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

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

AMENDMENTS		
No.	Date	Entered by

CORRIGENDA		
No.	Date	Entered by

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
UNFCC	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 CO_2 emissions (domestic and international) are approximately 2 per cent of the world's anthropogenic (human-made) CO_2 emissions (see Figure 1-1);

b) the amount of CO_2 emissions from aviation is projected to grow around 3 to 4 per cent per year; and

c) medium-term mitigation of CO_2 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 CO_2 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.

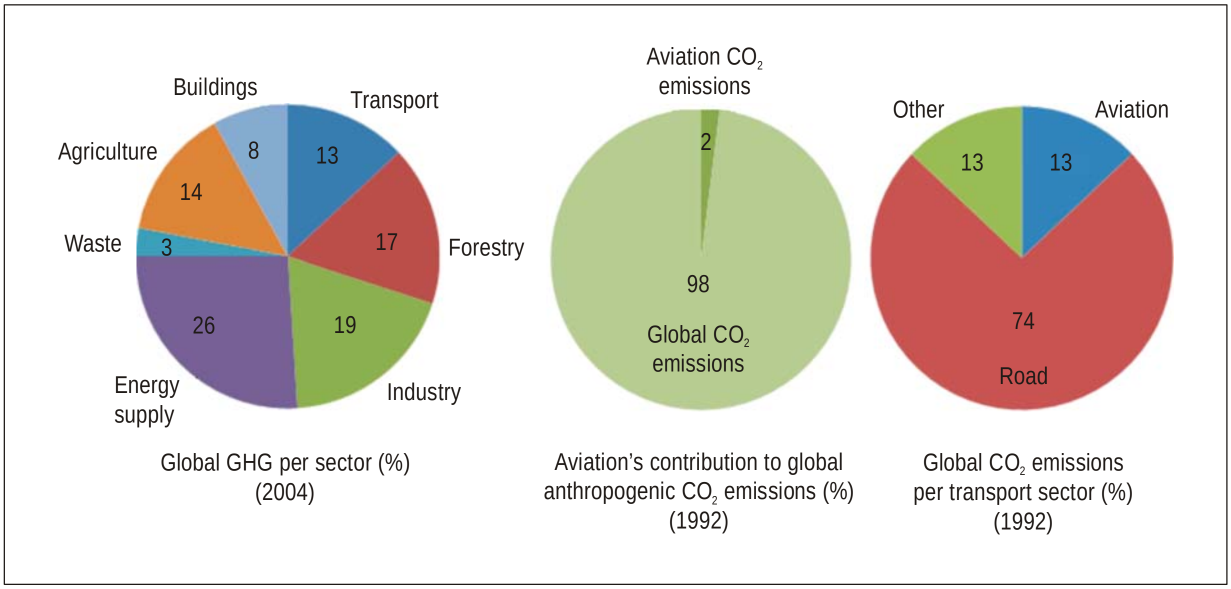

Figure 1-1. Aviation's contribution to global emissions[2]

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 CO_2 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.

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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 CO_2 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 CO_2 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 CO_2 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

Measure	*Description*	*Comments*
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

Measure	*Description*	*Comments*
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.

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 (GPUs)*. Ground power units provide 400 Hz of electrical power to aircraft when the aircraft's APU and the main engines are not operating. Given a choice between GPU and APU usage, airlines typically use GPUs because they cost less to operate. There are two basic types of GPUs. 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 fixed electrical ground power (FEGP) which includes a frequency converter (mains 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) drawing power from the airport's electrical grid.

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

2.5.4 Mitigation options for GSE emissions can realize significant reductions. Table 2-3 lists some examples of the operational opportunities that may exist to reduce fuel usage and emissions from GSE.

Table 2-3. Examples of operational opportunities to minimize fuel usage and emissions from GSE

Measure	*Description*	*Comments*
Modify GSE operations	Enhancing maintenance.	Difficult to predict emissions reduction. Existing maintenance may already be optimized, limiting the reductions that may be realized.
	Reducing driving distances through route planning.	Emissions reduction and fuel savings are route-specific.
	Avoiding unnecessary idling of equipment.	Emissions reduction and fuel savings are site-specific.
	Operating a performance monitoring, awareness, reporting and follow-up scheme.	This is essential to effective operation of existing equipment and in prioritizing and justifying replacement and upgrade strategies.
GSE engine retrofit	Retrofitting gasoline engines with oxidation catalysts.	
	Retrofitting gasoline engines with three-way catalysts.	
	Retrofitting diesel engines with oxidation catalysts.	
	Retrofitting diesel engines with particulate traps.	Retrofit filter may require ultra-low sulphur fuel (15 to 25 parts per million (ppm) of sulphur).

Measure	*Description*	*Comments*
	Installing turbo charging/intercooling/ timing retard.	Retrofits available only for some models.
	Reducing the sulphur content in diesel fuel.	Availability of low sulphur fuel varies geographically, but it is becoming more common.
	Diesel fuel additives/emulsifiers.	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 3-way catalyst.	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.	Improvements to fuel burn as well as significant NO_x and HC reductions may be realized depending on the application of new engine technologies.
	Replacing two-stroke gasoline engines with four-stroke gasoline engines.	
CNG/LPG GSE after-treatment devices	Installing oxidation catalysts.	
	Installing three-way catalysts.	
Alternative fuels	Retrofitting/replacing diesel engines with engines fuelled by compressed natural gas/liquefied petroleum gas (CNG/LPG).	Relative to uncontrolled gasoline and diesel engines, purchase of new CNG/LPG engines may reduce NO_x and PM, but may increase CO and HC emissions. *Note.— The CNG option typically requires substantial infrastructure improvements that must properly address safety and reliability issues. Retrofits of existing engines may increase emissions if not properly installed and maintained.*
	Retrofitting/replacing gasoline engines with CNG/LPG-fuelled engines.	The CNG fuel option typically requires substantial infrastructure improvements that must properly address safety and reliability issues. Retrofits of existing engines may increase emissions if not properly installed and maintained.

Measure	*Description*	*Comments*
	Using electric GSE.	May achieve up to 100 per cent reduction in ramp emissions (excludes emissions arising from electric power generation). Electrification may require a substantial investment in infrastructure. Such improvements must properly address safety and reliability issues. *Note.— 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.*
	Using electro engines powered by fuel cell/hydrogen.	Currently a significant proportion of hydrogen is produced from natural gas. However it could potentially be generated from more sustainable sources in the future.

2.5.5 Costs for operational modifications vary widely; any analysis should include the cost of required enhancements to infrastructure. The infrastructure costs for alternate fuels (e.g. 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 dispensing units 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. Further, equipment costs for electricity-powered units typically do not include the cost of batteries, and batteries must be replaced every three to five years. If additional power must be supplied to the airport/terminal, costs 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. Another benefit associated with electrical GSE is that the equipment can deep-cycle charge during off-peak hours when there is a lower demand for electricity and the cost of charging is typically less than during peak demand times.

2.5.6 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 90 per cent or more reduction in HC and NO_x. Compared with CNG/electric conversions, the savings 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.

2.5.7 As with cost considerations, any operational change must continue to ensure that the minimum duty/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 continue to provide power over a typical operating day;

b) provide sufficient power;

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

d) perform in cold climates.

2.5.8 However, these limitations should not preclude the use of electric GSE when it can 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, CNG and LPG.

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

2.6 SURFACE ACCESS TRANSPORT

2.6.1 Depending on their size, airports serve as destinations for up to hundreds of thousands of vehicles daily. These vehicles in turn can 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 reductions.

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

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

b) passengers and freight; and

c) providers of airport services such as hotel and parking lot shuttles.

Table 2-4 provides examples of measures for reducing VKT for on-airport activities. 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. 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.

Table 2-4. Examples of operational opportunities to minimize ground transport fuel usage and emissions

Measure	*Description*	*Comments*
Employee trip reduction	Compressed work week/ telecommuting: • 10 hours per day, 4 days per week, etc.; and • working at home/remotely, where appropriate, etc.	May realize up to 5 per cent reduction in VKT. Requires substantial planning and implementation.*
	Employee rideshare/carpool incentives: • carpool matching; and • enhanced compensation or benefits for rideshare.	Reduction in VKT varies based on the programme.
	Parking pricing: • increased fees for single occupancy of vehicles; and • positive incentives for alternative fuel/zero-emissions vehicles (ZEV).	Reduction in VKT varies based on the programme.
	Bicycling infrastructure including bike paths, secure parking racks and showering facilities together with positive incentives for their use.	
	Public transit and alternate mode incentives, e.g.: • discount/free pass on public transport; • enhanced compensation for use of ZEV/alternative fuels; and • bus and rail infrastructure.	Depending on incentives and the existing transit system, may increase public transport usage.
Passenger transport management options	Provide a public transport infrastructure, secure public transport services and promote their use.	Often requires partnership planning, development and funding.
	Provide a safe, secure and efficient pedestrian infrastructure at ground transport nodes, including covered pedestrian routes.	This also applies to public access.
	Use remote car-parks with low-emission transit shuttles to the airport.	Relocating emissions may not necessarily reduce overall inventory emissions, but may reduce the concentration of emissions at sensitive receptors around the airport.

Measure	*Description*	*Comments*
	Alternative fuels for buses/taxis/ shuttles/rental cars/freight vehicles: • retrofit existing units with catalysts/traps/filters; • accelerate the retirement of older vehicles; • purchase new alternate fuels/zero-emissions vehicles for replacement and growth; • provide an alternative-fuel infrastructure; and • provide sponsorship and other incentives, etc.	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.
	Impose idle restrictions on cars/taxis/buses/delivery vehicles.	Possible emissions reduction.
	Manage circulation of cars/taxis/ vans/buses. Consolidate shuttles to hotels and car rental agencies.	Potential decrease in VKT is site-specific; may enhance the use of alternative-fuel-powered equipment.

* 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 degree of adoption of the operational measure.

Chapter 3

MAINTENANCE

3.1 INTRODUCTION

3.1.1 As an airframe or engine ages, aerodynamic and performance deterioration will tend to increase fuel burn and therefore emissions. Over a period of 5 years, the drag of an aircraft can increase by up to 2 per cent.[1]

3.1.2 Although performance retention is largely designed into the engine and airframe, and original performance is largely restored during overhauls, continuous monitoring and regular line maintenance activities are very important in detecting and correcting performance deterioration. Careful attention to the items highlighted in this chapter will help to prevent unwarranted increases in fuel consumption. Periodic visual inspections of the airframe and engines, flight crew reports, aircraft performance and engine trend monitoring will aid in the identification of components that require maintenance action. Often a small investment of time on a repair will result in a substantial fuel saving. Good maintenance practices minimize costs and unnecessary fuel consumption and are based on cost-benefit analyses that establish the cost-effectiveness of maintenance actions. In addition, in some cases failure to address matters such as a degraded airframe condition may have an impact on the safe operation of the aircraft.

3.1.3 This chapter is divided into three parts:

a) aircraft performance and engine trend monitoring;

b) airframe maintenance and aerodynamic deterioration; and

c) engine maintenance and performance deterioration.

3.1.4 Examples are given to illustrate possible magnitudes of fuel penalties for deviations from a baseline aircraft. These assume the example aircraft is flown for 3 500 hours per year over an average stage length of 1 000 nautical miles (NM). Unless otherwise noted, the examples which follow are for a medium-size, single-aisle passenger jet aircraft and are compiled from a range of information from manufacturers. It should be stressed that these examples are provided for illustration only, and actual fuel penalties will depend on many factors, including aircraft type, the way the aircraft is operated and the actual maintenance discrepancy. Aircraft and engine manufacturers produce guidance material for specific aircraft and engine types and models, and reference should be made to them for specific advice.

3.2 AIRCRAFT PERFORMANCE AND ENGINE TREND MONITORING

3.2.1 An aircraft performance monitoring (APM) programme can provide important data to monitor the degradation of aircraft fuel burn performance over time. This information can assist the aircraft operator to identify opportunities to take remedial action. APM compares the performance of an individual aircraft in cruise to the baseline aircraft performance, which is the specified performance when the aircraft is delivered new. Monitoring covers the entire aircraft, including the airframe, engine and systems. Aircraft communications addressing and reporting system (ACARS)

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1. Airbus, *Getting Hands-on Experience with Aerodynamic Deterioration — A Performance Audit View*, Issue 2, 2001.

data are typically used in APM and can be processed using specialized APM software. The APM software can, to some extent, predict how much fuel burn deterioration stems from aerodynamic deterioration and engine performance degradation.

3.2.2 The APM results are used to update the operator's flight planning system and the aircraft's flight management computer system to provide more accurate performance data. In lieu of a regular aerodynamic inspection, the APM results can also be used by the operator's maintenance department to trigger an aerodynamic inspection for aircraft with higher than normal fuel burn deterioration and subsequently to prioritize corrective action.

3.2.3 Engine trend monitoring is used to determine engine health and performance and is based on data recorded by engine condition sensors. The data are analysed to identify trends in engine performance, such as anomalously high fuel burn, which can then be acted on by the maintenance department.

3.3 AIRFRAME MAINTENANCE AND AERODYNAMIC DETERIORATION

Critical airframe areas

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

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

b) *Zone 2: Good aerodynamic smoothness required.* This zone consists of the centre fuselage and the areas of the wings, empennage and engines not included in Zone 1. Deviations in surface profile in this zone may result in significant drag and fuel consumption.

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

Doors

3.3.2 Attention may be given to the rigging and seal condition of doors since substantial fuel penalties can occur. A misrigged door will not only give rise to a step on the airframe surface which spoils clean airflow, but may also imply badly fitting pressure seals and consequent air leakage. In both cases the resulting local turbulence will increase drag. Additionally, greater engine bleed airflow will be necessary due to the greater leakage from the cabin, and therefore engines may have to run at a slightly higher power setting to maintain the thrust required. This will have more of an effect on smaller aircraft due to scale effects.

3.3.3 Table 3-1 shows examples of the consequences of mismatched doors. It is worth noting that one hour of corrective action represents an average economy equivalent to 500 litres of fuel per aircraft per year. Passenger comfort will also be enhanced since air leaks increase cabin noise levels and can cause local low temperature areas inside the cabin near the doors. Table 3-2 shows the effect of missing or damaged door seals.

Table 3-1. Examples of the estimated fuel penalty In litres per year per aircraft for a given step and per millimetre of mismatch

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

Assumption: A medium-size, single-aisle passenger jet aircraft flown for 3 500 hours per year over an average stage length of 1 000 NM. Reference should be made to the manufacturer's documentation for actual aircraft operations.

Table 3-2. Examples of the estimated fuel penalty in litres per year per aircraft for missing door seals

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

Assumption: A medium-size, single-aisle passenger jet aircraft flown for 3 500 hours per year over an average stage length of 1 000 NM. Reference should be made to the manufacturer's documentation for actual aircraft operations.

Control surfaces

3.3.4 Although control surface rigging is probably more carefully monitored than that of inspection hatches and cover plates, there is still likely to be room for improvement in most fleets. Quite apart from affecting the aircraft handling characteristics, the degree of accuracy with which control surfaces are rigged can contribute considerably to the final efficiency of the aircraft. Flight crew reports or performance monitoring systems may be used to identify rigging problems, though it is important to note that aerodynamic trim loads can be held by control systems and may not necessarily be apparent to the handling pilot. Some examples of control surface misrigging and its consequences are shown in Table 3-3.

