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Airport Air Quality Guidance Manual

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International Civil Aviation Organization

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This publication is the first part of the work indented to be revised and published in a hard copy by 2010 when the second part of this project will be included.

PREFACE

This guidance manual covers an evolving area of knowledge and represents currently available information that is sufficiently well-established to warrant inclusion in international guidance. The guidance will be updated periodically in the future.

This guidance manual covers issues related to the assessment of airport-related air quality that are either specifically within the remit of International Civil Aviation Organization (ICAO) (such as main engine emissions) or where there is established understanding on other non-aircraft sources (such as boilers, ground support equipment, and road traffic) that will contribute, to a greater or lesser extent, to air quality impacts.

There are potential emission source issues relevant to but not covered in the guidance (e.g. forward speed effects of aircraft, influence of ambient conditions on aircraft emissions, aircraft start-up emissions, aircraft brake and tyre wear) that have been identified and are the subject of further investigation by ICAO, contracting states, observer organizations or other expert organizations taking into account practical experience. Those interested to explore the issues mentioned previously or other issues not covered by this guidance can seek wider contacts as appropriate.

This first edition of the guidance manual includes chapters on the Regulatory Framework and Drivers for local air quality measures, Emissions Inventory Practices and Emission Temporal and Spatial Distribution. Future chapters on the completed Emissions Inventory (to include a more detailed sophisticated aircraft emissions calculation approach), Dispersion Modelling, Airport Measurements, Mitigation Options, and Interrelationships will be developed between 2007 and 2010, under the CAEP/8 work programme, for inclusion in a future update of this guidance, subject to future consideration by CAEP.

ICAO Airport Air Quality Guidance Manual

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INTRODUCTION

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Purpose

This guidance document contains advice and practical information to assist ICAO Contracting States in implementing best practices with respect to airport-related air quality. Information related to State requirements, emissions of airport sources, emission inventories and emissions allocation are addressed throughout the document.

The document also provides a process for States to determine the best approaches and analytical frameworks for assessing airport-related air quality and identifies best practices for different needs or scenarios. It is not intended as a basis for any regulatory action, it does not describe specific projects or actions nor does it address research-related aspects of airport air quality.

Because this guidance material was developed to potentially assist all ICAO Contracting States in implementing best practices in airport related air quality, it is necessarily broad and extensive. Accordingly, some States may already have some, or many, of the processes and measures in place that are addressed in this guidance material. In such cases, this guidance material may be used to supplement those processes and measures, or used as an additional reference.

Since the guidance material is broad and extensive, it cannot be expected to provide the level of detail necessary to assist States in addressing every issue that might arise, given that there may be unique legal, technical, or political situations associated with airports and/or air quality at particular locations. As with any guidance material of broad application, it is advised that States use it as a reference to be tailored to specific circumstances.

The Committee on Aviation Environmental Protection

ICAO has been involved with airport-related emissions for many years. In particular, the ICAO Committee on Aviation Environmental Protection (CAEP) and its predecessor, the Committee on Aircraft Engine Emissions, have continually addressed emissions standards for new engine types, their derivatives and new production engines since the late 1970s. One of the principal results arising from their work is the ICAO provisions on engine emissions in Volume II of Annex 16 to the Convention on International Civil Aviation (the “Chicago Convention”). Among other issues, these provisions address liquid fuel venting, smoke and the following main gaseous exhaust emissions from jet engines: hydrocarbons (HC), nitrogen oxides (NO_x) and carbon monoxide (CO). Specifically, they set limits on the amounts of smoke and gaseous emissions of these three pollutants in the exhaust of most civil engine types. In addition to technological innovation and certification standards, CAEP also has pursued two other potential approaches for addressing aviation emissions: (1) alternative airfield operational measures and (2) the possible use of market-based emission reduction options.

ICAO also has produced several guidance documents related to aircraft emissions including: the *Airport Planning Manual* (Doc 9184) and the ICAO Circular - *Operational Opportunities to Minimize Fuel Use and Reduce Emissions* (Cir 303, 2004).

The *Airport Planning Manual* is published in three parts: (1) *Master Planning*, (2) *Land Use and Environmental Control*, and (3) *Guidelines for Consultant/Construction Services*. Part 2 — *Land Use and*

Environmental Control provides guidance on land use planning in the vicinity of airports and include information on available options for reducing airport-related emissions and improving fuel efficiencies of aircraft engines.

The ICAO Circular, *Operational Opportunities to Minimize Fuel Use and Reduce Emissions*, also identifies and reviews various operational opportunities and techniques for minimizing aircraft engine fuel consumption and, therefore, emissions associated with civil aviation operations.

In the context described previously, CAEP established that there was a complementary need to develop this guidance material to help States implement best practices related to assessing airport-related air quality.

Background

Interests in aircraft and airport air pollutant emissions have been rising ever since the substantial increase in commercial turbojet traffic in the 1970's. For example, aircraft emissions produce air contaminants such as NO_x, HC, and fine particulate matter (PM), which in turn can become involved in broader environmental issues related to ground level ozone (O_3), acid rain, climate change, and present potential risks relating to public health and the environment. Unlike most transportation modes, aircraft travel great distances at a variety of altitudes, generating emissions that have the potential to impact air quality in the local, regional and global environments.

ICAO also recognizes that airport-related sources of emissions have the ability to emit pollutants that can contribute to the degradation of air quality of their nearby communities. As such, national and international air quality programs and standards are continually requiring airport authorities and government bodies to address air quality issues in the vicinity of airports. Similarly, attention must also be paid to other possible airport-related environmental impacts associated with noise, water quality, waste management, energy consumption and local ecology in the vicinity of airports, to help ensure both the short- and the long-term welfare of airport workers, users, and surrounding communities.

Notably, significant improvements have been made over the past two decades regarding aircraft fuel-efficiency and other technical improvements to reduce emissions. However, these advancements may be offset in the future by the forecasted growth of airport operations and other aviation activities. Because aircraft are only one of several sources of emissions at an airport, it is also considered essential to effectively manage emissions from terminal, maintenance and heating facilities; airport ground service equipments (GSE); and various ground transport travelling around, to and from airports. Optimizing airport design, layout and infrastructure; modifying operating practices for greater efficiencies; retrofitting the GSE fleet to "no-" or "low-" emitting technologies; and promoting other environmentally-friendly modes of ground transport are some of the current opportunities airports and the rest of the aviation industry can adopt or apply to help meet these goals and encourage sustainable development in commercial air transportation.

Air Quality Assessment

In most areas, air quality is regulated by a combination of national, regional and/or local regulations[1] that establish standards on emission sources and/or ambient (i.e. outdoor) levels of various pollutants, and define the procedures for achieving compliance with these standards. For example, Figure 1 shows the relationship of the principle requirements of an air quality assessment reflecting this legal framework.

