tank, pump, hose and spray gun to transport and spray de-icing/anti-icing fluid 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, which are not self-propelled, have small engines used to power pumps that transfer lavatory fluids between the ground and the aircraft.