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

Note.— Table 3-3 is provided for illustrative purposes only. Lower values for control surface misrigging than those shown in the table may restrict the airworthiness of some aeroplanes (continuing airworthiness).

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

Assumption: A medium-size, single-aisle passenger jet aircraft flown for 3 500 hours per year over an average stage length of 1 000 NM. Reference should be made to the manufacturer's documentation for actual aircraft operations.

Skin dents and surface roughness

3.3.5 A certain amount of deterioration of airframe surfaces comes about during normal operations. In addition, bird strikes, grit abrasion (sand, volcanic ash and other particulates), hail impacts, mishaps during servicing and baggage handling can all result in damage to aircraft surfaces. Aside from the safety hazards associated with some of these events, such damage, particularly on the engine nacelle, can increase fuel burn. Paint blisters and peeling and other deteriorations in paint and protective layers should also be taken into account when considering scratches and surface roughness. Each defect alone may not represent a large increase in fuel consumption, but collectively they can add up to a considerable amount. See Tables 3-4 and 3-5 for examples.

Parts missing from the airframe

3.3.6 The sort of items that tend to be missing from the aircraft structure include rubber seals and fairings, cover plates and small inspection hatches. However, sometimes larger items may not be installed at all. Aircraft minimum equipment lists and configuration deviation lists allow the aircraft to be dispatched without these parts installed since they do not affect the aircraft's safety for the specified flight operation. However, their absence will contribute to increased fuel burn in the same way as misrigged control surfaces. Table 3-6 gives examples of the related penalties. Care should be taken when assessing the performance impact of combinations of defects because if there are any interrelationships between the defects under consideration, the resulting performance effect may be either greater than, or smaller than, the sum of all the individual effects.

Table 3-4. Examples of the estimated penalty in litres per year per aircraft for single dents or blisters in Zone 1 areas

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

Assumption: A medium-size, single-aisle passenger jet aircraft flown for 3 500 hours per year over an average stage length of 1 000 NM. Reference should be made to the manufacturer's documentation for actual aircraft operations.

Table 3-5. Examples of the estimated fuel penalty in litres per year per aircraft for 0.3 mm of skin roughness over 1 m^2

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

Assumption: A medium-size, single-aisle passenger jet aircraft flown for 3 500 hours per year over an average stage length of 1 000 NM. Reference should be made to the manufacturer's documentation for actual aircraft operations.

Table 3-6. Examples of the estimated fuel penalty in litres per year per aircraft for parts missing from the airframe

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

Assumption: A medium-size, single-aisle passenger jet aircraft flown for 3 500 hours per year over an average stage length of 1 000 NM. Reference should be made to the manufacturer's documentation for actual aircraft operations.

Skin joints

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

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

Instrument accuracy

3.3.9 New technologies have greatly increased the accuracy of sensors and instruments. However, inaccurate readings, however small, may mean that the aircraft is not achieving its optimum performance and therefore is consuming more fuel than the optimum. In terms of fuel conservation in cruise, the machmeter is an important instrument. Flying faster or slower than the optimum Mach number, or flying higher or lower than the optimum altitude for the particular operation, will result in increased fuel burn and emissions. The actual fuel burn penalty will vary considerably between different airframe and engine combinations and will also vary with the aircraft weight. This topic is addressed further in Chapter 8.

3.4 ENGINE MAINTENANCE AND PERFORMANCE DETERIORATION

General

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

3.4.2 The major cause of deterioration of specific fuel consumption (SFC) in modern turbofan engines is erosion, which can change airfoil contours and surface finishes. Increases in radial clearances between blades and vanes and their respective sealing surfaces, as well as increases in radial clearances of rotating/stationary seals, also contribute to loss of performance. The typical contribution of each of these factors to engine deterioration is shown in Figure 3-1. The information in this chapter relates primarily to engine performance in cruise; performance deterioration measured in the landing and take-off cycle may produce different results and is discussed in the ICAO *Airport Air Quality Manual* (Doc 9889).

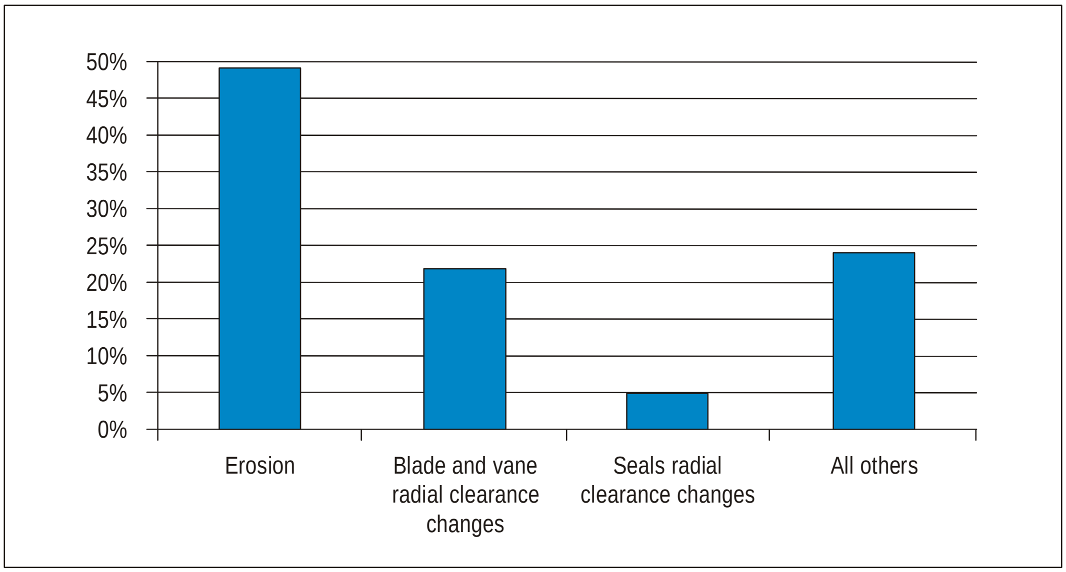

Figure 3-1. Example of primary causes of SFC deterioration in a modern turbofan engine

Note.— The values in Figure 3-1 are indicative only and are provided to illustrate the magnitude of the possible impacts on SFC. Engine manufacturers should be consulted for information on specific engine types.

3.4.3 For guidance, a 1 per cent deterioration in SFC typically results in a fuel penalty of approximately 40 litres of fuel per engine flight hour for a medium-size turbofan engine. Note that engine design varies considerably so the examples given are not applicable to all engine types or sizes.

3.4.4 Increases in exhaust gas temperature (EGT) over time, particularly step changes, can indicate engine deterioration and should be continuously monitored. High EGT is a clear indicator of a deteriorated engine and is the primary metric indicating the need for end-of-life engine removal. Higher EGT also results in greater production of NO_x, so activities that improve engine performance will often have the additional benefit of reducing NO_x emissions.

Engine gas path

3.4.5 The engine gas path is where the most significant aerodynamic and thermodynamic deterioration occurs and, in turn, is where the largest performance restorations can be made via timely maintenance. Table 3-7 lists examples of common deterioration causes for a particular engine, including the corresponding estimated penalties if not recovered.

Table 3-7. Examples of engine deterioration and its impact on thrust specific fuel consumption (TSFC) at cruise

Item	*Condition*	*Impact on TSFC at cruise**
Fan blades	Leading-edge erosion Foreign object damaged/blended Blades	Up to 0.6 per cent Up to 0.3 per cent
Fan rub strip	Wear resulting in increased tip clearance	0.2 per cent for a 12.5-mm increment
Fan flow path fairing	Leading-edge erosion	Up to 0.7 per cent
Fan/compressor airfoils	Accumulation of dirt	Up to 1.0 per cent
Compressor airfoils	Foreign object damage observed at low compressor inlet guide vanes	Up to 0.3 per cent
Engine core	High time/cycles	Up to 2 per cent
First stator	Anti-ice failed “on”	1.7 per cent
Engine core	Internal engine dirt	Up to 1.5 per cent

** Note.— These figures are indicative only and are provided to illustrate the magnitude of the possible impact of each type of condition on TSFC. The combined impact of different conditions cannot be derived by summing these percentages. Engine manufacturers should be consulted for information on specific engine types.*

3.4.6 The part of the engine gas path that is most accessible and which has a heavy impact on fuel consumption is the fan section. Leading-edge erosion of the fan blades, deterioration of the fan rub strip and damage to the fan blades, rub strip or low-pressure compressor inlet are easily detected by visual inspection. An accumulation of dirt, fan rub strip debris or other contaminants will cause performance losses that increase over time if not addressed, as will fan blade surface damage and degradation. The benefit of addressing fan section deterioration is that most maintenance actions can be performed without removing the engine from the aircraft.

3.4.7 Fuel nozzles can become contaminated by dirt or by coking. Coking can partially or even totally block nozzles, driving asymmetry in temperature distribution in the combustor and turbine. Consequential “hot spots” can then accelerate deterioration in the engine downstream from the combustor.

3.4.8 Some engine performance can be recovered by periodic fuel nozzle cleaning (for some engines only) or by water-washing the engine. Periodic engine water-washing serves to retain performance and can readily be accomplished without engine removal, which is a benefit for engines that, due to their reliability, are able to remain on the wing for long periods without removal for maintenance. Due to the fuel-saving benefits of engine-washing, more emphasis has been focused on new techniques for on-wing engine-washing systems. Besides the reduction in fuel burn, freshly washed engines operate at a lower exhaust gas temperature (EGT), which lowers NO_x production and increases the time between overhauls. The lower frequency of engine overhauls decreases maintenance costs.

3.4.9 Some fan surface degradation may not be recoverable by washing, for example erosion due to particles pitting the fan blade surface. Fan blade erosion can be mitigated at the design stage by fabricating blades with erosion-resistant materials and/or coatings, or by polishing the blades to reduce the degree of roughness.

3.4.10 Combustion chamber integrity and turbine distress can also have an impact on engine performance efficiency. Maintaining the combustor to ensure a consistent turbine inlet temperature profile will help to minimize local distress and degradation.

Engine systems

3.4.11 Engine systems such as the fuel control system, the surge bleed system, the pneumatic system and the turbine case cooling system can have an adverse impact on fuel consumption if out of trim or malfunctioning. In certain cases, high EGT and/or throttle stagger will indicate the need for immediate maintenance action. However, other more subtle deficiencies may go undetected for a period of time until limits in a performance monitoring system are exceeded. An indicator in the cockpit will accompany certain system malfunctions. Others may require a visual inspection, a trim run or a troubleshooting procedure to verify their existence. Table 3-8 lists examples of those systems which are most likely to have an adverse impact on fuel consumption.

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

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

Nacelle and cowling

3.4.14 The engine nacelle and cowling require careful attention to prevent them from causing performance deterioration. Table 3-9 gives examples of these potentially detrimental effects.

3.4.15 Cowl load-sharing reduces bending of the engine due to thrust and/or g-loading and serves to maintain tighter running clearances. Seal deterioration that allows fan air to enter the nacelle or allows air in the nacelle to be exhausted normal to the fan airstream will result in increased fuel consumption. A less-than-optimum nacelle surface condition, i.e. surface roughness, dents and mismatched panels, will have an adverse impact due to increased drag, as on other Zone 1 parts of the airframe (where high aerodynamic smoothness is required).

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

Table 3-8. Examples of engine system deterioration and its impact on thrust specific fuel consumption (TSFC) at cruise

Item	*Condition*	*Impact on TSFC* at cruise*
Turbine case cooling system	Fully or partially inoperative (mechanical system)	0.9 to 1.9 per cent (penalty depends on engine configuration and altitude)
	Fan air leakage (supply system)	Up to 0.5 per cent
	Turbine cooling air supply leakage	Up to 1.4 per cent
Buffer air supply	Air leakage	Up to 0.3 per cent
Stator anti-ice plumbing	Air leakage	Up to 1.7 per cent

** Note.— These figures are indicative only and are provided to illustrate the magnitude of the possible impact of each type of condition on TSFC. The combined impact of different conditions cannot be derived by summing these percentages. Engine manufacturers should be consulted for information on specific engine types.*

Table 3-9. Examples of nacelle and cowling deterioration and its impact on thrust specific fuel consumption (TSFC) at cruise

Item	*Condition*	*Impact on TSFC* at cruise*
Fan duct and thrust reverser seals	Deteriorated seals due to age and door opening and closing	Up to 0.2 per cent
Cowl load-sharing system	Maladjustment/wear in thrust reverser cowl load-sharing system	Up to 1 per cent
Pre-cooler system	Fan air leakage	Up to 0.5 per cent
Service bleed system	Bleed air leakage	Up to 1.3 per cent
Service bleed system/reverser activator air supply	Bleed air leakage	Up to 1.8 per cent
Translating cowl seals	Poor fit	Up to 0.35 per cent
Fan reverser static structure seals	Poor fit	Up to 0.28 per cent
ECS duct	Poor bellow fit	Up to 0.13 per cent
Fan frame	Deteriorated seals and strut end leaks	Up to 0.04 per cent
Fan frame to reverser seals	Deteriorated seals	Up to 0.05 per cent

** Note.— These figures are indicative only and are provided to illustrate the magnitude of the possible impact of each type of condition on TSFC. The combined impact of different conditions cannot be derived by summing these percentages. Engine manufacturers should be consulted for information on specific engine types.*

Ground-run practices

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

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

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

Chapter 4

WEIGHT REDUCTION

4.1 INTRODUCTION

4.1.1 Aircraft weight reduction can be divided into two main areas: reducing the dry operating weight (DOW) and reducing the amount of on-board fuel. This chapter reviews opportunities for reducing fuel burn and emissions by reducing the DOW. Considerations related to the fuel weight carried are addressed in Chapter 7.

4.1.2 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.[1] For example, 500 kg of extra weight for a ten-hour flight could result in the additional consumption of 125 to 225 kg of fuel and an increase in CO_2 emissions of 390 to 710 kg.

4.1.3 Some changes to aircraft equipment requirements may have regulatory, operational, safety or passenger comfort implications. These factors must be considered.

4.2 GENERAL WEIGHT REDUCTION

4.2.1 In general, aircraft manufacturers and component suppliers are making great strides toward reducing the weight of new aircraft through extensive use of lighter materials (e.g. composites) and less complex assemblies. This accounts for airframes, engines and on-board equipment.[2]

4.2.2 Airlines and component suppliers have also sought opportunities to reduce aircraft weight, ranging from water supply reduction and more frequent waste-tank emptying, to catering, galley and cabin supplies. Examples are shown in Table 4-1.

4.2.3 Aircraft will generally become heavier as they age. This can be as a result of repairs, equipment additions or upgrades and accumulation of dirt and moisture, as well as the carriage of non-essential or excess equipment and supplies. These changes can be monitored by regularly reviewing the aircraft empty weight and in-flight fuel consumption.

4.2.4 The need for safety equipment is generally standardized worldwide (see ICAO Annex 6 — *Operation of Aircraft*) and in general cannot be removed from the aircraft without safety consequences. Certain safety equipment is related to specific operations, such as polar or overwater flights and can be removed if the aircraft will not be undertaking those operations.

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1. IATA, *Guidance Material and Best Practices for Fuel and Environmental Management*, Third Edition, 2008.
2. According to Boeing, only 1 per cent of the original 747 was made of composites. The percentage increased with the 757 and 767 to about 3 per cent and with the 777 to 11 per cent. The 787 is now over 50 per cent composite materials. Airbus has made similar changes.