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[1] This guidance generally uses the term "regulations" to refer to national air quality laws and regulations (which can include national regulations adopted to incorporate ICAO emissions standards for aircraft engines) and "standards" when referring to ICAO engine emission standards. Some national air quality regulations, however, are themselves called "standards" (e.g. the National Ambient Air Quality Standards, or NAAQS, in the US). Where national schemes refer to their own air quality provisions as "standards," that terminology will be used in this guidance when referring to those provisions. To avoid confusion in terminology, the guidance will specifically refer to ICAO engine emissions standards as "ICAO" standards

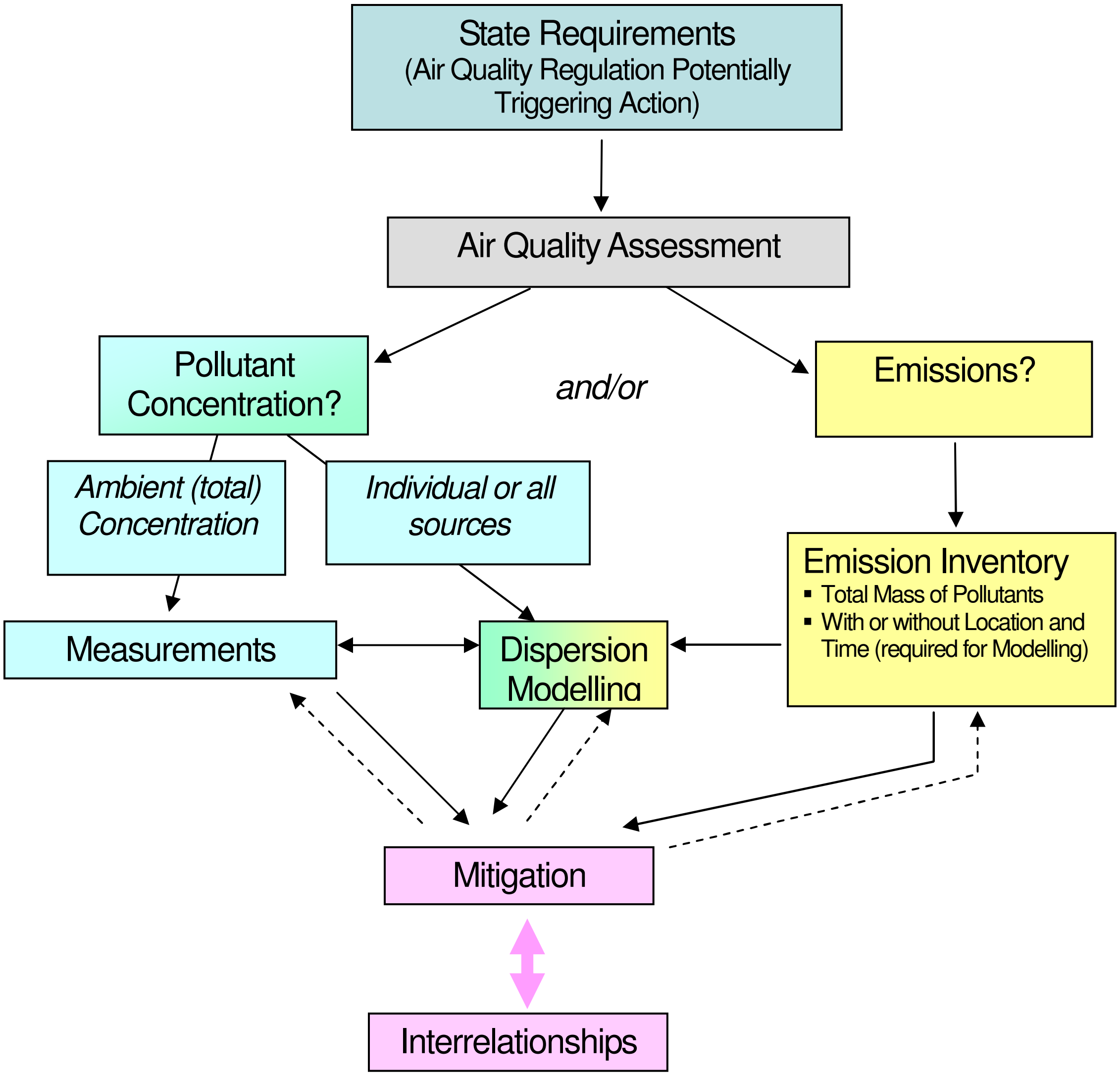

Figure 1 - Local Air Quality Elements and their Interactions

As shown, the two main areas of an air quality assessment are (1) the emissions inventories and (2) the dispersion modelling of pollution concentrations. An emission inventory gives the total mass of emissions released into the environment and provides a basis for reporting, compliance, mitigation planning, and can be used as input to modeling pollution concentrations. In order to link emissions to pollution concentrations, the spatial and temporal distribution of the emissions have to be assessed as well. This combined approach of using emission inventories and dispersion modeling enables the assessment of historical, existing, and/or future pollution concentrations in the vicinities of airports or from individual emission sources.

Existing pollution concentrations can also be assessed by measuring (e.g. sampling and monitoring) ambient conditions; although this assessment method can include contributions from other nearby and distant sources, including those that are non-airport related. Depending on the specific task, computer modelling results and ambient measurements can be used for evaluating existing or historical conditions. In contrast, future conditions can only be simulated using computer modelling.

The emission inventory, concentration modelling and ambient measurement elements of an air quality assessment can be used individually, and or combination, to aid the process of understanding, reporting, compliance and/or mitigation planning by providing information on overall conditions as well as specific source contributions.

Subsequent air quality mitigation or other implemented measures – with proper consideration of the interrelationship with, primarily noise and other airport environmental impacts – can have beneficial results on the total emission mass, the concentration model results, and measured concentrations.

Chapter 1
REGULATORY FRAMEWORK AND DRIVERS

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1.1 Introduction

1.1.1 States (and their delegates) have historically adopted local air quality regulations to protect public health and the natural environment. Local air quality may be generally described as the condition of the ambient air to which humans and nature are typically exposed. In most cases, determining the quality of the air is based on the concentration of pollutants (both from natural and anthropogenic sources i.e. man-made sources). These concentrations are compared to regulations and standards that are established to define acceptable levels of local air quality; including the necessary measures to achieve them. Many issues particular to the local air quality in and around airports are subject to these same regulations. In this context, there are assorted and varying pressures on individual States relating to air quality in the vicinity of airports, including:

- Worsening local air quality leading to reduced margins against existing regulations;
- Increased awareness of health impacts, prompting the introduction of new regulations, including the addition of new pollutant species;
- Development constraints resulting from limitations imposed by the need to meet local air quality regulations;
- Increasing public expectations regarding local air quality levels; and
- Increasing public concerns over the effects of aircraft.

1.1.2 These pressures also need to be considered in the wider context of other pressures on aviation – notably the potential impact of aviation emissions on climate, the impact of aviation noise on the community, and the economic status of the aviation industry. These additional pressures bring their own economic and regulatory measures which in most cases raise trade-off issues with each other and with local air quality in the vicinity of airports.

1.1.3 Typically, airport environments comprise a complex mix of emission sources – including aircraft, GSE, terminal buildings, and ground vehicular traffic. For any given State' there are often an associated complex mix of existing regulations and standards covering many of the sources of emission that are present at airports (e.g. aircraft engines, transport vehicle engines, power/heat generating plants, and aircraft maintenance facilities). In this regard, regulations covering non-aircraft sources are generally established nationally. By comparison, emissions standards for aircraft engines are agreed internationally through the ICAO CAEP, and subsequently adopted into domestic regulations by each ICAO Contracting State.

1.1.4 In most countries, national authorities establish the guiding principles and objectives for attaining and maintaining acceptable air quality conditions. Together with regional and local authorities, they also have important tasks in taking air quality measurements, implementing corrective plans and programmes and informing the general public of matters pertaining to local air quality conditions.

1.2 Drivers for Action

1.2.1 Local air quality regulations have, since their very inception, been based around the need to protect public health and the natural environment. Early examples of local air quality regulations include the 1881 local air quality controls in Chicago and Cincinnati. These initial regulations focused on the most visible of fuel and waste combustion products; namely smoke and particulates. By the mid 20th century, regulation of emissions to reduce smoke moved from the local to the national level, with the introduction of national air quality laws in the USSR (1949), U.S. (1955) and the UK (1956).

1.2.2 In the case of the UK's 1956 regulations, the Great Smog of 1952 was the driver for legislative action along with a significant rise in the death-rate observed in people suffering from respiratory and cardiovascular diseases associated with this event. The resultant 1956 Clean Air Act focused its attention on reducing smoke pollution associated with industrial sources.

1.2.3 In the U.S., the 1955 Air Pollution Control Act was just the beginning of a series of measures taken to improve local air quality; affecting a broad range of industries. Major revisions in 1963 evolved into the "Clean Air Act", with additional regulations covering long-range transport, power generation, and a variety of industrial activities. At the same time, the federal government established the U.S. Environmental Protection Agency (U.S. EPA) and in 1971, the National Ambient Air Quality Standards (NAAQS) were introduced. The NAAQS established air quality regulations on a national level covering six pollutants[2] and stipulating that the standards had to be met by 1975. In 1990, extensive amendments to the Clean Air Act significantly tightened these requirements.

1.2.4 These legal requirements, established for the protection of public health and the environment, created a driver for action by many industries (including aviation), and the need to comply with the regulations. In some cases, air quality compliance in Environmental Impact Statements and Assessments became a required consideration in development initiatives.

1.2.5 In parallel with the local air quality regulations, increased public awareness and expectations regarding air quality, expressed through media, government and stakeholder groups, also applied pressure upon the aviation industry. These initiatives also served as drivers upon the aviation industry to inform and, where appropriate, to attempt to meet those expectations.

1.2.6 Among the options open to the aviation industry as a response to these drivers, one is the control of emissions from aircraft engines. In 1971, ICAO published its *Annex 16: Environmental Protection, Volume I - International Noise Standards* followed, in 1981, by the *Annex 16 Environmental Protection, Volume II – Aircraft Emissions Standards*. These standards covered the prohibition of fuel venting and limiting of emissions of HC, CO, and NO_x, and smoke; the latter in the form of a smoke number (SN).

1.2.7 The ICAO engine emissions standards are applied through national and multi-national certification processes to turbojet and turbofan engines greater than 26.7 kilo Newtons (kN) of thrust; but not turboprops, turboshafts, piston engines, or the aircraft auxiliary power units (APU). The ICAO standards are based upon uninstalled engine performance measured against an idealised landing and take-off cycle (LTO) up to 915 meters (3,000 feet) above ground level (agl). Certification procedures are carried out on a single engine in a test cell, referenced to static sea level and International Standard Atmosphere (ISA) conditions. It is widely recognized that the ICAO standards used in certification vary from actual aircraft emissions that occur in specific locations and operational situations. Nevertheless, some States currently use the ICAO standards as default values for some local air quality assessment purposes. Therefore, one of the key purposes of this guidance is to provide methodology that produces a more precise assessment of actual aircraft engine emissions than the use of default ICAO standards.

[2] Carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), particulate matter, ozone and sulphur dioxide (SO_2). Particulate matter is subdivided into particulates less than or equal to 10 microns (PM_{10}) and PM less than or equal to 2.5 microns ($PM_{2.5}$).

1.2.8 Finally, it is worth noting that aircraft engine technology has reached a stage where there are fewer developments which reduce both noise and emissions together. With the continuing drive to reduce aircraft environmental impacts, there are expanding needs to assess the trade-offs between reducing noise and emissions and the effect on greenhouse gas emissions (amongst these emissions is carbon dioxide (CO_2), associated with fuel burn), whenever a new aircraft is designed and operated.

1.3 Local Air Quality Regulations and Pollutant Regulation

1.3.1 Local air quality regulations often regulate specific emissions species as well as the secondary pollutants that these emissions may form. As a result, regulations may vary and be tailored to the local conditions and priorities in the countries where they are applied. An example of this is the difference in emphasis that the European Union (EU) and the U.S. place on NO_2, NO_x, and O_3, with many EU States more concerned with NO_2 concentrations and the U.S. and others more concerned with NO_x emissions, which is an O_3 precursor.

1.3.2 States have also historically developed their own local air quality regulations and/or guidelines, and therefore a number of national regulatory criteria exist world-wide. Table 1-1, although not comprehensive in its coverage, is included to demonstrate the variability that exists between States for a number of air pollutants. Beyond the detail shown in the table, this variability also extends to the manner in which the numerical standards are applied. For example, some regulations are treated as maximum acceptable levels, whilst some have specified number of acceptable exceedances. Also included in the table are the EU Air Quality Framework Directive and the World Health Organization (WHO) guidelines for comparison. It is noteworthy that local air quality regulations are typically in the form of micrograms per cubic meter ($\mu g/m^3$) and for a specified time frame (usually hour, day, or year) by pollutant.

Table 1-1 Local Air Quality Regulations in Different Countries

Country/Organisation	Pollutant (Averaging period)	Sulphur Dioxide			Nitrogen Dioxide			Carbon Monoxide		Ozone			PM_{10}	
		1 hr.[3]	24-hrs.	Annual	1 hr.	24-hrs.	Annual	1 hr.	8-hrs.	1 hr.	8-hrs.	24-hrs.	24-hrs.	Annual
		µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
WHO	WHO Guidelines	-	125	-	200	-	40-50	30	10	-	120	-	-	-
EU	Air Quality Framework Directive	350	125	20	200	-	40	-	10	-	120	-	50	40
Australia	National Environmental Protection Measure for Ambient Air Quality	520	200	50	220	-	50	-	10	200	-	-	50	-
Brazil	Resolution 03 of CONAMA (National Council for the Environment)], June 1990 - Air Quality National Standards	-	365	80	320	-	100	40	10	160	-	-	150	50
Canada	National Ambient Air Quality Objectives Canadian Environmental Protection Act June 2000	900	300	60	400	200	100	35	15	160	-	50		
China	Ambient Air Quality RegulationsGB3095-1996	500	150	50	150	100	50	10	-	160	-	-	150	100
India	G.S.R.6(E), [21/12/1983] - The Air (Prevention and Control of Pollution) (Union Territories) Rules, 1983	-	80	60	-	80	60	4	2	-	-	-	100	60
Japan	Ministry of the Environment Environmental Quality Standards	260	100	-	75-110	-	-	12	23	120	-	-	-	-
South Africa	SANS1929 Guidelines[4]	-	125	50	200	-	40	30	10	200	120	-	75	40
Switzerland	Swiss Luftreinhalteverordnung (LRV)	-	100	30	-	80	30	-	-	120	-	-	50	20
USA	NAAQS		360	80	-	-	100	40	10	240	160	-	150	50

µg/m³ = micrograms per cubic meter

1.3.3 Importantly, Table 1-1 is a snapshot of States air quality regulations in 2005 and it should be noted that the regulations may periodically change. A brief examination of the table shows that the regulations vary by country and may be more, or less, strict than the WHO guidelines. For example, in the case of NO_2, over an hourly period the WHO guideline is 200 µg/m^3 but the variation for this pollutant is from 75 to 400 µg/m^3. For particulate matter equal to or less than 10 microns (PM_{10}), there is no WHO guideline, but regulations vary from 50 - 150 µg/m^3 over a 24-hour period. By contrast, for O_3 there is no hourly or 24-hour WHO guideline, but there is an 8-hour guideline of 120 µg/m^3, with national regulations varying from 120 - 160 µg/m^3.