4.2.5 The removal or replacement of aircraft equipment or components can reduce the weight of the aircraft. Factors to be considered in such decisions might include safety considerations (including the manufacturer's and regulator's recommendations or requirements), the cost of removing or changing the component, and operational considerations. Examples are the addition of new advanced navigation equipment or electronic flight bags which can facilitate the removal of obsolete or unneeded navigation units or flight manuals/charts and replacement of cathode ray tube (CRT) display units with flat panel displays. In many cases, the weight savings and fuel burn reductions associated with these activities are used to justify the cost of the modifications or replacement.

4.2.6 A review of non-essential on-board items may also present opportunities to reduce their quantities or eliminate them altogether, at least from some flights. Decisions on items such as passenger amenities (for example, in-flight magazines and newspapers, provision of beverages) will usually need to take into account other considerations such as marketing and customer expectations. Tax- or duty-free items could be purchased prior to departure or on-board and delivered to the passenger at the destination airport to eliminate the need to carry the items from origin to destination.

4.2.7 Lighter on-board equipment and fittings can save considerable weight, for example, lighter catering units, in-flight entertainment units and serving ware. Portable electronic devices can also be used in place of seatback entertainment units.

4.3 EXAMPLES OF WEIGHT REDUCTION

Table 4-1 presents examples of potential opportunities to reduce aircraft operating weight. It should be noted that not all opportunities will be applicable to all aircraft types, versions or operations.

Table 4-1. Examples of potential opportunities to reduce aircraft operating weight

Opportunity	*Comments*
Reducing the amount of potable water uploaded	The potable water load can be optimized to suit the requirements of each flight.
Using plastic beverage bottles instead of glass	The weight saved can be up to 0.5 kg per bottle by stocking beverages in plastic bottles instead of glass.
Reducing the number of duty-free items carried	Commercial factors could be a consideration.
Using lighter serving ware	Metal cutlery can be replaced by a lighter plastic type.
Removing galley components	Some galley components, such as water heaters, coffee makers and ovens, may not be needed in all operations, for example, short-haul operations. This could save around 12 kg for a water heater, 18 kg for a coffee maker and 22 kg for an oven, depending on the model.
Reducing the number of in-flight magazines	The total weight of magazines, catalogues and related material placed in seatback pockets can be significant, as can the weight of newspapers distributed in the cabin.
Using lighter safety equipment	Lighter types of items such as life rafts and life jackets may be available.

Opportunity	*Comments*
Using lighter aircraft seats	High-strength and high-comfort lightweight seats are now available using lightweight composite materials.
Using lighter toilet modules and catering units	Lighter passenger service modules are now available.
Reducing the weight of in-flight entertainment systems	Reduction in the weight of seat display systems may be possible, including the use of wireless cabin interiors.
Emptying waste tanks more frequently	More frequent toilet waste-tank servicing should be considered.
Cleaning the aircraft interior	Maintaining the cleanliness of aircraft interiors, including holds and bays, can help to minimize weight increase from the accumulation of dirt.
Cleaning the aircraft exterior	Cleaning will not just reduce the weight of dirt and other contaminants, but will also help to reduce drag.
Reducing the weight of condensation	Some aircraft can accumulate and retain more than 200 kg of moisture from condensation. Excess weight due to condensation can be avoided by careful maintenance of insulation blankets. The installation of zonal driers may also help to control condensation in operating environments, but the system itself has a weight penalty.
Reducing the contents of fly-away kits	The contents of fly-away kits carried on board for supporting the aircraft when it is away from base could be reviewed.
Using lighter cargo containers	Lighter aluminium containers are being used, and containers made from carbon fibre are also available.
Removing the brake cooling fan	This may save between 12 to 25 kg. Removing brake fans may increase brake cooling time and minimum aircraft turnaround time.
Removing the second APU generator in applicable aircraft	If a second APU generator is not required, removal could save around 45 kg.
Using radial tires	May save over 100 kg for an aircraft, compared with bias tires.
Installing carbon brakes	May save around 300 kg for a mid-size, single-aisle passenger jet, e.g. Boeing 737-800.
Removing the cargo loading system	May save around 180 kg for a mid-size, single-aisle passenger jet (e.g. A320). Requires some structural modifications.

Chapter 5

THE EFFECT OF PAYLOAD ON FUEL EFFICIENCY

5.1.1 The payload carried on a flight is another factor that can affect fuel efficiency. This is because the fuel efficiency of one flight compared to another is determined on the basis of the amount of fuel consumed relative to the amount of revenue-generating payload, i.e. passengers and cargo, transported.

5.1.2 Commercial aircraft payload for a certain flight may be limited by a number of factors like demand, mission distance, performance limitations, airport features, flight conditions and interior configuration. The maximum payload on passenger aircraft types may be either volumetrically or structurally limited, and it is determined by the seating configuration selected by the airline. Market conditions dictate the number and type of seats according to the kind of service airlines choose to offer. High-density seating implies greater payload and, potentially, higher proportional fuel efficiency when the cabin is full. On cargo aircraft, maximum payloads tend to be structurally limited.

5.1.3 For any given flight, a payload increase means higher fuel efficiency in relation to productivity. With air fares and air shipping fees set in a highly competitive air transport market, airlines are motivated to achieve the highest load factor possible on every flight. The steady increase in load factor reported over the years is evidence of the airlines' general desire to fill available capacity.

5.1.4 Coupled with the greater fuel efficiency potential afforded by airline investment in new aircraft and engine technology, and operational measures to conserve fuel, the increased load factor has generally helped add to overall flight fuel efficiency.

5.1.5 Occasionally, an operator's ability to achieve the most fuel-efficient load factor may be reduced due to performance limitations and/or noise abatement constraints. Similarly, because operators have to manage complex and dynamic route networks, sometimes a less-than-optimum load factor for an individual flight is acceptable in order to achieve a greater efficiency for another flight or for the entire route network. It is important, therefore, that a holistic perspective covering interdependencies is maintained by rule-makers and procedure designers and when evaluating load-factor efficiency performance generally.

5.1.6 The airlines' effort to maximize revenue yield has been aided by the development of sophisticated computer techniques allowing them to better manage their inventory of available seats and cargo capacity, both freighter cargo and hold cargo. These computer programmes, sometimes called yield management systems, and the pricing freedom introduced with deregulation, have allowed carriers to use pricing to fill seats that otherwise would have gone unsold. Also, the Internet and other distribution channels have helped the airlines reach more potential passengers. By filling more seats, airlines have been able to reduce the average price of all seats, thereby stimulating greater demand.

5.1.7 Load factors may change from flight to flight and over time due to changes in passenger (and air shipment) demand. In addition to seasonal peaks, there are also weekly and daily peaks that are driven by leisure and business travel demands. For example, business travellers increase the weekly demand on Monday through Friday and the daily demand on morning and early evening flights. The new inventory management computer packages allow airlines to reduce prices during low-demand periods in order to fill empty seats. The peak load factor during holiday and summer peaks can average 85 per cent, or even higher, on a daily basis. This high load factor would be difficult to maintain on a year-round basis because of the lack of demand during off-peak periods. Alternatively, there are certain times of the day, or days of the week, where demand in some markets is so low that pricing or using smaller aircraft will not stimulate enough demand to make an operation profitable. As a consequence, some airlines have adopted “day of week” flying: specifically, flights are not scheduled during these low-demand times. This scheduling practice has the dual benefit of increasing load factors on other flights and reducing emissions.

5.1.8 To the extent possible, airlines try to optimize the deployment of specific aircraft families, types or, in some cases, even individual aircraft, on particular routes. For example, air carriers have purchased more of the smaller- and medium-size jets to serve routes with less demand. The concept of the aircraft “family” allows the use of last-minute change-of-aircraft techniques, like “demand-driven dispatch”, thereby increasing load factors by using the right size of aircraft for last-minute demand variations, where they are available.

5.1.9 A primary risk associated with a high load factor is that during peak periods of demand, airlines will not be able to accommodate all travellers. A traveller whose schedule is not flexible with respect to time may not be able to find a seat and may then choose not to travel. This “unaccommodated” demand, or “spill” factor, should be considered when setting prices and load factor goals.

5.1.10 There also can be challenges with tracking load factor statistics. Actual load factor may differ from what is recorded due to the following challenges:

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

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

c) aircraft performance considerations may limit the actual maximum payload capability to less than the nominal maximum, but the load factor remains based on the latter.

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

5.1.11 As more market performance data are accumulated and more sophisticated computer revenue and yield management tools become available, airlines will have a greater ability to optimize the load factor. However, there still remain practical and physical limits to how much improvement can be made in the future. Load optimization may be able to increase load factors up to 100 per cent on some flights; however, the practicalities of booking and operations make it difficult to obtain and maintain load factors close to the maximum through the whole network. In this respect, there are limits to the role that an improved load factor can play in operational fuel efficiency.

Chapter 6

AIR TRAFFIC MANAGEMENT

6.1 INTRODUCTION

6.1.1 Air traffic management (ATM) is the dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management — safely, economically and efficiently — through the provision of facilities and seamless services in collaboration with all parties.

6.1.2 Significant fuel and emissions savings can be realized by an efficient ATM system. To ensure the environmental and operational efficiency of air traffic management, the three basic elements of ATM should be addressed and optimized: airspace management, air traffic services and air traffic flow management. New and established technologies and concepts of operations in communications, navigation and surveillance (CNS), such as data link communications, performance-based navigation (PBN), automatic dependent surveillance (ADS), flexible use of airspace (FUA) and airport collaborative decision making (A-CDM) can provide opportunities to improve the efficiency of ATM.

6.1.3 It is vitally important to match airspace planning initiatives with operational limitations and requirements. Airspace planners need to consider factors such as flight operational requirements, aircraft equipage, airspace capacity (including adjacent airspace sectors), location of adjacent airports and routes, interdependencies between arriving and departing traffic, areas of special-use airspace, runway capacities, terminal capacities, taxiway limitations, restrictive terrain and any local or regional environmental regulations or procedures. Each of these areas can influence the effectiveness of air traffic management and the resultant environmental impacts of aircraft operations. It should be noted that operational efficiency solutions in one phase of flight should be balanced with possible greater inefficiencies in another flight phase. ATM procedures and measures must be considered by all operational stakeholders, including the civil and military aviation authorities, air navigation services providers, air traffic controllers, pilots and aircraft operators.

6.1.4 It is important to understand the magnitude of variation in fuel burn between the different flight phases. Fuel burn rates are much greater in climb compared to cruise, and in cruise compared to descent. Opportunities to reduce fuel burn should not be restricted only to those phases of flight with the highest fuel burn, but rather to all phases of flight including surface operations. In addition, the duration of the different phases should be taken into account, as considerable fuel savings can be made even though differences in fuel burn rates are quite small.

6.1.5 This chapter describes both the current opportunities and the strategic work under way to improve the efficiency of the global ATM system with the aim of reducing fuel consumption and related gaseous emissions. In each phase of flight, the opportunities and challenges for achieving fuel-optimized operations are described, including practical initiatives that can be taken locally. Benchmarking is highlighted as a means of identifying and prioritizing fuel savings and environmental performance improvements. The appendix to this chapter gives information on two major regional programmes — NextGen in the United States and SESAR and the flight efficiency plan in Europe that are focusing on improving safety, capacity, efficiency, fuel consumption and environmental impact. They are aligned with *the Global Air Navigation Plan* (Doc 9750), which was developed considering the ICAO Global ATM Operational Concept and the Strategic Objectives of ICAO. The Global Plan provides the basis for an industry roadmap to ensure that focused efforts will lead to near- and medium-term benefits. New modules to improve specific performance areas will be added to the Global Plan as technologies mature and the supporting provisions are developed.

6.1.6 Other chapters, particularly Airport operations (Chapter 2), Flight/route planning and other operational issues (Chapter 7) and Aircraft operations (Chapter 8) provide more details on other operational issues addressed in this chapter.

6.2 STRATEGIC APPROACH

6.2.1 Subject to the operational limitations mentioned above, a good principle for enhancing the safety, efficiency and environmental benefits of air traffic management is:

a) where capacity is inadequate (airspace/airports), pursue operations concepts and technologies designed for maximum capacity and efficiency. This may require extra track miles to be flown, but efficient throughput will have greater environmental benefits over procedures designed for maximum fuel efficiency of individual flights; and

b) where capacity is not an issue, such as low-density airspace (defined geographically or by time), pursue operational procedures designed for maximum fuel efficiency (least track miles, efficient use of wind, continuous descent and climb operations, etc.).

6.2.2 Although a perfect ATM system is a desirable goal, in reality many aircraft compete for the best profiles in limited volumes of airspace. Fuel-optimized, four-dimensional trajectories of aircraft unconstrained by the ATM system are shown in Figure 6-1 b). These profiles define the minimum volume of fuel that must be burned for a given aircraft to fly for a particular distance, and an example of how they may compare to a more traditional profile is provided in Figure 6-1 a).

Note.— These diagrams are a simplification and generalization of the traditional and optimal profiles.[1]

6.2.3 Specific details of a particular fuel-optimized profile are highly dependent upon the aircraft type, prevailing winds and the distance flown; however Figure 6-1 gives an indication of the nature of an optimized profile that would increase fuel efficiency and hence reduce CO_2 emissions.

6.2.4 Improved fuel efficiency can be achieved through improved aircraft energy management, which relies on the aircraft constantly changing speed and altitude. It is recognized that aircraft may not fly these trajectories for a number of reasons, including the provision of safe separation, the existence of special-use airspace, delay management, and hazardous meteorological conditions. However, reference to these profiles for comparison with current performance allows the identification of potential areas for improvement in fuel efficiency.

6.3 AIR NAVIGATION SERVICES

6.3.1 Airspace design that takes advantage of PBN capabilities with an objective of allowing unrestricted climbs and descents will maximize the environmental benefits of aircraft operations.

6.3.2 In all of the examples listed below, consideration should be given to the work already under way at the regional and global levels when operational improvements are being determined, and efforts should be made to integrate national or local efforts with wider implementation activities. Air navigation services should consider the following:

1. United Kingdom National Air Traffic Services (www.nats.aero).

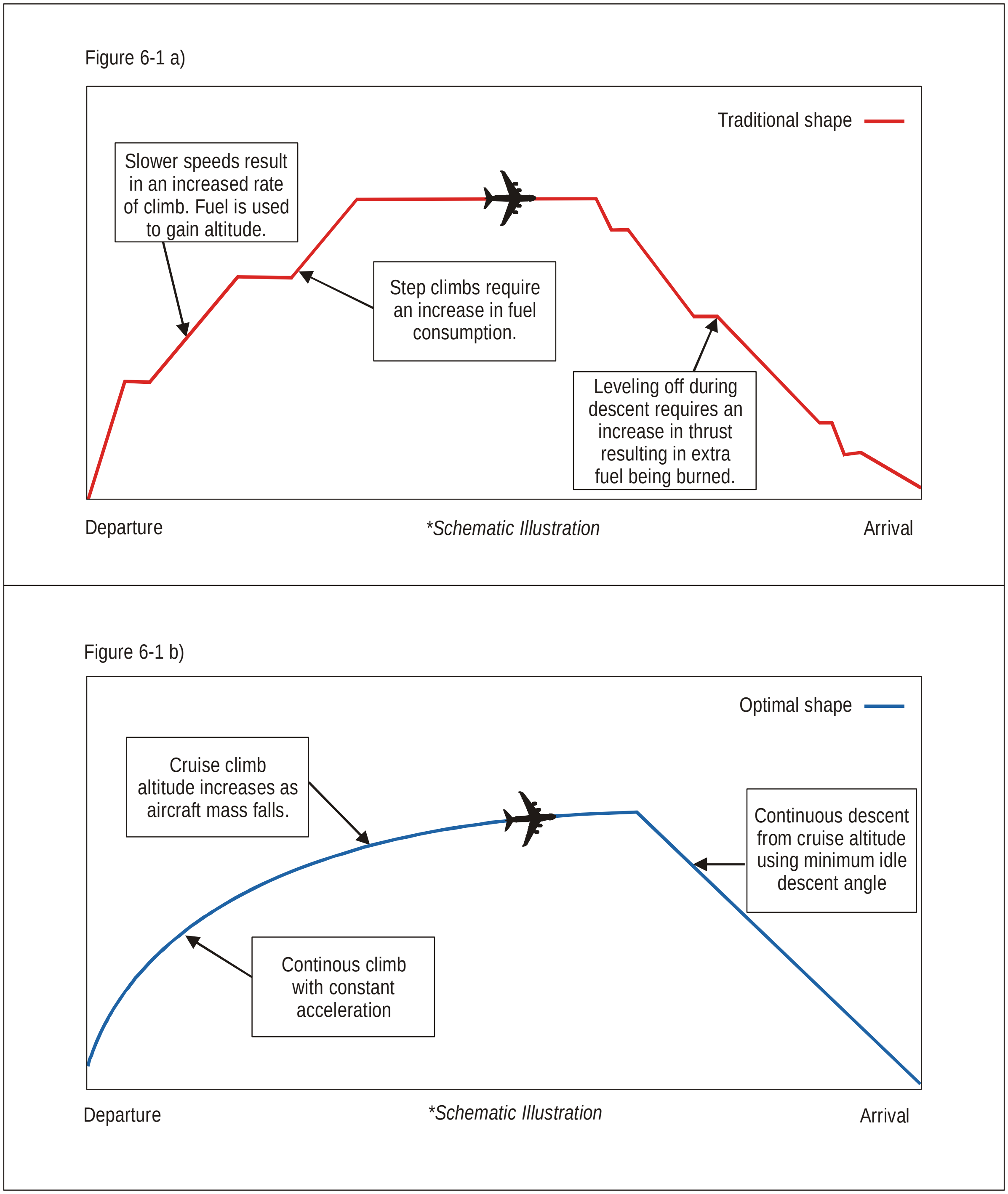

Figure 6-1. Flight profiles

a) Routes — general principles

i) Routes defined by navigating from navaid to navaid are usually the most environmentally inefficient means of navigation. PBN routes represent greater fuel savings in a fixed-route environment. The *Performance-based Navigation (PBN) Manual* (Doc 9613) provides the concept and definition of PBN, as well as guidance on its implementation. In areas of low-density traffic, published flexible tracks that take forecast upper winds into consideration or allow operations on user-preferred routes (UPRs) based on their specific operational and legal requirements, e.g. winds, temperature and availability of en-route alternate airports, represent the greatest potential for fuel and environmental savings. As an example, the three test flights between the United States and Australasia, conducted by the Asia and South Pacific Initiative to Reduce Emissions (ASPIRE) to demonstrate and measure gate-to-gate emissions and fuels savings achievable through the use of existing efficiency procedures, resulted in total fuel savings from 3 500 kg to 8 900 kg per flight and emissions reductions from 11 200 kg to 28 000 kg.[2]

ii) In areas of high-density traffic, closely-spaced, unidirectional parallel tracks expand the capacity and allow aircraft to operate at more fuel-efficient altitudes. However, airspace planners must be able to manage crossing traffic flows when determining if all altitudes can be made available to unidirectional traffic flows.

b) Route lengths and dimensions

Straight “great circle” routes usually provide the best fuel savings for short-haul routes that are less than 1 000 NM between departure and destination. However, for longer routes, the upper winds determine the routing for minimum fuel consumption. For city-pair distances that are further apart, the variance on what comprises the most fuel-efficient route of flight also increases and varies seasonally, as well as daily, based on the fluctuating upper wind patterns. It is not uncommon for the minimum fuel burn track for a 12-hour flight to deviate geographically by more than 1 000 NM from the “straight” great circle track. For example, a one-year study of the most fuel-efficient user-preferred routes for a westbound city-pair of Los Angeles to Hong Kong revealed a 2 700 NM difference between the northernmost track and the southernmost track. At no time was the “shorter” great circle track the most fuel-efficient route.

c) Wind effects

Aircraft crews generally want to fly routes and altitudes that avoid prevailing headwinds or take advantage of prevailing tailwinds. For example, the best route of flight for a westbound flight between San Francisco and Tokyo will be significantly different from the eastbound route that seeks to ride the prevailing westerly tailwinds. See Figure 6-2. Therefore, operators flying long-haul routes will need numerous routing options to meet the operational and legal requirements that vary from day to day.

d) Standard instrument departures (SIDs) and standard instrument arrivals (STARs)

Aircraft routings during climb-out and descent are in a critical phase of flight in terms of fuel consumption and CO_2 emissions. Consequently, SIDs and STARs that consider aircraft operational performance and ATC separation criteria offer tangible fuel savings and consequential environmental benefits. Best practices for environmental savings incorporate PBN SIDs and STARs that join anchor points for UPRs or published ATS routes for a truly integrated system.

2. Airservices Australia, *ASPIRE Annual Report* (www.airservicesaustralia.com; http://www.aspire-green.com).

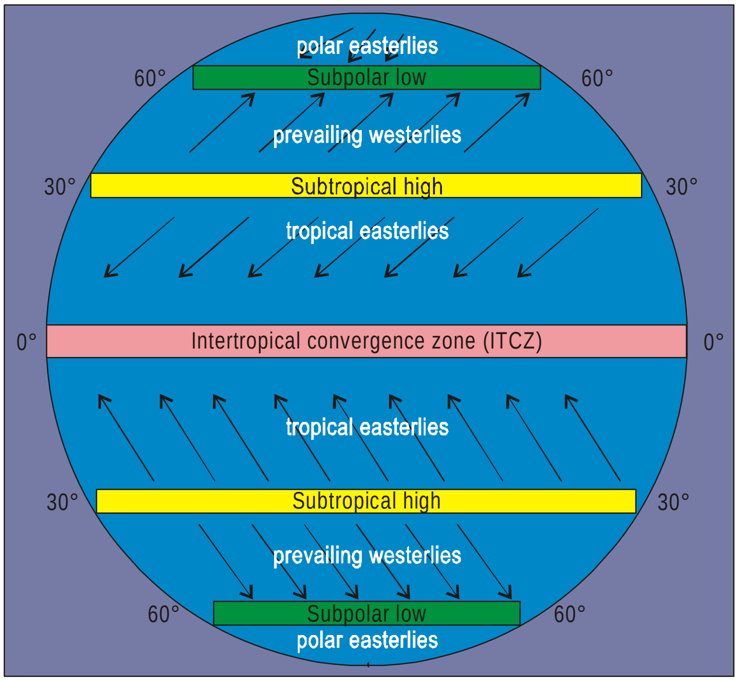

Figure 6-2. Wind effects

e) Civil and military airspace

In continental airspace and even near international airports, it is sometimes difficult to navigate off a fixed track or route due to the location and differing requirements for special-use airspace. Civil and military authorities and air navigation services providers should establish a mechanism that allows coordination and facilitates a more flexible use of the airspace and enables more efficient airspace sharing.

f) Establishing local forums to improve the efficiency of air traffic operations

Opportunities to reduce fuel consumption and environmental impacts and increase the safety and efficiency of air traffic operations can be identified through collaboration among all operational stakeholders. Since operations at any airport are unique to local conditions, circumstances and limitations, enhancements can be achieved by the establishment of local forums that allow all stakeholders to assess and understand the airspace and its constraints and explore what can be done to improve the safety and efficiency of air traffic management. Areas to consider include:

i) allowing early arriving flights to slow down to prevent gate holds and ramp congestion;

ii) providing opportunities for authorized aircraft to execute rolling take-offs;

iii) allowing cruise climbs, block clearances or step climbs in oceanic and remote airspace;

iv) allowing flexible flight planning so that airlines can plan routes and entry/exit points based on the best operational conditions, such as upper wind conditions;

v) educating controllers on the operational impact of optimum cruising levels. For example, a long-haul flight burns about 140 kg extra fuel per hour if it flies 2 000 ft below optimum altitude and about 450 kg extra fuel per hour if 4 000 ft below optimum level. At 8 000 ft below optimum cruising level the fuel penalty is about 1 200 kg extra fuel burned;

vi) providing tactical routing or altitude options to pilots, such as offering a small departure delay or alternate routing as an alternative to a penalizing en-route altitude. This may result in a significant fuel savings and emissions reduction, especially for long-haul flights that may be restricted for hours at an inefficient cruising altitude; and

vii) allowing departures to take off in the direction of flight. Airborne fuel flow is 6 times higher than ground idle, i.e. 18 minutes of taxi equals 3 minutes of airborne operation.

6.4 BEST PRACTICES FOR ENVIRONMENTALLY-FRIENDLY AIR TRAFFIC SERVICES

6.4.1 Paragraphs 6.4.2 to 6.4.15 provide examples of areas where current air traffic services can be evaluated against generally accepted best practices available today for the provision of environmentally-friendly air traffic services.

On the ground/at the airport

6.4.2 The airport is critical to ATM efficiency and has the potential to contribute significantly to reducing delays and fuel consumption and, therefore, CO_2 emissions. In searching for fuel and emissions savings, it is critical to analyse the use of the airport's assets (runways, stands, taxiways, tugs, etc.) to ensure a balance between operational and environmental needs. Technology offers the opportunity to progress the continuous improvement of ATM such as through the introduction of collaborative decision-making (CDM) processes, which bring together all airport data and share them with all stakeholders. The use of CDM can improve the efficiency of ground operations at an airport and deliver fuel and emissions savings and can also contribute to significant savings in the departure, en-route and arrival phases of flight. By acting collaboratively, airspace users, airport operators and ATM stakeholders can absorb known delays by holding aircraft on the ground rather than in the air, where delay or inefficiency leads to higher fuel-burn penalties. In particular:

a) at the departure gate/stand, ATC should keep flight crews informed of pushback and departure delays. This allows them to use the most efficient ground power source;

b) if traffic permits, consider gate-holds instead of taxi-holds;

c) early notification of departure sequence allows the flight crew to safely and efficiently start an engine(s) shutdown during taxi, thereby reducing fuel consumption and possibly reducing taxiway congestion caused by a late engine start or checklist completion;

d) to the extent possible, arrange tactical ground aircraft movements and give timely taxi clearances which allow for uninterrupted taxiing and will prevent stop/starts of aircraft;

f) prioritize moving aircraft to ground vehicles;

g) consider a marginally longer taxi to allow aircraft to depart on a runway more aligned with its direction of flight;

h) if possible and authorized, allow rolling take-offs;

i) when requested and if possible, authorize optimized climb speeds; and

j) replace inefficient SIDs as soon as feasible.

Departure

6.4.3 Departure is a critical phase of flight because aircraft can be at their maximum weight. It is particularly important for heavy aircraft. Consequently, any restrictions on the aircraft's climb-out to an optimum en-route cruising level will increase fuel burn and emissions.

6.4.4 A full load of fuel means the aircraft is heavier and has to burn more to climb. This phase of flight is therefore important in terms of optimization — any efforts to reduce inefficiency will result in proportionately greater fuel and emissions savings. As the demand for aviation has grown, airspace around airports has typically become busier, resulting in increased complexity in airspace terms. In order to manage this complexity, airspace design has focused on ensuring that traffic flows are strategically de-conflicted by using additional track miles and periods of level flight for climbing and descending aircraft. This compromise means aircraft often climb in a series of steps separated by periods of level flight to keep them separated from arrival traffic flows and aircraft from other airports. If departures are required to level off at low altitudes or climb at a speed below what is operationally efficient, the pilots must employ flap settings that increase drag. Such flap settings require additional thrust to maintain operational control of the aircraft, which increases fuel burn and CO_2 emissions. One potential ATM solution in the climb phase is to seek to ensure that an aircraft is able to conduct an optimum continuous climb from the runway to cruise altitude. Airspace design to strategically de-conflict arrival and departure flows can facilitate better achievement of continuous climb procedures and therefore delivers better fuel consumption performance.

6.4.5 In the departure phase, there may be significant trade-offs between providing noise relief and emissions reductions. Noise abatement procedures were first developed in the 1960s in response to the widespread introduction of the first generation of turbojet aircraft. Since then, through the evolution of new engine technologies and ICAO noise Standards, there has been considerable reduction in source noise. As a consequence, the noise footprints of new jet aircraft are significantly smaller than those of the early generation jet aircraft they replaced. In parallel, traffic has considerably increased.

6.4.6 Noise abatement procedures may come at the expense of additional fuel burn. The ICAO Standard for noise abatement (Annex 16, *Environmental Protection,* Volume I — *Aircraft Noise*, Part V) states: "Aircraft operating procedures for noise abatement shall not be introduced unless the regulatory authority, based on appropriate studies and consultation, determines that a noise problem exists." Additionally it states: "Aircraft operating procedures for noise abatement should be developed in consultation with the operators which use the aerodrome concerned." Civil aviation authorities should routinely review noise abatement departure procedures and discontinue noise abatement procedures where they are not justified.

6.4.7 The need to avoid noise-sensitive areas at low altitudes can lead to extra track mileage and fuel burn in the TMA. There is potential for PBN departure routes to optimize the noise performance of departing aircraft while simultaneously reducing flight track miles at lower altitudes. They have the potential to allow aircraft to optimize fuel uplift. Carrying extra contingency fuel can significantly affect the weight of the aircraft and therefore its fuel burn performance. Airline industry flight planning tools are increasingly tuned to reduce carriage of extra fuel. Shorter performance-based navigation routes can enable less fuel to be carried.

En-route operations

6.4.8 The aircraft cruise performance varies depending on factors such as weight, range, meteorological conditions and airspace characteristics. Modern on-board flight management systems can determine the most efficient cruise altitude and speed to optimize fuel consumption. ATM can assist in this process by providing capacity in the en-route phase of flight that offers aircraft the cruise levels and speeds they request.

6.4.9 Further efficiency gains are also enabled when ATM offers aircraft routing or altitude changes to take advantage of favourable wind conditions.

6.4.10 As aircraft approach the end of their en-route phase of flight (top of descent), ATM can potentially offer improved streaming to enable continuous descents and required time of arrival (RTA) to improve the efficiency of flows and reduce holdings. Specific actions include:

a) allow cruise or stepped climbs at the pilot's discretion where traffic permits;

b) approve higher altitudes when available and requested;

c) approve speed variances when requested;

d) cancel speed restrictions when no longer required;

e) offer direct or wind-optimized routes where available; and

f) if a coordination mechanism is in place, offer direct routing through special-use airspace when not in use.