1.3.4 The ability to conform to these national guidelines and regulations is highly dependent on local variables including meteorological conditions, background concentrations, population density, types and

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[3] Time periods given are those over which the average pollutant concentrations are measured.

[4] The South African air quality standard (SANS 1929) was published in October 2004 ahead of a new Air Quality Act. At the moment, it is not known how it will be incorporated into the Act and how it will be applied.

sizes of industry, and the types of emissions control technologies available in the area which may be limited by affordability. The WHO guidelines recommend that the regulations cover certain timeframes from 1 hour, 8-hours, 24-hours, or a year.

1.3.5 There are also parts of the world that do not have air quality regulations. In some developing countries, it is only recently that there has been rapid urbanisation and industrialisation resulting in the intensification of air pollution and deterioration in local air quality to levels that may warrant specific attention or corrective actions.

1.3.6 In response to the recommendations of *Agenda 21*[5] of the *United Nations (UN) Plan of Implementation* of the *2002 World Summit on Sustainable Development*, the Strategic Framework has been set up. This *Strategic Framework for Air Quality Management in Asia* aims to provide a regional approach to improving urban local air quality by facilitating the setting of local air quality priorities and providing direction on institutional development and capacity enhancement. The *Strategic Framework* is being proposed by the *Air Pollution in the Megacities of Asia* (APMA) project and the *Clean Air Initiative for Asian Cities*. APMA is a joint project of the UN Environment Programme, the WHO, the Stockholm Environment Institute and the Korea Environment Institute. APMA covers the megacities in Asia, defined as those with a population of more than ten million[6]. This *Strategic Framework* recommends the use of the WHO *Air Quality Guidelines* for the setting of standards and averaging times.

1.3.7 In many countries, regional and local authorities carry out the monitoring of local air quality but they also have an important task in taking corrective measures, implementing management plans and other programmes to meet the requirements of the local air quality regulations.

1.3.8 Increased urbanisation is a concern in many countries and there is a tendency for airports to attract new development areas. Some States use available land use planning measures to manage this growth in order to prevent incompatible development in the surrounding countryside from encroaching on airport boundaries. Providing a buffer for airport-related noise and emissions is also commonly practiced. Planning permission for the creation or expansion of airports requires consultation with key stakeholders and strategic decision-makers at national, regional and local levels. This often will include engaging with railway, highway and planning authorities.

1.3.9 For example, in the UK, although the government is committed to the mandatory EU local air quality regulations, it has also set national objectives in its *Air Quality Strategy*. These targets have a different legal status from the EU Limit Values, but they form part of a joint Department for Transport/Department for Environment, Food, and Rural Affairs (DfT/DEFRA) Public Service agreement and help underpin decisions on the future development of aviation in the UK.

1.3.10 Since December 1997 each local authority in the UK has been carrying out a review and assessment program of local air quality in its area. This involves measuring air pollution and trying to predict how it will change in the next few years. The aim of the work is to ensure that the *National Air Quality Objectives* are achieved throughout the UK. These *Objectives* have been put in place to protect human health and the natural environment. If a local authority identifies any areas where the *Objectives* are not likely to be achieved, it must declare an *Air Quality Management Area* there. This area could be just one or two streets, or it could be much bigger. The local authority can then form a *Local Air Quality Action Plan* to improve the local air quality.

[5] Agenda 21: Earth Summit - The United Nations Programme of Action from Rio ISBN: 9211005094 April, 1993.

[6] Bangkok, Beijing, Calcutta, Chongqing, Guangzhou, Hong Kong, Kathmandu, Manila, Mumbai, New Delhi, Osaka, Seoul, Shanghai, Singapore, Taipei, and Tokyo.

1.3.11 Within the EU, local air quality is also regulated by the *Framework Directive 96/62/EC*[7] on local air quality assessment and management. Daughter Directives then develop the stringencies and provide further detail where it is needed. The Daughter Directive relevant to local air quality at airports is 99/30/EC[8], which covers SO_2, NO_2 and NO_x, PM_{10}, and Pb. These *EU Directives* are in line with the WHO recommendations for Europe.[9]

1.3.12 Historically, many of the existing large hub airports have evolved from smaller airfields so that their positioning and the proximity of urban/residential areas have been difficult to manage. For example, in Hong Kong, the old Kai Tak Airport, which had an extremely challenging approach over densely populated areas, has been replaced by an entirely new facility. The new Hong Kong International Airport has been deliberately built away from main centres of population so that aircraft do not have to take-off and land over densely populated urban areas and the new night-time approaches are over water rather than over centres of population. This has a benefit from both a noise and local emissions perspective; although in the particular case of Hong Kong, the *Advisory Council for the Environment* did not find a connection between the relocation of the airport and local air quality[10]. Where regions have the space or perhaps geography to accommodate such planning and can subsequently prevent encroachment by incompatible development, it is clearly beneficial. Further local emissions reductions have been made by building an extensive public transport network so that road vehicles need not be the primary method of airport access for the travelling public.

1.3.13 In the U.S. the U.S. EPA regulates local air quality through Clean Air Act and the NAAQS, as previously discussed. Areas which have pollutant concentrations that exceed the NAAQS, or contribute to an exceedence to the standards in a neighbouring area, are designated a non-attainment area. Air quality monitoring is used to determine compliance with the NAAQS and establish the geographic limits of these non-attainment areas.

1.3.14 The consequence of non-attainment is that states must submit State Implementation Plans (SIP) identifying specific measures for improving local air quality and achieving attainment with the NAAQS. Regulated entities within the non-attainment area, as well as land use and transportation planning authorities, must then adhere to the SIP. Failure to do so incurs sanctions imposed by the U.S. EPA, usually in terms of civil penalties and/or in the form of a ban on further development and building of a particular new emissions source.

1.3.15 In addition to PM_{10}, the U. S. EPA also has a NAAQS regulating particulate matter equal to or less than 2.5 microns ($PM_{2.5}$). The $PM_{2.5}$ regulations are for a 24-hour and annual mean time periods. The regulations allow only one exceedance of the 24-hour standard in a calendar year, and no exceedances of the annual standard. Notably, at the time of the introduction of the $PM_{2.5}$ regulation there were more commercial service airports in $PM_{2.5}$ non-attainment areas (e.g. 53, not including general aviation or military airports) than there were in PM_{10} non-attainment areas (e.g. 38).

1.4 Aircraft Engine and Road Vehicle Emission Standards and Regulations

1.4.1 Presently, the regulations and standards affecting aircraft and other airport sources of emissions typically fall into two distinct categories:

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[7] *Council Directive 96/62/EC* of 27 September 1996 on ambient air quality assessment and management (OJ L 296, 21.11.1996, p. 55–63)

[8] *Council Directive 99/30/EC* of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air.

[9] *Air Quality Guidelines for Europe 2nd Edition*, WHO Regional Publications, European Series, No.91

[10] *ACE Paper 25/2004, Impact of Aircraft Emissions on Air Quality*

- Measures that set limits on particular sources of emissions. These include both ICAO aircraft engine emission standards (as adopted into national and multi-national regulations) and national measures establishing limits for non-aircraft sources such as stationary facilities (e.g. boilers, generators, incinerator) and road vehicles; and
- National regulations (in some States called "standards") establishing ambient pollutant concentrations for local air quality conditions (e.g. local air quality limit values).

1.4.2 This distinction is important because, whilst all the individual emission sources operating at, or in the vicinity of, a particular airport may meet limits pertaining to that type of source (including ICAO standards for aircraft engines), the local pollutant concentrations thresholds still may not be met. This may be due to a variety of factors particular to each locality including road and air traffic volumes, topography, short term meteorological conditions, and proximity to other emission sources and/or high background pollution levels.