Descent

6.4.11 Opportunities for reductions in fuel consumption and emissions in the descent phase through ATM facilitation include delaying the aircraft's descent from cruise, where fuel burn rates are more optimal, and using sophisticated arrivals management tools to better sequence and flow aircraft to minimize holdings. To achieve overall flight efficiency in the descent phase, a balance should be struck between expediting traffic; meeting airport capacity; and reducing flight times and distances, fuel consumption, emissions and noise within the overall requirement for safe operations.

6.4.12 When considering any solutions described for descent, it should be noted that the potential savings of these measures should not be outweighed by inefficiencies introduced in another flight phase. Examples include interdependencies:

a) between climbing and descending aircraft (e.g. interference with continuous climb operations);

b) with other simultaneous descent operations; and

c) with operations using adjacent airspace or airports.

6.4.13 Continuous descent operations, ideally from cruise flight levels, offer the opportunity for significant fuel savings, reduced emissions, quieter operations, as well as improved safety. The optimum vertical profile takes the form of a continuously descending path, with a minimum of level flight segments only as needed to decelerate and configure the aircraft or to establish the aircraft on the final approach segment. It should be tailored to the operating capability of the aircraft, with low engine thrust settings and, where possible, a low drag configuration. Aided by appropriate airspace and procedure design, air traffic control (ATC) clearances will enable the execution of a continuous descent. Ideally, ATC should refrain from tactical interference in the lateral and vertical flight path during the execution of a continuous descent. When vectoring is unavoidable, providing timely and accurate distance-to-go information to the pilot will facilitate resumption or continuation of an optimum descent profile to the extent possible. A continuous descent can save 150 to 600 kg of CO_2 per arrival. If a STAR or instrument approach procedure does not specify a continuous descent, the same reduction of CO_2 emissions can result if the controller can authorize a descent clearance at the pilot's discretion, or provides a predictable flight path with distance-to-go information to the pilot, again allowing descent in a fuel-efficient profile.

6.4.14 Particular actions to minimize fuel use during descent include:

a) for sequencing, if possible, offer speed control as far out as possible in lieu of radar vectoring;

b) allow "path-stretching" in lieu of holding, where possible;

c) allow continuous descent to the initial approach fix;

d) use PBN STARs that have been designed for continuous descent;

e) when traffic permits, allow pilot discretion descents, ideally from the top of descent;

f) avoid late descent clearances because height energy must be dissipated with drag; and

g) minimize holding at low altitude and provide pilots with realistic holding times.

Landing

6.4.15 For landing, the following should be considered:

a) provide advance taxi information to allow pilots to plan for fuel-saving techniques with respect to the landing roll;

b) publish coded taxi route instructions for efficient runway exit and reduced ATC radiotelephony;

c) if possible assign the runway that is closest to the passenger terminal and minimizes taxi time; and

d) clear to vacate the runway via a high-speed taxiway.

6.5 EVOLUTION TO A GLOBALLY HARMONIZED PERFORMANCE-BASED SYSTEM

6.5.1 Communication, navigation, surveillance and air traffic management (CNS/ATM) systems are known for the benefits they have delivered to civil aviation. As CNS systems continue to evolve they serve as key enablers in delivering to the aviation community a paradigm shift from an environment of air traffic control (ATC) to that of global air traffic management (ATM).

6.5.2 The global air traffic management system is transitioning from a technology-based system to one driven by the provision of services that are based on the expectations and performance requirements of the aviation community as a whole. Such performance requirements are enabled by appropriate technologies, which in turn allow the system to achieve the interoperability and seamlessness across all regions in order to meet safety and efficiency benchmarks during all phases of flight. Because aviation is a global system, it is crucial that requirements and enablers support a global framework that is safe, efficient and environmentally responsible.

6.5.3 ICAO's global air navigation plan and the aviation system block upgrade methodology are intended primarily to ensure that the efficiency of the aviation system will be maintained and enhanced, that ATM improvement programmes are effectively harmonized and that barriers to future aviation efficiency and environmental gains can be removed at a reasonable cost. In this sense the adoption of the block upgrade methodology significantly clarifies how ANSPs and airspace users should plan for future equipage.

6.5.4 Although the Global Plan has a worldwide perspective, it is not intended that all block modules are required to be applied in every State and region. Many of the block upgrade modules contained in the Global Air Navigation Plan are specialized packages that should be applied only where the specific operational requirement exists or corresponding benefits can be realistically projected. See Figure 6-3.

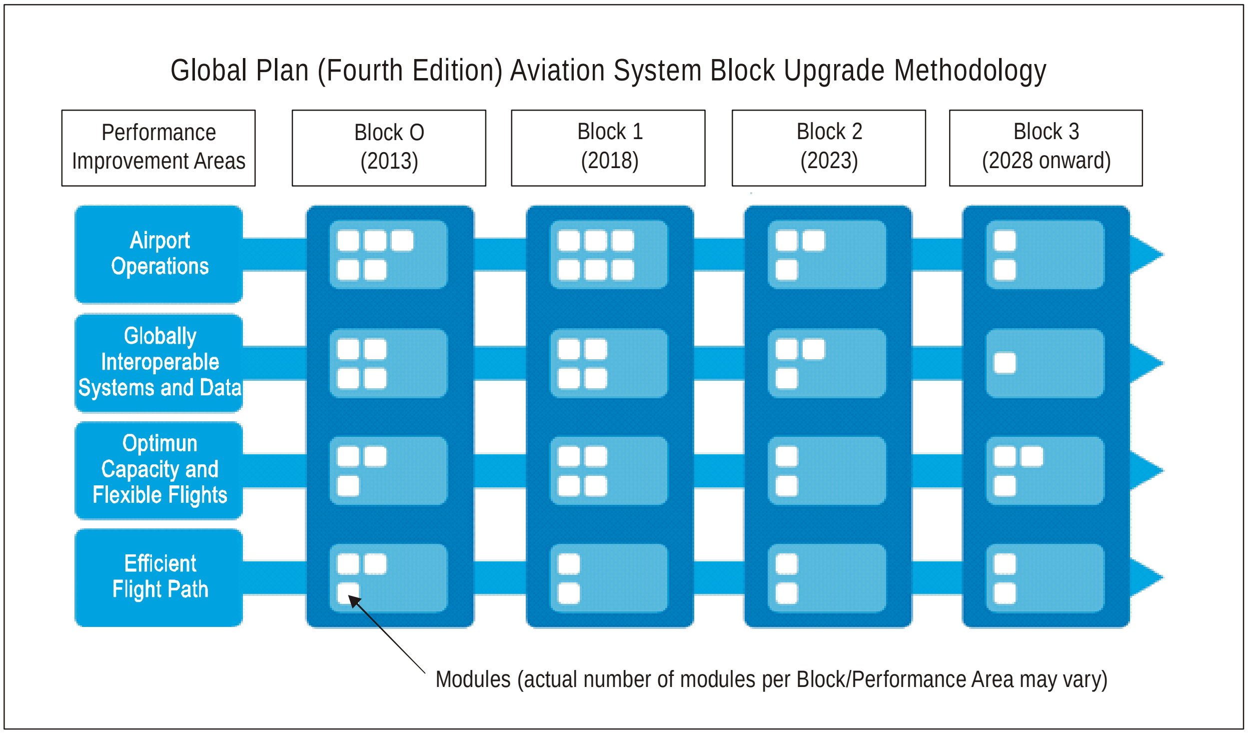

Figure 6-3. Aviation system block upgrade (ASBU) methodology

6.5.5 The ICAO *Global Air Traffic Management Operational Concept* (Doc 9854) and the *Global Air Navigation Plan* (Doc 9750) provide the guiding principles for States and ICAO planning and implementation regional groups (PIRGs) to improve the safety, efficiency and capacity of their ATM systems with the related environmental benefits. Other documents that support implementation planning activities include the *Manual on Air Traffic Management System Requirements* (Doc 9882), which converts the overall vision of the operational concept into material specifying the functional evolution of ATM, and the *Manual on Global Performance of the Air Navigation System* (Doc 9883), which provides a broad overview of the tasks that need to be undertaken to transition to such a system and gives guidance on how to establish a performance-based approach to planning of facilities and services. See Figure 6-4.

6.5.6 The Global Plan's block upgrade planning approach also addresses user needs, regulatory requirements and the needs of air navigation services providers and airport operators. This ensures one-stop, comprehensive planning.

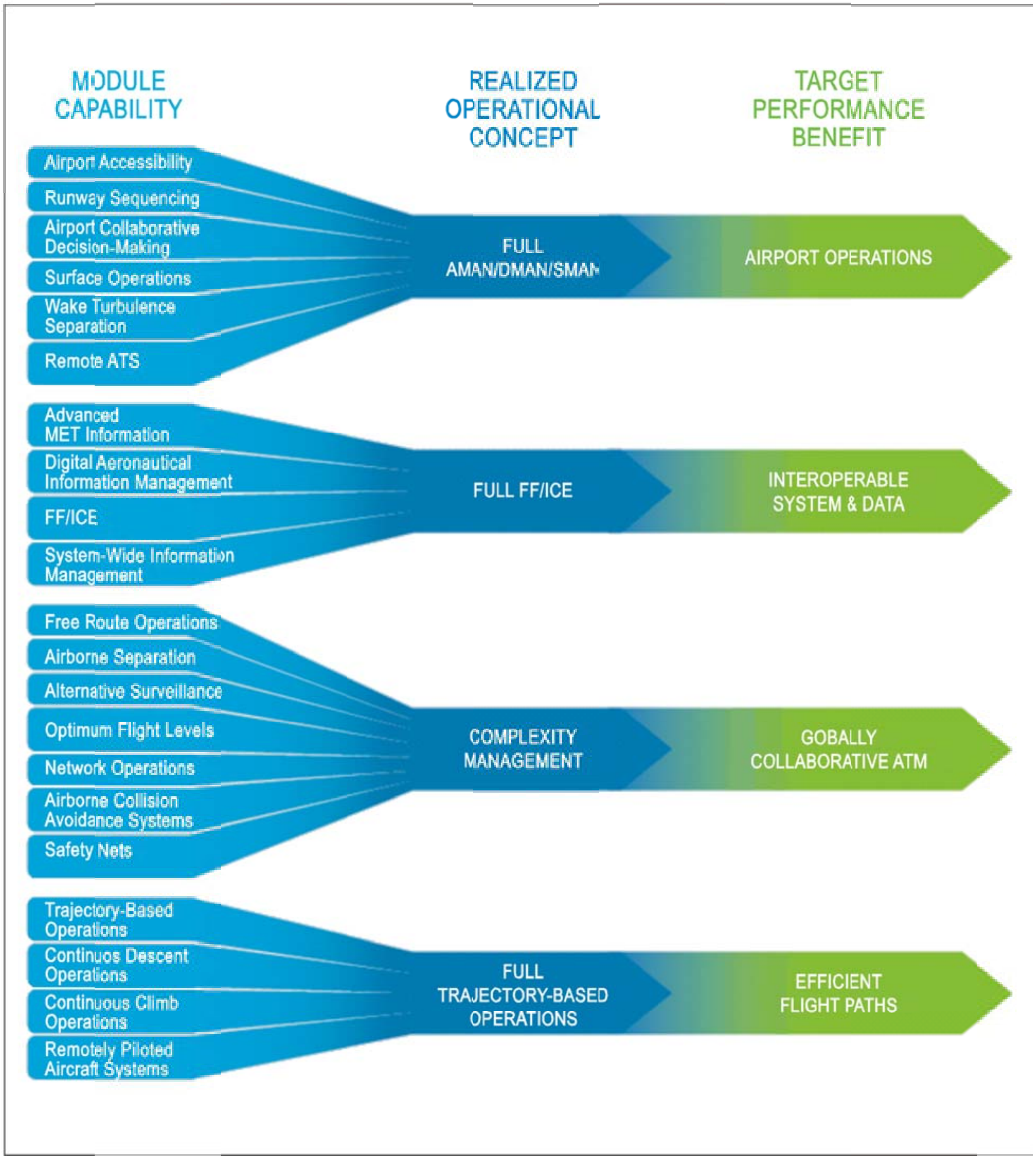

Figure 6-4. Block upgrade modules converging, over time, on their target operational concepts and performance improvements

6.6 THE GLOBAL PLAN MODULES

6.6.1 As the Global Plan progresses, module implementation will be fine-tuned through regional agreements by the ICAO planning and implementation regional groups (PIRGs). Less essential modules will be left to the discretion of national planning. The PIRGs will further ensure that all required supporting procedures, regulatory approvals and training capabilities are in place. These supporting requirements will be reflected in regional online air navigation plans (eANPs) developed by the PIRGs, ensuring strategic transparency, coordinated progress and certainty of investment.

6.6.2 All modules must be considered when implementing local solutions, in order to ensure specific benefits do not stymie those that can be achieved through the macro benefits of a global ATM.

6.7 BENCHMARKING

6.7.1 An important step in the improvement of fuel and emissions efficiency of the global ATM system is the development of a clear understanding of the current level of efficiency in the system. From that point, opportunities for improvement can be highlighted and addressed using the operational opportunities for improvement described by phase of flight.

6.7.2 The air navigation planning and implementation process prescribes reporting, monitoring, analysis and review of activities being conducted on a cyclical basis. The air navigation reporting form will be the basis for performance monitoring relating to block upgrade implementation at the regional and national levels.

6.7.3 Reporting and monitoring results will be analysed by ICAO and other aviation stakeholders and then utilized in developing the annual Global Air Navigation Report. The report will provide an opportunity for the world civil aviation community to compare progress across different ICAO regions in the establishment of air navigation infrastructure and performance-based procedures.

Chapter 7

FLIGHT/ROUTE PLANNING AND OTHER OPERATIONAL ISSUES

7.1 INTRODUCTION

7.1.1 This chapter reviews some flight planning and related issues from the aircraft operator's point of view. This includes aspects of the general infrastructure, applicable regulations, fuel characteristics and related issues that can affect the fuel efficiency of aircraft operations directly or indirectly. Other aspects of planning and executing a flight are covered in Chapters 2 and 8. The effects of ATM on a flight are addressed in Chapter 6.

7.1.2 Major factors resulting in less-than-optimal fuel consumption include non-optimal altitude and airspeed/ Mach number due to the need to avoid turbulence and conflicting traffic, and/or lack of flight planning optimization. Other factors may include increased fuel requirements due to scheduling constraints, punctuality considerations, noise abatement measures or the need to plan flights around special-use airspace.

7.1.3 Flight planning is directly related to flight safety and has its foundation in a body of national and international regulations and good operating procedures. From an ICAO perspective, the Standards and Recommended Practices contained in ICAO Annex 6 are the basis for responsible flight and fuel planning. The pilot-in-command, who is ultimately responsible for the safety of flight, is therefore ultimately responsible for route selection and the selection of the amount of fuel to be carried.

7.2 FLIGHT PLANNING

7.2.1 The planning of a route is a complex and constantly changing challenge. Minimizing the cost of operating the flight, which is largely affected by the quantity of fuel consumed, is one of the prime operational goals of the flight planning process. However, an optimized flight plan will typically take into account all operating costs, including time-based costs. This means that time-critical flights can be less fuel-efficient.

7.2.2 One of the most important principles of flight/route planning is that flights can be planned and operated more safely and efficiently if more accurate, comprehensive and timely information is available regarding individual aircraft performance, aircraft weight and traffic load, and other critical operational factors. Such operational factors could include terminal and en-route meteorological conditions, airspace congestion, other traffic and airport conditions.