1.4.3 Airport studies confirm that aircraft continue to be a relatively small contributor to regional pollution although aircraft-related NO_x contributions could increase as air traffic increases and other non-aircraft emission sources become progressively cleaner. Therefore, although reductions in aircraft emissions (through operational and air traffic measures and/or more stringent ICAO engine standards) can help to improve local air quality in the vicinity of airports, it is also important to consider the emissions from both regional and local road vehicles. Within this context, the emissions performance of new road vehicles is expected to improve significantly in coming years. Therefore, depending upon the circumstances in particular localities, the relative proportion of the total airport related emissions which are attributable to aircraft emissions could increase as a consequence.

1.4.4 The international nature of commercial aviation has resulted in the development of uniform international certification standards, developed within CAEP and adopted by the ICAO Council. New aircraft engines that are certified after the effective date of an ICAO standard are required to meet that standard. ICAO engine emissions standards are contained in *Annex 16 – Environmental Protection*, *Volume II – Aircraft Engine Emissions to the Convention on International Civil Aviation*; and were originally designed to respond to concerns regarding emissions that affect local air quality in the vicinity of airports. These engine standards establish limits of NO_x, CO, HC, and smoke for a reference landing and take-off (LTO) cycle up to 915 metres (3,000 feet) in height above the runway.

1.4.5 Presently, there is no ICAO standard for aircraft engine PM, though many national regulatory schemes contain ambient limits for that pollutant. Until recently, there was also no reliable and repeatable way to measure PM emissions from aircraft engines, but research on this subject is now ongoing. Finally, there are no ICAO standards applicable to any emissions from turbo-prop, piston engine and helicopter aircraft or smaller business jets.

1.4.6 The ICAO aircraft engine NO_x emissions standards have gradually been tightened since their introduction. Adopted in 1981, the ICAO standard for NO_x was then made more stringent in 1993 when ICAO reduced the permitted levels by 20 percent for newly certificated engines, with a production cut-off on 31 December 1999. In 1999,[11] the ICAO tightened the NO_x standard by about 16 percent on average for engines newly-certified from 31 December 2003. In October 2004, the ICAO Council ratified the CAEP decision for a further tightening of the NO_x standard so that the standard is now 12 percent more stringent than the levels agreed in 1999 and will take effect in 2008. For the engines to which they apply, the combined effect of these changes is a 40 percent tightening of the original ICAO NO_x emissions standards.

1.4.7 As a result, the emissions certification regime has gradually become more stringent and engine manufacturers have greatly improved the average margin to the ICAO standards. However, the

[11] Percentage reductions quoted refer to reductions at an engine overall pressure ratio (OPR) of 30. Reductions at other engine OPR may vary from these values.

tendency towards the more efficient higher overall pressure ratio (OPR) engines means that absolute NO_x emissions from an updated fleet may not decrease by the same percentage as the change in the ICAO NO_x standard.

1.4.8 National application of ICAO standards in the certification process for aircraft engines employs a "type-testing" approach. This involves the engine manufacturer demonstrating to the certificating authority by use of a limited number of engines that the engine type pending certification meets the ICAO standard. All of the engines of this type are then given an emissions certification on an engine-type basis. This certification is also effective for the life of the engine type (e.g. there is no requirement for an emissions check after engine maintenance/overhaul procedures). However, there is typically only a small change in emissions during the service life of the engine and this is discussed elsewhere within this guidance material.

1.4.9 There are also ICAO standards regarding the reduction of smoke to non-visible levels; again using manufacturer demonstration by type testing described previously. ICAO standards also require that fuel not be vented from the main propulsion engines during normal engine shutdown. At present there are no ICAO standards related to aircraft APU.

1.4.10 Non-aircraft emissions sources at, and in the vicinity of, airports are subject to nationally-determined emissions source limits rather than standards set by international bodies such as ICAO. Identifying and quantifying these key non-aircraft emission sources is important for assessing local air quality in the vicinity of airports. These sources include other airport-related activities, such as road vehicles accessing the airport and operating on nearby roadways; airside vehicles such as tugs, other GSE, and fire-engines; as well as other sources in the geographical area deemed relevant to the assessment under the national regulatory scheme.

1.4.11 As previously mentioned, road vehicles fitted with engines are typically regulated to some degree under national regimes but they differ in how they are regulated. For example, heavy goods vehicles are typically regulated based on the engine performance characteristics alone (e.g. in grams per kilowatt-hour). This is because of the wide variety of vehicles (from light box trucks to 38-tonne articulated vehicles and buses) in which these engines can be used. In this sense, these emission source regulations are comparable to the ICAO standards applicable to aircraft engines, which are also based on the engine type alone. For "light duty road vehicles" (e.g. cars, vans, etc.) regulations are established for each vehicle/engine combination. Hence there are a myriad of regulations, covering the different requirements for each combination of vehicle type, fuel type, engine type, power rating and emission reduction device. Within the EU, passenger road vehicles are regulated based on their emissions per kilometre, using test drive cycles[12] designed to be representative of on road conditions and load. The test cycles are effectively traces of vehicle speed versus time, simulating a predetermined set of on-road urban and rural and motorway driving conditions.

1.4.12 Ground support equipment and vehicles operating airside are also subject to an assortment of emission regulations based on their heavy–duty/light-duty (or off-road/on-road) utilization characteristics. For example, many GSE fall under "non-road mobile machinery" standards if the vehicle is never intended for road use. These vehicles are regulated based on the engine alone; typically with a test-cycle representing off-road duty patterns. Vehicles used at airports that are also used in a normal road context, such as fire engines or delivery vehicles, are subject to a State's normal road emission regulations, as previously discussed.

1.4.13 Hence, whilst aircraft, road vehicles and airside vehicles are regulated using specified procedures (e.g. reflecting steady state or theoretically representative conditions either for the engine or for the total vehicle), the emissions actually produced at a particular site will likely show differences to these

[12] The "New European Drive Cycle"

conditions. For example, the range of road vehicles tested is relatively small for each production vehicle/engine combination; there are wide variations in traffic conditions, driving style, and weather conditions - all of which have a bearing on the actual emissions levels.

1.5 Changing Regulations and Technology Targets

1.5.1 Local air quality regulations are still evolving and gradually becoming more stringent as industrial activities and transportation systems expand and the impact of local air quality on human health is better understood. The reduction of the EU NO_2 limit values from 200 μg/m^3 in 1985[13] to 40 μg/m^3 in 1999[14], along with further subsequent reductions enabled in the EU Daughter Directive 99/30/EC, are examples. In 99/30/EC, the annually averaged NO_2 limit of 40 μg/m^3 had a 50 percent margin of tolerance when it was introduced in 2001 and then reducing annually by equal percentages to a margin of zero by 2010, so that the stringency gradually increases over the ten year period. Given the continued expansion of most industry sectors, technological improvements to airport-related emissions sources must be made if these increased stringencies are to be met.

1.5.2 In recognition of growing pressures from possible local air quality and climate effects, coupled with the predicted continued growth in air traffic, aviation stakeholders have set out their goals and vision for the future of aircraft emissions in the medium and long term. Those set by *Advisory Council for Aeronautics Research in Europe* (ACARE) and the *National Aeronautics and Space Administration* (NASA) in the U.S. are two examples.