7.2.3 The introduction of a performance-based approach to regulatory compliance for flight planning and fuel management, as provided for in Annex 6 Part I, and presented in the ICAO *Flight Planning and Fuel Management (FPFM) Manual* (Doc 9976), may assist in improving overall operational efficiency and reducing emissions while maintaining safe flight operations. This type of approach, which is designed to complement existing compliance-based regulations, can foster the application of statistically-driven and risk-managed alternatives to prescriptive alternate selection and fuel-planning regulations through the continuous and proactive management of safety risks.[1] It should be

1. See also the ICAO *Safety Management Manual (SMM)* (Doc 9859).

understood that the application of a performance-based approach presents a different set of challenges to regulators and operators alike, requiring the use of specific knowledge, skills and resources through a continuous and complex assessment process supported by the appropriate data.

7.3 ROUTES

7.3.1 Minimum route lengths (great circle) are not necessarily the most fuel-efficient because aircraft operate in an atmosphere that is constantly moving and which varies in temperature and hence density. Consequently, with strong winds, particularly where jet streams exist, the route that gives the least flying distance through the air (the least equivalent still-air distance) may be longer than the great circle distance. Whenever possible, routes should be planned to take advantage of the most beneficial winds. Routes can also be planned to take advantage of lower air temperatures (deviation from the International Standard Atmosphere (ISA)), which may result in a longer route over the ground but achieve a reduction in fuel burn. Further considerations relating to flight in low temperatures are discussed in paragraph 7.10 on fuel freezing point, .

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

a) special-use airspace, which might have to be avoided for a number of different reasons;

b) en-route or terminal congestion (demand and capacity imbalances), which often necessitates a non-optimum route or altitude, being slowed to a less efficient airspeed, or being placed in a holding pattern;

c) altitude restrictions;

d) extended diversion time regulations, which may require a longer-than-optimum route (see paragraph 7.8);

e) overflight charge differences that can make it more costly to fly optimum routes in some cases;

f) airspace and route structures based solely on ground navigation aids;

g) hazardous meteorological conditions that must be avoided for safety;

h) noise abatement procedures that result in aircraft flying longer distances during terminal area operations; and

i) exclusionary airspace, i.e. airspace reserved for use by aircraft that meet certain equipage requirements.

7.3.3 The impacts of some of these constraints can be mitigated through collaborative efforts among airspace users, aerodrome operators and ATM service providers. An example of such initiatives and tools is the collaborative decision-making (CDM) process used by air traffic flow managers, aircraft and airport operators to improve ground movements and manage demand/capacity imbalances (see Chapter 6).

7.3.4 Flexible and dynamic routing may be available to appropriately equipped aircraft and qualified operators and flight crews, particularly in non-congested airspace. Examples of these services are user-preferred routes (UPR), dynamic airborne re-route procedures (DARP) and flexible track systems.

7.3.5 More efficient routings and altitudes can also be facilitated through separation reductions for qualified aircraft and operators in airspace where these procedures have been authorized and implemented. Examples include reduced vertical separation minimum (RVSM), performance-based navigation (PBN) and in-trail procedures (ITP).

7.4 FUEL RESERVES

7.4.1 With fuel mass being up to ten times that of passenger mass, even a small reduction in the fuel carried has considerable potential for reducing fuel burn (see Chapter 6). As a general rule, carrying additional fuel can result in a total increase in fuel burn of 2.5 to 4.5 per cent of the additional mass of fuel carried per hour of flight, depending on a variety of factors, including aircraft type, mission length, flight profile and speed.[2] In general, keeping the fuel reserves carried to a safe minimum is therefore one way of reducing fuel consumption.

7.4.2 ICAO Annex 6 and Doc 9976 set general guidelines for minimum fuel requirements and should be the basis for establishing State regulations and managing fuel planning. Minimum fuel required usually includes amounts to cover:

a) engine start, auxiliary power unit (APU) use and taxi out;

b) flying to the destination aerodrome and executing an approach and landing;

c) performing a missed approach and conducting an approach and landing at the nominated destination alternate aerodrome, if required;

d) en-route contingency (discussed below);

e) final reserve fuel; and

f) additional fuel if required.

7.4.3 Fundamentally, contingency fuel is the fuel required to compensate for factors that could not be foreseen during flight planning. The amount of en-route contingency fuel may vary on a flight-by-flight basis, but takes into account several factors, including the following:

a) unforecast meteorological conditions;

b) unplanned or unanticipated routings, cruising levels and traffic delays; and

c) other unexpected operational issues that could increase fuel consumption or delay.

7.4.4 The contingency allowance is often specified as a function of the trip time or trip fuel. For example, an extra 5 per cent of the fuel to destination could be added to the total fuel load. For longer-range flights, a contingency fuel reserve requirement that is based on a percentage of destination fuel can be excessive, especially for modern aircraft equipped with advanced communications and navigation systems and supported by sophisticated flight planning systems and weather forecasting. On certain flights, State regulations may allow for a reduction of contingency fuel by authorizing what is known as a “re-clearance” or “re-dispatch” procedure or allowing for a “statistical” or performance-based approach with an equivalent level of safety as the existing prescriptive regulations.

2. IATA, *Guidance Material and Best Practices for Fuel and Environmental Management*, 2008.

7.4.5 The subject of fuel reserves is a complex combination of regulations, experience, real-time operational factors, including the desire to minimize the probability of diversions, and overall risk assessment. State regulations and safety considerations limit opportunities to reduce fuel reserves. Nonetheless, regulatory authorities should be mindful of advances in flight planning, weather forecasting, navigation and communications when establishing fuel reserve requirements, or adapting variations from such requirements based on an individual operator's ability to achieve target levels of safety performance.

7.5 FUEL TANKERING

7.5.1 Fuel tankering — the carrying of fuel for subsequent flights — is done for a number of reasons. Factors that can influence decisions on tankering include:

a) operational reasons, for example where rapid turnaround is required or where the aircraft is required to complete several flight segments without adequate time for refuelling;

b) fuel prices being significantly higher at the destination airport than the departure airport;

c) a lack of availability of appropriate fuel; and

d) uncertainty about fuel quality at the destination airport.

7.5.2 There may be some potential for reducing the amount of tankering. Aircraft operators should take into account the full cost of carrying extra fuel when making decisions on tankering. The full cost includes the additional fuel required to carry the tankered fuel. Aircraft operators should also check fuel prices frequently to ensure that tankering is still justified by any fuel price differentials.

7.6 CENTRE OF GRAVITY

7.6.1 Effective management of the centre of gravity (CG) of an aircraft can yield appreciable savings in fuel consumption, The CG varies according to the distribution of the load on each flight. The further forward the CG, the greater the degree of downward force required from the tailplane/horizontal stabilizer, which has to be balanced out by increased lift from the wings, thus increasing induced drag (trim drag). Depending on the aircraft type, loading an aircraft to the most forward CG limit can increase drag by as much as 3 per cent compared with loading it to the most rearward CG limit (source: IATA). Therefore, in general a more aft centre of gravity will reduce drag and improve fuel consumption. However, the available centre of gravity range is limited by aircraft stability considerations. Calculations of CG must take into account the fact that burning fuel during the flight gradually reduces the weight carried and may produce a shift in the CG; it is possible for an aircraft to take off with the CG in a position that allows full control and yet later develop an imbalance that exceeds control authority.

7.6.2 The effects of CG on fuel consumption can be expressed in terms of impact on specific range. The effects can vary depending on the aircraft type. For example, CG has a negligible effect on specific range on some types. On certain other aircraft flying at an optimum altitude, a maximum forward CG can decrease specific range by up to 1.8 per cent and a maximum aft CG can increase specific range by up to 1.8 per cent compared with a reference CG. However, many aircraft are fitted with an automatic CG management system which optimizes the CG position in flight in accordance with the distribution of the aircraft's load.

7.6.3 It is sometimes possible to redistribute cargo or passengers in order to move the CG nearer the optimum position. Some aircraft also have a fuel tank in the tail (sometimes called a trim tank) which facilitates achieving a more efficient CG position. As a flight progresses, consumption of fuel changes the aircraft's centre of gravity. A trim tank transfer system enables fuel to be transferred into and out of the trim tank to maintain a target CG value during the flight.

7.7 OPERATIONAL NOISE CONSTRAINTS

7.7.1 Operational constraints implemented to control aircraft noise in the vicinity of airports may result in increased fuel burn and emissions by increasing flight track miles in the terminal area or by increasing ground taxi times.

7.7.2 Routes and climb-out profiles intended to minimize or redistribute noise near airports may result in less efficient climb and descent profiles and procedures. The use of noise-preferential runways may result in runway capacity being restricted, extended arrival or departure flight segments and increased ground taxi times. Other local operating limitations intended to reduce noise impacts can have similar results.

7.7.3 Night-time restrictions such as curfews or other operational limits at origin or destination airports can introduce inefficiencies into aircraft operations, such as extra landings and take-offs, flying at non-optimum speeds and holding longer to prevent arriving too early, or flying faster to arrive before the start of a curfew. Extra congestion can also arise by forcing more flights into periods near the beginning and end of curfews.

7.8 EXTENDED DIVERSION TIME OPERATIONS (EDTOs)

Extended diversion time operations (EDTOs) enable more direct routes to be flown and allow for greater flexibility to take advantage of any beneficial en-route conditions such as tailwinds. However, an EDTO is subject to the approved maximum diversion time approved by the State of the Operator. The higher the maximum diversion time, the greater the flexibility and thus the potential for minimizing fuel use. Attachment D to Annex 6, Part I, provides more guidance on how to calculate maximum diversion times.

7.9 PUNCTUALITY MONITORING AND REPORTING

7.9.1 In many regions of the world there is a focus on the monitoring and reporting of punctuality performance, based on departure time or the time an aircraft leaves the airport gate. As a result of this, airlines seeking to improve their punctuality key performance indicator (KPI) may request early or on-time pushback from the gate, even at times when there is significant taxiway and runway congestion. This practice will involve additional taxi and/or ground holding time with engines running and thus excess fuel burn and emissions.

7.9.2 Arrival management tools (discussed in Chapter 6) are useful to assist in smoothing the flow of traffic through the ATM system and reducing excess fuel burn and emissions, but their benefits can be compromised by a focus on on-time departure or off-stand time. States and regulators should consider, in setting their environmental and punctuality KPIs, the interaction of these two potentially competing objectives in order to ensure the achievement of an appropriate balance between punctuality and environmental performance, or the measurement of punctuality in a manner that does not drive operational behaviours that unnecessarily increase fuel burn and emissions.

7.10 FUEL FREEZING POINT

7.10.1 The trend towards longer and higher-altitude flights has highlighted one limitation that can occasionally prevent flying in the most fuel-efficient manner: the need to maintain the aircraft fuel above the fuel freezing point. The temperature of the fuel in an aircraft tank always remains well above the local ambient temperature. However, with typical atmospheric temperatures in the stratosphere as low as –55°C, and with the freezing point of some jet aviation fuel at –40°C (e.g. Jet A fuel), occasions can arise where cold-soaked fuel will approach these temperatures. In order to overcome this, the aircraft may be required to fly at either a lower altitude and/or faster speed in order to warm the fuel; both options will normally increase fuel consumption.

7.10.2 In order to reduce the fuel-burn penalty associated with flying at less-than-optimum altitudes due to low temperatures on certain long-range routes, some airlines test samples of fuel prior to departure to determine the actual freezing point of the on-board fuel. This information, together with operational considerations such as fuel temperature monitoring, is given to the flight crew, allowing them greater freedom to operate their aircraft at the most efficient altitude for that flight. Some operators also use dedicated software to predict or avoid routes where low fuel temperatures could be a limitation.

7.11 METEOROLOGICAL INFORMATION

7.11.1 The accuracy of forecast and real-time meteorological information enables accurate flight planning and operations. The effects of this are particularly significant for the planning of ultra-long-haul flight sectors. For a given time, location and altitude, the meteorological forecast data need to be accurate, timely and delivered in an appropriate way, encompassing information on en-route winds as well as forecasts for destination and alternate airports. This permits accurate fuel planning and avoids “extra” fuel being loaded as a contingency for unanticipated changes during the flight, which in turn reduces the quantity of fuel used. In-flight uplinking of accurate real-time weather enables optimized management of a flight, including selection of cruising altitude, cruise and descent speeds, and top-of-descent.

7.11.2 Accurate information on the location of severe or hazardous meteorological conditions is important in order to operate a flight both safely and efficiently. For example, operating in icing conditions is potentially hazardous and is not fuel-efficient because power has to be bled from the engines for the de-/anti-icing systems, resulting in additional fuel burn. Any ice accretion on the airframe and/or engines reduces the aerodynamic efficiency of the aircraft and increases its mass. This added mass and drag require higher thrust settings, further increasing fuel burn.

7.11.3 Accurate and timely information on the location of hazards such as volcanic ash and ionizing solar radiation is also important for safe and efficient flight operations; however, avoiding these hazards will almost always require longer routings or a non-optimal cruising altitude and therefore a higher fuel burn.

7.11.4 Data streaming of real-time meteorological information from meteorological service suppliers to operators, air navigation services providers and aircraft will improve the capability of operators and flight crews to plan and carry out safe and efficient flights.

7.12 AIRCRAFT ENGINE AND FUEL MONITORING

7.12.1 An essential tool in minimizing fuel consumption is accurate aircraft and engine performance monitoring. Monitoring and analysing aircraft and engine performance provide benefits that tend to reduce fuel carried and fuel used. This process can provide general fleet data or detailed data for a specific aircraft on a specific route. The results of performance data analyses should be part of a closed-loop system that would include maintenance, engineering, flight performance, flight planning and flight training. This enables specific aircraft performance criteria to be utilized operationally to gain efficiencies and improve safety.

7.12.2 Fuel monitoring and reporting should be used to give flight crews confidence by presenting statistics on the performance of the flight plan. As an example, some airlines collect cruise performance data for every aircraft on every flight. The deviation from the nominal or “book” performance is determined and the result loaded into the flight planning system. An individual deviation is applied to every aircraft. By this means, depending on the applicable regulations, contingency fuel may be reduced.

7.13 MINIMUM EQUIPMENT LIST/CONFIGURATION DEVIATON LIST (MEL/CDL) ITEMS

7.13.1 Another source of extra fuel burn can be aircraft dispatched with allowable minimum equipment list (MEL) and configuration deviation list (CDL) defects. These defects may have fuel, performance and/or operational penalties associated with them.

7.13.2 Fuel penalties from increased drag or non-standard system usage will directly influence fuel burn. Performance penalties may restrict payload and cruising altitudes. Operational penalties may imply non-compliance with area operational requirements with respect to communication, navigation or surveillance, e.g. EDTO, RVSM, minimum navigation performance specification (MNPS), PBN and airborne collision avoidance systems (ACAS), which may restrict efficient flight planning.

7.13.3 In this respect, the longer the aircraft keeps flying without MEL and CDL defects being rectified, the greater the potential for extra fuel burn. Therefore it is important to minimize the amount of time spent flying with outstanding MEL or CDL items that carry a direct or indirect fuel penalty.

Chapter 8

AIRCRAFT OPERATIONS

8.1 INTRODUCTION

8.1.1 This chapter covers opportunities to reduce fuel burn and emissions across the various phases of a flight. The main subject of this topic is the optimization of the flight trajectory.