1.6 Regulatory Responses

1.6.1 The introduction and expansion of all industry sectors has lead to local air quality regulations that are designed to protect public health and the environment. Further growth and expansion means that it will become increasingly necessary for all sectors to improve their performance and either reduce their net emissions or else their emission rate as a function of productivity. This can be seen in the ever more stringent NO_x standards in both the motor vehicle and aviation industries. In addition, a steadily improving understanding of the impact of various pollutants on public health means that the emphasis may shift from one emission or pollutant to another. So far, this has lead to an increase in stringency for local air quality regulations.

1.6.2 The introduction and tightening of the U.S. NAAQS and EU Air Quality Framework Directive for PM_{10}, and increasing interest in $PM_{2.5}$ are also resulting in considerable activity within ICAO CAEP. A prerequisite for ICAO standards is a repeatable and reliable means of measurement – which for the small particle sizes on aircraft engine exhaust does not yet exist. Once measurement systems are developed, the current SN measurement may be replaced with a PM-based parameter which better represents current relatively low levels of carbon-based particulate emissions from aircraft engines. In a longer timescale, ICAO standards for volatile particle precursors from HC may also be considered, but again reliable measurement methods will be required. Of additional concern is the emission of volatile particle precursors from sulphur. Whilst this can be controlled by fuel sulphur content, measurement of engine emission is in its infancy and direct ICAO emissions standards would only be feasible on a longer timescale.

1.6.3 Looking forward, CAEP is anticipating further stringency increases in ICAO aircraft engine emission standards by LTO. In particular, NO_x will be examined, although potential reductions will be assessed against trade-offs with noise, fuel consumption and cost. Engine technology has reached a stage of maturity such that there are few developments which can be made and have wholly beneficial effects. Evaluation of the trade-offs from any regulatory change and its attendant technological consequences will therefore be required for all future changes in ICAO engine standards. To support this activity, CAEP has

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[13] *Air Quality Standards on Nitrogen Oxides Directive 85/203/EEC* (7 March 1985)

[14] *The Sulphur Dioxide, Nitrogen Dioxide and Lead in Ambient Air Directive* 99/30/EEC

established a process to set medium (e.g. 10-year) and long term (e.g. 20-year) NO_x technology goals. CAEP will use this process in determining the degree to which technology-based NO_x reductions are appropriate to meet local air quality needs whilst taking into account other environmental and economic requirements and their interdependencies. Such goals will facilitate concerted government and industry efforts on this issue as well as allowing for better informed forecasts and scenarios in aviation-related air quality over the next 20-year timescale.

Chapter 2
EMISSIONS INVENTORY

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2.1 Introduction

2.1.1 Airports and their associated activities are sources of an assortment of gaseous and particulate emissions. Within the context of airport air quality, the total amounts (or mass) of airport emissions meeting particular characterizations is an important value with respect to their relative impacts and regulatory compliance issues. This value is determined through the completion of an emissions inventory. Emissions inventory objectives can include, but are not necessarily limited to, the following:

- Collecting information on emissions whilst monitoring trends and assessing future scenarios;
- Benchmarking emissions against legal requirements (e.g. thresholds);
- Creating input data for dispersion models in an effort to determine pollution concentrations; and
- Establishing mitigation program baselines.

2.1.2 A bottom-up process is typically used to calculate emission inventories as this approach can provide a high level of accuracy. As such, the first step requires the calculation of the emission mass, by source, time period, and pollutant. These variables are calculated by using individual emission source information with their associated emission factors (expressed as grams per kilogram of fuel, grams per hour of operation or grams per kilowatt of power), and the respective operational parameters over a determined period of time. These two parameters are then used to calculate the total source-related emissions at the airport. The total source emissions can then be expressed in various forms such as an individual source or group of sources, by pollutant or by period of time (e.g. hour, day, week, month or year).

2.1.3 In order to develop an emissions inventory, the following steps are required:

- Define general inventory parameters such as the purpose, spatial and functional perimeter and frequency of updates;
- Determine emission species to be considered;
- Determine existing emission sources;
- Quantify the emissions from those sources;
- Consider macroscale issues (regional emission inventories) to the extent relevant; and

- Implement quality assurance and control measures (to characterize uncertainties and limitations of data).

2.2 Emission Inventory Parameters

2.2.1 The following factors should be considered when developing an emissions inventory:

Factors to Consider When Developing Emissions Inventory	
Inventory Purpose	The use and requirement of an emissions inventory largely determines its design. If the requirement is solely to calculate the total emission mass, then the methodologies utilized will be simple and straight forward. If the inventory is to be utilized as part of a dispersion model, the methodologies could be different and more detailed as dispersion modeling requires spatial and more detailed temporal information. The design of the emission inventory has to take this into account so as not to limit its future use.
System Perimeter	The system perimeter defines the spatial and the functional area within which emissions will be calculated. The spatial area could be the airport perimeter fence, a designated height (e.g. mixing height) and/or access roads leading to the airport. The functional area is typically defined by emission sources that are connected functionally to airport operations, but could be located outside the airport perimeter (e.g. fuel farms).
Updates	The frequency of inventory updates influences the design of the inventory and any applied databases or data tables (e.g. one annual value versus many values over the year determines the necessary temporal resolution). It is also important to evaluate the efforts needed and available to compile the inventory at a certain frequency.
Level of Accuracy/Complexity	The necessary accuracy level of data inputs is determined by the fidelity required for the analysis and the knowledge level of the analyst. This guidance is to be a framework for conducting analysis at various levels of complexity. Whenever possible, guidance is given for three different levels of complexity: Simple Approach Advanced Approach Sophisticated Approach.

2.2.2 As shown in the following section, an emissions inventory can be conducted at various levels of complexity, depending on the required fidelity of the results as well as the availability of the supporting knowledge, data and other resources. This guidance is to be a framework for conducting studies at various levels of complexity. Whenever possible, guidance is given for three different levels of complexity (e.g. Simple, Advanced and Sophisticated). When conducting an analysis, the applied approach should also be stated.

Approach	Simple	Advanced	Sophisticated
Complexity	Little knowledge required, necessary data easy and standardised available, straight forward methodology	Advanced knowledge, airport specific and/or access to additional data sources is required.	In depth knowledge, cooperation among various entities and/or access to proprietary data might be required.
Accuracy	Generally conservative	Good	Very high
Confidence	Low	Medium	High

2.2.3 Unless required otherwise for specific legal reasons or regulatory compliance, it is recommended to make use of the best available data for creating emission inventories whilst considering the level of accuracy and confidence required. This could evolve to using Advanced and/or Sophisticated Approaches rather than a Simple Approach. Approaches can also be combined by using one approach for one emission source and a different approach for another emission source in compiling the inventory. In addition, combinations of approaches could be used for the same emission source where various parameters are needed to calculate the emission mass.

2.3 Emission Species

2.3.1 There are a variety of air pollutants present as gaseous and particulate emissions from aviation-related activities that can potentially impact human health and the environment. However, not all of them are relevant or needed for emission inventories. State requirements should be consulted to determine which emission species are actually necessary to the inventory. Generally, the following common species could be considered as primary species in emission inventories:

- NO_x Nitrogen oxides, including nitrogen dioxide (NO_2) and nitrogen oxide (NO);
- VOC Volatile organic compounds (including non-methane hydrocarbons (NMHC));
- CO Carbon monoxide;
- PM Particulate matter (fraction size $PM_{2.5}$ and PM_{10}); and
- SO_x Sulphur oxides.

2.3.2 Carbon dioxide (CO_2) is sometimes included in inventories (using the total fuel burn as a basis for calculation). It has to be recognised that CO_2 is of a global rather than strictly local concern, but local CO_2 inventories can feed into global inventories where required.

2.3.3 Additional emission species of potential health and environmental concern may also need to be considered in emission inventories including so called hazardous air pollutants (HAPs). Low levels of HAPs are also present in aircraft and GSE exhaust in both the gaseous and particulate forms. HAPs research is at an early stage and it should to be noted that knowledge of emission factors is therefore very limited for many of these species. Therefore, the creation of an inventory of HAPs might not be possible or such an inventory cannot be expected to have the same level of fidelity as other, more common species. In such cases, the proper authorities would have to provide further guidance. Examples of HAPs that have been identified as being representative of airport sources of air emissions include (but are not necessarily limited to) the following:

- 1,3-Butadiene
- Acetaldehyde

- Acrolein
- Benzene
- Diesel Particulate Matter
- Formaldehyde
- Lead (this is relevant for leaded fuel, e.g. AVGAS, which is only used in a few small aircraft types)
- Naphthalene
- Propionaldehyde
- Toluene
- Xylene

2.4 Airport Related Emission Sources

2.4.1 A wide assortment and number of emission sources can be found at airports. However, depending on the specific activities at individual airports, not all types of emission sources are actually present (e.g. some are located off-airport). To better account for this variability, the emission sources have been grouped into four categories:

- Aircraft emissions;
- Aircraft handling emissions;
- Infrastructure or stationary related sources; and
- Vehicle traffic sources.

2.4.2 Categories of aircraft emission sources are typically comprised of the following[15]

Aircraft Main Engine	Main engines of aircraft within a specified operating perimeter (from start-up to shut-down).
Auxiliary Power Units	APU located on-board aircraft providing electricity and pre-conditioned air during ground times and bleed air for main engine start.

2.4.3 Aircraft handling emission sources are typically comprised of the following:

Ground Support Equipment	GSE necessary to handle the aircraft during the turnaround at the stand: ground power units, air climate units, aircraft tugs, conveyer belts, passenger stairs, fork lifts, tractors, cargo loaders, etc.
Airside Traffic	Service vehicle and machinery traffic (sweepers, trucks (catering, fuel, sewage) cars, vans, busses, etc), within the airport perimeter fence (usually restricted area) that circulate on service roads.

[15] There are potential emission source issues relevant to but not covered in the guidance that have been identified and are the subject of further investigation.

Aircraft Refuelling	Evaporation through aircraft fuel tanks (vents) and from fuel trucks or pipeline systems during fuelling operations.
Aircraft De-icing	Application of de-icing and anti-icing substances to aircraft during winter operations.

2.4.4 Stationary- or infrastructure- related source categories of emissions comprise the following:

Power/heat Generating Plant	Facilities that produce energy for the airport's infrastructure: Boiler house, heating/cooling plants, co-generators.
Emergency Power Generator	Diesel generators for emergency operations (e.g. for buildings or for runway lights).
Aircraft Maintenance	All activities and facilities for the maintenance of aircraft, i.e. washing, cleaning, paint shop, engine test beds.
Airport Maintenance	All activities for the maintenance of airport facilities (cleaning agents, building maintenance, repairs, greenland maintenance) and machinery (vehicle maintenance, paint shop).
Fuel	Storage, distribution and handling of fuel in fuel farm and vehicle fuel stations.
Construction Activities	All construction activities in airport operation and development.
Fire Training	Activities for fire training with different fuel (kerosene, butane, propane, wood).
Surface De-icing	Emissions of de-icing and anti-icing substances applied to aircraft moving areas and service and access roads.

2.4.5 Landside traffic emission sources are comprised of the following[16]:

Vehicle Traffic	Motor bikes, cars, vans, trucks, busses and motor coaches associated with the airport on access roads, curbsides, drive-ups, and on- or off-site parking lots (including engine turn-off, start-up and fuel tank evaporative emissions).

2.4.6 The mass of emissions from each of these source categories are considered (to the extent they are relevant to the study) and the totals are summed to provide the emission inventory for the entire airport.

2.5 Local and Regional Emissions

2.5.1 When creating airport emission inventories it is important to note that an airport is always part of a wider environment that goes beyond the perimeter fence and property line of the airfield. For certain purposes such as modelling of O_3 formation, emission inventories of a larger regional perimeter (e.g. an airshed) may be developed. The relevant governmental bodies (e.g. local, regional and/or national

[16] Landside sources may also include trains, which are not currently within the scope of this guidance.

authorities) would conduct these larger inventories; typically in cooperation with the airport. In particular, the system boundaries must be defined to avoid double-counting of emissions. Depending on the chosen assumptions (e.g. the considered sources and their spatial extent or area boundaries) the airport inventory itself might only contribute with a relatively small percentage to the overall area emission inventory. However, an inventory in and of itself does not necessarily give an indication of the full impact of an emission source. In some cases, dispersion modeling is used to better define the air quality impact.

2.6 Quality Assurance

2.6.1 Depending on the local situation, developing an emission inventory can be a complex exercise which might lead to some simplifications or limitations. In order to generally achieve reliable results, emission inventories should go through a quality control process during and after their development. As within the following discussion, this quality control includes, but is not limited to, the discussion of missing information, the use of assumptions, error estimations, transparency/traceability of data sources and methodologies, and validation of the results.

2.6.2 Missing Information: Due to the lack of availability of certain data (i.e. operational data and/or accurate emission factors), information or data might be missing. In these cases, estimations or assumptions should be made prior to omissions, as inventories or methodologies can be improved once data or information become available. It is generally more difficult to justify the addition of sources that have not been considered previously.

2.6.3 Error Estimations: For credibility reasons and for evaluating the accuracy of an inventory, error estimations are an important part in the development of the inventory. Available data and information usually have one of three levels of quality, as shown in the following:

Measured:	Data are actually measured with or without calibrated and verified tools and methods, counted or else assessed by other means directly associated with the data source. This can also include calculation of a measured value with a relationship factor (i.e. taking the actually measured fuel flow and using a CO_2 relationship factor of, for example, 3150 grams per kg fuel to determine CO_2 mass emissions from kerosene burning engines)..
Calculated:	Data are calculated using available algorithms and data not directly associated with the data source.
Estimated:	Data are estimated using reference information, experience from the past or qualified assumptions.

2.6.4 For each level of data quality, an error bar (value +/- absolute deviation) or percentage (value +/- percent) can be pre-defined and a total error can be calculated. If applied for all sources, it can easily be determined where it is appropriate to improve data quality or where higher levels of uncertainty can be accepted without significant detriment to the overall result.

2.6.5 Transparency and Traceability: In order to enable an effective quality control and the potential duplication of emission inventory calculations with improved data, the applied calculation methodology needs to be outlined and properly documented. Sources of information and emission factors used in inventories must be identified and referenced. When an identified ideal data source might not be a viable option, then other (e.g. next best) data sources need to be specified.

2.6.6 Validation: The final results should be validated and crosschecked by a proper quality control system. This can include comparison with reference data of similar systems or recalculation of specific emission inventory elements with different tools.

2.7 Forecasting

2.7.1 Whilst conducting air quality analysis for the past and present conditions, analysts may also wish to consider the contribution of future airport emission sources. In preparing an airport emission inventory representing future scenarios (e.g. 5, 10, or 25 years into the future), a methodology should be employed that addresses all airport elements, including aircraft operations and movements, passenger and cargo handling, airport infrastructure needs, and surface vehicle traffic volumes. Forecasting methodologies can become very complex undertakings and often require many assumptions and/or advanced knowledge of the airport and its environs, of market behaviours, airline equipment usages, and regulatory enactments. The description of detailed forecasting methodologies is generally beyond the scope of this emissions inventory guidance.