8.1.2 Operational measures for fuel efficiency are in general influenced by applicable air regulations, safety considerations, good operating practices, air traffic management (ATM) (discussed in detail in Chapter 6), and noise restrictions. Within these constraints, aircraft operations can be optimized for fuel efficiency and reduced emissions. Collaboration among all relevant stakeholders, which may involve trade-offs among environmental goals, is required for successful implementation.

8.1.3 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 (e.g. fuel consumption) 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. For example, within congested airspace, or when constrained by airspace boundaries or structure, it may not be possible to offer simultaneous opportunities for continuous descent operations (CDOs) and continuous climb operations (CCOs). A non-optimized airspace structure can also impede effective route planning, thereby increasing miles flown or restricting the optimum flight level. Nonetheless, opportunities to optimize lateral and vertical profiles during the course of a flight should not be overlooked (e.g. shortening terminal routings, and minimizing level-offs during climb and descent). Flight and route planning are considered in further detail in Chapter 7.

8.1.4 In the vicinity of most airports, there are challenging interdependencies between noise reduction and fuel burn and emissions reduction. These interdependencies must be accommodated, often within the context of applicable environmental regulations when exploring opportunities to reduce fuel burn and emissions during climb and descent in the vicinity of an airport. As a result, implementation of optimized, more fuel-efficient arrival and departure routings and profiles may be delayed, or adjusted to incorporate the interdependencies between noise reduction and fuel burn and emissions reduction. This may be the case even when individual flight profiles reflect reductions in noise and emissions, but are routed over new areas that did not previously experience over-flights. For example, noise-preferential arrival and departure routes can add track miles and hence increase fuel use, whereas both CCOs and CDOs can reduce fuel use and emissions, and often noise.

8.1.5 Given the above observations, the following general principles should be adopted when considering operational opportunities to reduce aircraft fuel use and emissions:

a) safety must not be affected negatively;

b) operational procedures must be certified and incorporated into daily operations;

c) actual flight procedures must be developed in accordance with the appropriate ICAO or regulatory guidance and manufacturer's and operator's capabilities;

d) proposals should be considered within the context of the entire flight trajectory and the trajectories of other flights;

e) consultation and/or collaboration with appropriate affected stakeholders should be part of the process from an early stage;

f) adverse or disproportionate trade-offs should be avoided to the extent possible;

g) opportunities to optimize the performance of the initiative through positive impacts other than fuel use and emissions (i.e. synergies) should be considered, such as flight safety, flight predictability and capacity;

h) appropriate assessment methods, tools, data and assumptions should be used.[1]

8.1.6 One valuable approach is the development of a “perfect flight trajectory” from gate to gate where operational stakeholders jointly plan a flight that demonstrates, to the extent possible, all possible flight efficiency techniques available. This provides an operational and collaborative benchmark for an optimized flight profile towards which all stakeholders can plan, and also identifies areas that need further improvement. The collaborative process itself can facilitate greater teamwork and mutual understanding and thereby form the foundation required for more frequent optimized flights.

8.2 TAXI

8.2.1 Taxi times can vary depending upon many factors such as operational conditions, airspace congestion, airfield design and time of day. For a short-haul flight, taxiing may account for a higher proportion of total fuel burn. Taxiing out typically takes considerably longer than taxiing in because the aircraft must often wait in the departure queue. This coincides with the aircraft being more heavily loaded and thus requiring more thrust, resulting in higher emissions compared with aircraft taxiing in. However, when delays are expected and operating conditions permit, aircraft may taxi out with one or more engines shut down to save fuel and reduce emissions. This must be authorized in the aircraft operations manual and approved by the operator and appropriate regulatory authorities. Collaboration between the airport operator, air navigation services provider (ANSP) and the airline/operator is recommended to reduce the time spent taxiing out and to improve the efficiency of the departure sequence.

8.2.2 Operational flexibility, which allows selection of the most advantageous runway in a multi-runway environment when the traffic situation and local regulations permit, can help minimize taxi time, distance and fuel burn. In an ideal operating environment and with the appropriate safety considerations (surface conditions, crosswinds, restricted visibility, taxi routings, etc.), ATC can authorize an aircraft to depart from a runway more aligned with its direction of flight. Total fuel burn for the flight may be reduced in this situation even if it involves a longer taxi, depending on the airport geometry and the terminal departure routings available.

8.2.3 Airport CDM aims to improve the overall efficiency of ground movements at an airport and has a particular focus on aircraft turnaround and the pre-departure sequencing process. Through effective stand management, the amount of time spent holding (stopped) while taxiing can be reduced, while concepts such as the departure management (DMAN), a tool used for the sequencing of departures, can reduce taxiway congestion and controller workload, improve schedule reliability and predictability, and maximize the departure capacity of the runway by keeping an optimum number of aircraft waiting for take-off.

1. ICAO advice on assessing operational proposals, including interdependencies, is provided in the *Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes* (Doc 10031).

8.2.4 Fuel burn and emissions can be reduced by taxiing to the gate or stand with one or more engines shut down after landing, when conditions permit and as authorized by the operator and manufacturer. Taxiing to the gate with less than all engines operating has been found to result in significant fuel burn reduction together with a reduction in ground noise.[2]

8.2.5 Additional ground movement and airfield configuration considerations, including the provision of more efficient infrastructure such as rapid/high-speed exit taxiways, are discussed in Chapter 2.

8.3 TAKE-OFF AND CLIMB

Take-off and climb are the operations that require the greatest engine thrust and hence the highest rate of fuel use and generation of engine emissions, as well as the highest noise levels to have an impact at ground level. Changes to take-off and departure routes or procedures may therefore have a significant effect on emissions and noise contours around the airport. At lower altitudes, the most fuel-efficient departure routes and procedures may not always be possible since, in the majority of cases, mitigation of the noise impact is considered the primary environmental objective. *Guidance on the Balanced Approach to Aircraft Noise Management* (Doc 9829) describes best practice for providing noise relief for airport communities.

8.4 DERATED AND REDUCED THRUST TAKE-OFF AND CLIMB

8.4.1 Take-off thrust directly affects aircraft performance and cannot be directed towards achieving environmental outcomes without considering possible safety consequences. The selection of the take-off thrust setting for an individual flight involves careful consideration of aircraft performance, engine life and maintenance requirements, aircraft status (inoperative components/systems), terrain, weather and runway conditions.

8.4.2 Nonetheless, the use of derated and reduced thrust for take-off and climb is a widely used operational procedure aimed at reducing maintenance costs. The use of derated or reduced thrust take-off and climb tends to increase fuel consumption slightly compared to full-thrust take-off and climb because the increased time at low level offsets the slight reduction in fuel flow induced by the lower thrust.[3] However, the benefits of reduced engine wear, and therefore reduced engine deterioration, may outweigh this small effect by significantly increasing engine life. Derated and reduced thrust take-offs also reduce NO_x production, but reduced climb rates may slightly extend noise contours around an aerodrome even though absolute engine noise levels may be lower at points along the take-off path.

8.5 OPTIMIZATION OF CLIMB TRAJECTORIES

8.5.1 There are opportunities in the climb phase of flight to safely optimize the vertical profile of an aircraft according to business imperatives, including fuel-efficiency goals. Airspace or other constraints that hold aircraft below their optimal climb profiles (e.g. level-offs and speed restrictions), or that demand a fuel inefficient climb gradient, should be avoided or removed to the extent possible. Fuel burn and emissions may be reduced by enabling continuous climb operations (CCOs)[4] where a flight flies an unconstrained, optimized profile to initial cruise altitude. While the benefits of this may arise in the climb phase of flight, it requires close coordination between the airport, terminal area and en-route ANSPs. Changes in airspace design, controller-decision support tools and air traffic flow management may be needed to facilitate CCOs, and they may have an impact upon airport or airspace capacity and adjacent traffic flows.

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2. http://www.sesarju.eu/environment/aire.
3. Airbus, *Getting to Grips with Fuel Economy*, Issue 4, 2004.
4. See the *Continuous Climb Operations (CCO) Manual* (Doc 9993).

8.5.2 The implementation of new PBN procedures designed to harness the advanced capability of modern aircraft may allow the design of strategically de-conflicted arrival and departure routes through the use of altitude or window constraints or fixed flight path angle (FPA) segments. This may reduce or eliminate any level-offs while removing the necessity to extend low-altitude TMA routes in order to solve inbound-outbound conflicts. Often the achievement of CCO and CDO is interrelated, and it is recommended that a collaborative, transparent airspace design and environmental impact assessment process be established to determine the relative benefits of implementing either or both of the procedures.

8.5.3 Fuel-saving benefits can also be gained by optimizing the speed of aircraft in climb. Differences in climb speed of ±30 kt may result in extra consumption of as much as 130 kg of fuel for some aircraft over the duration of a climb to FL 350.[5] Optimum climb speeds however may be gained at the expense of time or airspace congestion. The optimum climb speed will depend upon aircraft type, weight, ambient conditions and even cost index (see also section 8.9 on flight management systems (FMSs) and cost index). Generally the most efficient climb speed schedule is used; however, a 250-kt indicated airspeed (IAS) limit below 10 000 ft is observed globally.[6] It should be recognized however that such speed control may be an ATC safety mechanism to maintain separation, especially at busy airports, or it may be a bird hazard reduction requirement. However, under certain traffic conditions and within certain types of airspace, this limit can be removed when advised by ATC. Collaborative discussions on this topic may provide the possibility of exceptions without loss of safety.

8.5.4 The fleet of aircraft operating from an aerodrome is typically composed of aircraft with differing performance levels. It can be difficult to design procedures that are optimized for all aircraft, and there can be a tendency for procedures to be designed to accommodate less capable aircraft. This may result in reduced efficiency because the more capable aircraft may be forced to operate on sub-optimal routes. Where noise management rules and procedures permit, and where noise impact can be reduced, high-performance standard instrument departures (SIDs), for example, can be offered to suitably equipped aircraft. These high-performance SIDs can be designed to exploit the improved navigational or operational performance of certain aircraft models, which can help to reduce fuel burn and emissions while also having a positive impact upon capacity. Likewise, lack of appropriate equipage or insufficient performance may deny certain aircraft access to a particular procedure or airspace. Thus, when procedures are designed, they should take into account the traffic mix typically expected to use the airport.

8.6 OPTIMIZATION OF CRUISE TRAJECTORIES

8.6.1 Operational stakeholders are recommended to collaboratively evaluate and, where possible, implement initiatives that facilitate the pilot’s ability to optimize the aircraft’s cruise trajectory to the extent possible. This should include becoming aware of the air traffic management (ATM) measures discussed in Chapter 6 and, where appropriate, supporting their implementation for reducing fuel burn and emissions. Once such large-scale measures are implemented, operational stakeholders should collaborate to fully optimize the cruise performance improvements they bring.

8.6.2 The fundamental fuel efficiency aims in cruise are to fly:

a) as closely as possible to the most fuel-efficient speed and altitude for the aircraft mass;

b) using the shortest air distance (e.g. wind- and temperature-optimized routes); while

c) managing aircraft systems to minimize fuel usage and facilitating the optimum fuel-efficient trajectory in accordance with meteorological conditions; and

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5. Airbus, *Getting to Grips with Fuel Economy*, Issue 4, 2004.
6. It should be noted that modern flight management computers (FMCs) may command a speed of 240 kt when the aircraft is flown in the vertical navigation (VNAV) mode because a tolerance range of 10 kt is incorporated in the software.

d) operating within any ATM constraints (covered in Chapter 6) and in accordance with applicable or required commercial constraints on the flight (e.g. schedule, connecting passengers, curfews, etc.).

8.6.3 Many of the decisions to optimize the cruise phase of flight must be applied before take-off and are addressed in other chapters of this document, particularly Chapter 7 concerning route and flight planning and optimizing centre-of-gravity position.

8.7 SPEED AND ALTITUDE OPTIMIZATION IN GENERAL

8.7.1 Within the business and safety constraints placed on a flight, the pilot will endeavour to fly the aircraft at an optimum cruise speed and altitude to reduce fuel burn and emissions. Aircraft mass and weather conditions (wind) are the key factors in the flight's fuel efficiency. For current aircraft designs, flying at speeds or altitudes other than the optimum can significantly increase fuel burn and emissions. For example, a representative heavy widebody aircraft could burn 400 kg extra fuel on a typical flight when flying 4 000 ft below the optimum altitude.[7] The optimum altitude is based on a number of complex variables, but the primary ones are aircraft weight, wind, ambient temperature and speed. These will already be taken into account in the flight planning stage. While in flight, operational stakeholders should make every effort to improve the aircraft's trajectory, for example, by making use of route replanning on long-distance flights, short-cut vectors and step climbs. However such tactical optimization may not deliver its full potential where constraints later in the flight, such as a night-noise curfew or stand non-availability, cause holding or routing on a non-optimal trajectory. Where possible therefore, it is recommended to collaboratively identify such opportunities or constraints and to plan the flight's operation accordingly.

8.7.2 For long-haul flights, generally there is a relatively limited opportunity to optimize cruise speed because operators already tend to fly at or close to the optimum. However, in some airspace, cruise airspeed/Mach number must be closely controlled (assigned by the controlling agency) to maintain safe (reduced) separation and thereby maximize airspace capacity. On balance, the increased route capacity results in more aircraft being able to fly more optimum (shorter) routings, and this more than offsets the incremental fuel burned due to the non-optimum speed. As a rule of thumb and driven by the cost index, fuel efficiency at presently used speeds is typically only around 0.5 per cent worse than maximum-range cruise speed. However even a fraction of 0.5 per cent is a valuable improvement.

8.8 CRUISE CLIMB

Where airspace and separation requirements allow, a useful fuel conservation technique is use of cruise climb (or descent), where an aircraft's altitude is allowed to drift (up or down) according to its reducing mass and the changing ambient conditions it passes through. The facilitation of this technique is presently limited but as more advanced aircraft and ATM capabilities become available, greater opportunities to deploy cruise climb may become available and should be exploited. Pre-planned or air traffic control (ATC) negotiated step climbs can also save fuel and reduce emissions when traffic conditions permit. The introduction of automatic dependent surveillance — broadcast (ADS-B) based cockpit display of traffic information and appropriate software applications will enable more frequent step climbs in non-radar airspace and reduce fuel use and emissions.

8.9 FLIGHT MANAGEMENT SYSTEMS (FMSs) AND COST INDEX

Most air carrier aircraft now have flight management systems (FMSs) with a cost index input that is vital in selecting the most cost-efficient speed and altitude, particularly above 10 000 ft where speed restrictions and other constraints are not

7. Airbus, *Getting to Grips with Fuel Economy*, Issue 4, 2004.

as frequent. The cost index is the cost of time divided by the cost of fuel. The cost index generally flown by commercial aircraft will tend towards the most fuel-efficient profile; however, the commercial costs of missed connections for passengers and crew and other factors may be more significant beyond a certain threshold. Minimum fuel use would result from a cost index of 0. The cost index determination is typically done in the flight and route planning stage before take-off and can be route-specific. However it remains for the pilot to update some of the input data (en-route winds) and to fly, to the extent possible, according to the output from the FMS. This cost-indexed trajectory is embedded in the flight plan for a specific flight, and its achievement depends on the plan being facilitated by ATC and on the ability to update the cost index according to changes to the plan. It is important that all of the operational stakeholders involved in facilitating a flight understand the generic implications of variance from plan according to cost index and take this into account in their decision making.

8.10 DESCENT AND LANDING

8.10.1 Descent performance is a function of the cost index: the higher the cost index, the higher the descent speed. However, contrary to climb, the aircraft gross weight and the top-of-descent flight level appear to have a negligible effect on the descent-speed computation. The descent phase uses less fuel when compared to climb and cruise; however it is still a significant source of emissions (both in terms of greenhouse gases and air quality pollutants) and the opportunity to mitigate such emissions is quite considerable.

8.10.2 Operational stakeholders are recommended to collaboratively evaluate and, where possible, implement initiatives that facilitate the pilot's ability to optimize his or her descent trajectory to the extent possible. This should include becoming aware of ATM measures mentioned in Chapter 6 and, where appropriate, supporting their implementation for fuel-efficiency purposes. Once such large-scale measures are implemented, operational stakeholders should collaborate to fully optimize the descent-performance improvements they bring.

8.10.3 The fundamental fuel-efficiency aims in descent are to:

a) fly as closely as possible to the most fuel-efficient descent profile. This includes avoiding unnecessary level-off segments and providing information to the pilot on the aircraft's progress along the proposed flight path in order to allow him or her to follow or regain the optimum descent profile;

b) avoid the use of holding, which is the largest single emissions source in the descent profile;

c) reduce the amount of vectoring and speed control assigned to aircraft, which also increases predictability;

d) reduce the circumstances that might cause go-arounds or missed approaches.

8.10.4 Alterations to descent or landing profiles can have a knock-on effect in other phases. For example, reduced queuing on the ground may reduce airborne holding, and the achievement of CDO could produce level-offs in the departure phase and may prevent CCOs unless airspace is suitably designed, which is not always possible.

8.11 DESCENT PROFILE OPTIMIZATION

Trials and early implementations of CDO indicate a wide range of potential benefits depending on the base-case profile, the height at which CDO are triggered and the aircraft type. Many flights into less congested airspace already achieve CDO for a significant part of the flight and should be accounted for in the base case. As a rule of thumb, reported benefits can range from around 10 kg to over 400 kg, with average fuel savings from implementation of CDO in the European Civil Aviation Conference (ECAC) estimated at between 50 to 150 kg per flight.[8] In ECAC, it is estimated that fuel savings from CDO could reduce annual fuel costs by over 100 million Euros and reduce CO_2 by around 0.5 million tonnes a year.[9] Implementation of CDO requires a collaborative team of operational stakeholders seeking to maximize CDO performance as local conditions allow. It is recommended to ATM stakeholders that CDO, using the most appropriate combination of facilitation methods, be implemented for as many aircraft as possible, from as high an altitude as possible and for the maximum time period possible. There should be an ongoing collaborative effort to continuously extend CDO performance and achievement in terms of quality, altitude and period of application. CDO implementation guidance is provided in the *Continuous Descent Operations (CDO) Manual* (Doc 9931). Often the achievement of CCO and CDO is interrelated, and it is recommended that a transparent impact assessment to determine the relative benefits of implementing either or both procedures be applied.

8.12 HOLDING

8.12.1 It should be recognized that any form of holding in the air or on the ground with engines running entails a fuel penalty and increases emissions. For example, NATS (United Kingdom) estimates that 1.5 per cent of total fuel burn in their airspace is generated by aircraft holding at London Heathrow.[10] Predictability and time management are the key enablers to reduce holding in terminal airspace. Reduced holding can be facilitated by:

a) flow control coupled with airport collaborative decision making (A-CDM) to ensure that aircraft are held on the ground with engines off to avoid holding in the air. An example of this is the EUROCONTROL Central Flow Management Unit (CFMU) and Dynamic Management of the European Airspace Network programme;[11]

b) better planning and optimized stand management achieved through A-CDM to reduce the risk that congestion on the ground stimulates holding in the air. This is covered in the CDM section of this document;

c) at a strategic level, effective airfield-capacity planning and enhancement reduces the need for (or risk of) holding in the air. It is worthwhile to benchmark airfield capacity and to pursue improvements that ensure that the maximum airfield capacity is available at peak hours in all operational configurations and weather conditions;

d) sharing information among all operational stakeholders to ensure the availability and provision of commonly understood quality information to the right people at the right time;[12]

e) holding or slowing aircraft at cruising flight levels rather than at lower altitudes, such as in a terminal holding stack, when unforecast airspace or airport capacity constraints or meteorological conditions reduce airport arrival rates.

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8. http://www.eurocontrol.int/sites/default/files/content/documents/nm/airports/2011-cd-brochure-web.pdf.
9. European Joint Industry CDA Action Plan, and based on a fuel price of 750€ per tonne of kerosene (January 2012).
10. http://www.theccc.org.uk/publication/meeting-the-uk-aviation-target-options-for-reducing-emissions-to-2050.
11. More information can be found at www.eurocontrol.int.
12. A global concept of system-wide information management (SWIM) is under development by ICAO and contributing States and organizations.

8.13 REDUCED VECTORING

8.13.1 Vectoring in the descent phase is used to maintain safe separation and to ensure more efficient airspace operations (e.g. sequencing, delay absorption) and use of runway capacity. Vectoring may result in additional track miles from the height at which it is initiated. This introduces unplanned and non-optimal vertical profiles with extended level flight, which results in higher fuel burn, emissions and noise. Alternatively, keeping an aircraft too high for too long may necessitate a steeper–than-optimum descent that can require the aircraft to increase drag within its certificated operating envelope in order to meet ATC requirements. These effects can be mitigated by tactical advisories on distance to go (i.e. a form of CDO facilitation), but it is better to reduce the need for vectoring if possible. Vectoring can be reduced by the use of controller tools and the publication of optimized conventional or performance-based navigation (PBN) standard terminal arrival routes (STARs). Area navigation (RNAV) and required navigation performance (RNP) flight procedures provide the pilot and controller with a published procedure that uses the capabilities of an aircraft flight management system to fly a repeatable lateral, vertical and, potentially, optimum profile. These procedures can be designed to minimize the need for tactical intervention during the arrival and departure phases of flight. Finally, the use of existing tools such as arrival management (AMAN) and emerging concepts such as RTA (required time of arrival) and time-based metering can allow a more accurate prediction and management of the gate-to-gate profile of a flight based on time.

8.13.2 Arrival routes may be designed to avoid or minimize noise in residential areas around airports; however, this can often add track miles to be flown and therefore increase fuel use and emissions, particularly at low altitudes. In contrast, the PBN capabilities of modern aircraft offer the opportunity to design quieter and more optimized lateral and vertical flight paths due to the enhanced track-keeping ability. However, PBN procedures may result in a concentration of flight tracks. Vectoring can spread noise impacts and is specifically required at some airports for noise dispersal reasons. Although a common issue at many airports, aircraft noise is considered a local issue, and thus operational stakeholders are recommended to collaborate with local ATM stakeholders to evaluate the different options in order to mitigate the environmental impacts of arriving aircraft at an airport.

8.14 REDUCING GO-AROUNDS

8.14.1 Go-arounds and missed approaches, whether initiated by ATC or the pilot, are a standard flight procedure and can occur for a variety of reasons, including as a required manoeuvre in flight training. All operational stakeholders seek to minimize the frequency of missed approaches and go-arounds, since they increase noise, emissions, fuel used and the time for the flight.

8.14.2 Review and compilation of go-around causal factors may yield opportunities to reduce their frequency. Seeking means to reduce unnecessary go-arounds and missed approaches will yield safety and operational benefits and reduce fuel burn and environmental impacts. It is recommended for airport operators to undertake a collaborative review process to track trends in go-arounds and to investigate their cause. The local environmental implications of go-arounds should be assessed and considered. Initiatives with the potential to reduce the likelihood of go-arounds should include the fuel and environmental implications as part of their justification and post-implementation monitoring.

Appendix

REGIONAL PROGRAMMES

1. EUROPE'S FLIGHT EFFICIENCY PLAN

1.1 The Flight Efficiency Plan is a joint initiative launched by EUROCONTROL, IATA and CANSO in September 2008 to drive immediate efficiency improvements. The five action points of the Flight Efficiency Plan are:

a) enhancing European en-route airspace design through annual improvements to the European ATS route network, with high priority being given to:

   i) implementing a coherent package of annual improvements and shorter routes;

   ii) improving efficiency for the most mileage- and altitude-penalized city pairs;

   iii) implementing additional conditional routes (to enable better use of military airspace) for main traffic flows;

   iv) supporting initial implementation of free-route airspace — allowing aircraft to route more directly on point-to-point routes;

b) improving airspace utilization and route network availability by:

   i) actively supporting and involving aircraft operators and the computer flight plan service providers in flight plan quality improvements;

   ii) gradually applying route availability restrictions only where and when required;

   iii) improving the utilization of civil/military airspace structures;

c) efficient terminal manoeuvring area design and utilization by:

   i) implementing advanced navigation capabilities (such as area navigation (RNAV));

   ii) implementing continuous descent operations (CDOs), improved arrival/departure routes and optimized departure profiles;

d) optimizing airport operations by:

   implementing airport collaborative decision making;

e) improving awareness on performance.

1.2 The implementation of the improvements is expected to bring benefits of approximately 0.5 million tonnes of fuel bum (1.5 million tonnes of CO_2) per year, which equates to just over 1 per cent improvement over the 2005 baseline for Europe.

2. EUROPE'S SESAR PROGRAMME

2.1 The Single European Sky Air Traffic Management Research Programme (SESAR) is the European Union's €30 billion air traffic management modernization programme. The current patchwork of 35 air traffic control organizations is based largely on national borders; through the SESAR programme this pattern will be replaced by "functional airspace blocks" based on operational requirements, in particular, traffic flows. SESAR aims at developing the new generation air traffic management system capable of ensuring the safety and fluidity of air transport worldwide over the next 30 years.

2.2 The SESAR Consortium joins the forces and expertise of 29 companies and organizations together with 20 associated partners. It includes airspace users, airport operators, air navigation services providers, the supply industry, safety regulators, the military, pilot and controller associations and research centres, as well as expertise from EUROCONTROL. SESAR will have some overlap with the initiatives highlighted in the Flight Efficiency Plan above.

2.3 SESAR is a performance-driven programme designed to ensure sustainable air transport system development in Europe. By 2020 the aim is to bring about a threefold increase in capacity, to improve safety by a factor of 10 and to reduce by 10 per cent the environmental impact per flight while cutting ATM-related costs by 50 per cent.

2.4 The European Commission estimates that implementation of SESAR could save 16 million tonnes of CO_2 a year through more efficient air traffic control, shorter routings and fewer delays. This equates to a reduction of approximately 5 million tonnes of fuel burn per annum.

3. THE SESAR IMPLEMENTATION PLAN

3.1 The aim of SESAR is to improve air traffic services, resulting in flight operations which are better optimized. The latter has been translated into the following SESAR performance objectives:

a) achieve emissions improvements as an automatic consequence of the reduction of gate-to-gate excess fuel consumption addressed in the KPA efficiency plan. The SESAR target for 2020 is to achieve 10 per cent fuel savings per flight as a result of ATM improvements alone, thereby enabling a 10 per cent reduction of CO_2 emissions per flight;

b) improve the management of noise emissions and their impacts to ensure that these are minimized for each flight to the greatest extent possible;

c) improve the role of ATM in enforcing local environmental rules: ensure that flight operations comply 100 per cent with aircraft type restrictions, night movement bans, noise routes, noise quotas, etc. Ensure that exceptions are allowed only for safety or security reasons;

d) improve the role of ATM in developing environmental rules. The aim is to ensure that all proposed environmentally related ATM constraints will be subject to a transparent assessment with an environmental and socio-economic scope; following this assessment the best alternative solutions from a European sustainability perspective will be adopted.

3.2 More information about SESAR can be found at http://www.sesarju.eu/.

4. U.S. FAA'S DESTINATION 2025

4.1 The Federal Aviation Administration's (FAA's) Destination 2025 (D2025) is the strategic plan for the agency and includes discussion of the U.S. Next Generation Air Transportation System (NextGen) initiative, which is described below. D2025 includes five aspirational areas: move to the next level of safety, create our workplace of the future, deliver aviation access through innovation, sustain our future, and advance global collaboration. Under sustain our future, the goal is to “to develop and operate an aviation system that reduces aviation’s environmental and energy impacts to a level that does not constrain growth and is a model for sustainability.” Intended outcomes, associated challenges, strategies for achieving the goal, and performance metrics for 2018 are outlined.

4.2 The 2018 performance metrics are:

a) the U.S. population exposed to significant aircraft noise around airports will be reduced to less than 300 000 persons;

b) a replacement fuel for leaded aviation gasoline will be available by 2018 that is usable by most general aviation aircraft;

c) NAS energy efficiency (fuel burned per miles flown) will be improved by at least 2 per cent annually;

d) aviation emissions will contribute 50 per cent less to significant health impacts and will be on a trajectory for carbon-neutral growth using a 2005 baseline;

e) one billion gallons of renewable jet fuel will be used by aviation by 2018.

5. U.S. NEXTGEN PROGRAMME

5.1 The Next Generation Air Transportation System (NextGen) represents a comprehensive transformation and evolution of the U.S. air transportation infrastructure by the year 2025, as well as how the infrastructure will be developed, operated and maintained. NextGen is a wide-ranging transformation of the entire national air transportation system to meet future demand and support the economic viability of the system while improving safety and protecting the environment. It is a unique coalition of government agencies and private sector partners, with the Federal Aviation Administration (FAA) managing the work.

5.2 A key element of NextGen is that it will replace ground-based technologies with new and more dynamic satellite-based technology. To describe the transformation to NextGen, there are nine functional areas listed below:

a) trajectory and performance-based operations and support;

b) airport operations and support;

c) safety management;

d) layered adaptive security;

e) environmental management framework;

f) weather information services;

g) net-centric infrastructure;

h) positioning, navigation and timing services; and

i) surveillance services

5.3 Since environmental constraints could limit system capacity, one of the primary strategies of the NextGen Integrated Plan is to develop environmental protection that allows sustained aviation growth. The NextGen vision includes the management of critical environmental resources and impacts through the environmental management framework (EMF) functional area that is fully integrated into all NextGen operations. The EMF is an overall strategy designed to balance aviation operational growth with environmental protection goals to achieve a sustainable air transportation system. Objectives of the NextGen EMF include:

a) reduce the impact of significant community noise and air quality emissions in absolute terms;

b) limit or reduce the impact of aviation greenhouse gas emissions on global climate including the rate of fuel consumption;

c) improve the energy efficiency of air traffic operations;

d) support alternative fuels development; and

e) proactively address other environmental issues.

5.4 To help achieve these goals, the NextGen EMF promotes the development of a national environmental management system (EMS) approach. EMS includes a management process to help users systematically identify, manage, monitor and adapt to the environmental demands associated with the high volume and dynamic nature of the air transportation system. The national EMS approach is intended to facilitate an effective and common process that is adopted by all applicable U.S. aviation organizations and therefore provides a mechanism for integrating environmental protection objectives into the core business and operational decision making of NextGen. While EMF provides the overarching strategy needed to achieve environmentally sustainable aviation growth, EMS delivers a management process for achieving environmental protection in user actions.

— END —

ISBN 978-92-9249-412-4