Chapter 2
EMISSIONS INVENTORY
Annex 1
AIRCRAFT EMISSIONS

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A1.1 Introduction

A1.1.1 Aircraft main engines may, at times, receive the most amount of attention from those parties concerned with aviation emissions as they can be the dominant airport-related source. This chapter recommends methodologies for the estimation of aircraft engine emissions. Main engines are those used and propel the aircraft forward. Other on-board engines include APU that provide electrical power and pneumatic bleed air when the aircraft is taxiing or parked at the gate and no alternative is available. Fuel venting from aircraft fuel tanks is not allowed and therefore is not addressed as an emission source.

A1.1.2 Main engines are generally classified as either gas turbine turbofan (sometimes referred to as turbojet) and turboprop engines fuelled with aviation kerosene (also referred to as jet fuel) and internal combustion piston engines fuelled with aviation gasoline.

A1.1.3 Operational Flight Cycle Description

A1.1.4 The departure and arrival phases of an actual operational flight cycle for a commercial aircraft are more complex than the four modal phases (i.e. approach, taxi/idle, takeoff, and climb) typically used for ICAO certification purposes. Actual cycles employ various aircraft engine thrust settings, and the times at those settings are affected by factors such as aircraft type, airport and runway layout characteristics, and local meteorological conditions. However, there are a number of segments that are common to virtually all operational flight cycles. These are depicted in the following diagram (Figure A1-1) and described in the subsequent sections:

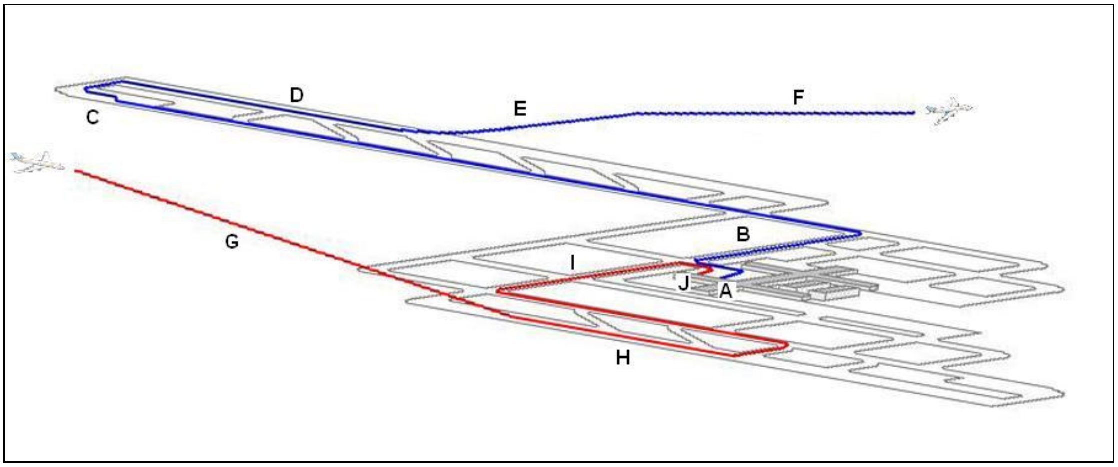

Figure A1-1 Operational Flight Cycle

A1.1.5 Departure

A. Engine start – It is normal to start the main engines prior to, or during, pushback from the aircraft gate/stand. Where aircraft do not require pushback, the main engines are started immediately prior to taxi.

B. Taxi to runway – Aircraft typically taxi out on all engines to the runway or holding area prior to entering the runway; though aircraft may taxi on fewer than all engines under some circumstances. Taxi-out is normally carried out at the idle/taxi power setting apart from brief bursts of power to overcome the initial inertia at the start of taxiing; or if necessary, to negotiate sharp turns.

C. Holding on ground – Where necessary, aircraft may be required to hold in a queue whilst awaiting clearance to enter the runway and taxi to the take-off position. Main engines are normally set to idle thrust with brief bursts of power to move into position.

D. Take-off roll to lift-off – The aircraft is accelerated along the runway to the predetermined rotation speed and the end of the take-off, with the main engines set to take-off power. Operators rarely use full power for takeoff; rather, a pre-determined thrust setting is set at the beginning of the take-off roll. Operators use either de-rated take-off thrusts or, more often, reduced (e.g. flexible) thrust settings, which are determined by the aircraft actual take-off weight, runway length and prevailing meteorological factors. Take-off can also be a staged throttle setting whereby the throttles are initially advanced to an intermediate position then a few seconds later to the take-off power setting.

E. Initial climb to power cutback – After leaving the ground, the undercarriage (i.e. wheels) of the aircraft is raised and the aircraft climbs at constant speed with the initial take-off power setting until the aircraft reaches the power cutback height (i.e. between 800 and 1,500 feet agl) and the throttles are retarded.

F. Acceleration, clean-up and en-route climb – After the throttle cutback, the aircraft continues to climb at a thrust setting less than that used for take-off with flap/slat retraction following as the aircraft accelerates and reaches cruising altitude.

A1.1.6 Arrival

G. Final approach and flap extension – The stabilized final approach from the Final Approach Fix (FAF) follows a relatively predictable glide slope at low engine thrusts. Thrust settings increase as flaps and the undercarriage are lowered, whilst speed decreases towards the flare.

H. Flare, touchdown and landing roll – Throttles are normally retarded to idle during the flare and landing roll. This is followed by application of wheel brakes and (where appropriate) reverse thrust to slow down the aircraft on the runway.

I. Taxi from runway to parking stand/gate – Taxi-in from the runway is a similar process to taxi-out to the runway described above; however, operators may shut down one or more engines, as appropriate, during the taxi if the opportunity arises.

J. Engine shutdown – Remaining engines are shut down after the aircraft has stopped taxiing and power is available for onboard aircraft services.

A1.1.7 APU operation, for aircraft equipped with this equipment, is usually confined to periods when the aircraft is taxiing or stationary at the terminal. The APU is typically shut down just after main engine start-up and after landing, the APU is generally started when the aircraft is approaching the terminal area parking position. If one or more main engines are shut down during the taxi, it may also be necessary to start the APU during the taxi-in. A number of airports specify maximum APU running times, principally to limit noise in the terminal area.

A1.1.8 As contained within the following discussion, aircraft activity at an airport is quantified in terms of either LTO cycles or operations. An operation represents either a landing or a takeoff, and two operations can equal one LTO cycle (e.g. taxi in, a landing, taxi out, and takeoff).

A1.1.9 Emissions Certification LTO Cycle

A1.1.10 For emissions certification purposes, ICAO has defined a specific reference LTO cycle below a height of 915 meters (3,000 feet) agl, in conjunction with its internationally agreed certification test, measurement procedures and limits.

A1.1.11 This cycle consists of only four modal phases chosen to represent approach, taxi/idle, take-off and climb and is a much simplified version of the operational flight cycle. An example of its simplification is that it assumes that operation at take-off power abruptly changes to climb power at the end of the take-off roll and that this is maintained unchanged up to 3,000 feet. Whilst not capturing the detail and variations that occur in actual operations, the emissions certification LTO cycle was designed as a reference cycle for the purpose of technology comparison and repeatedly has been reaffirmed as adequate and appropriate for this purpose.

Operating phase	Time-in-mode (minutes)	Thrust setting (percentage of rated thrust)
Approach	4.0	30
Taxi and ground idle (in)	7.0	7
Taxi and ground idle (out)	19.0	7
Take-off	0.7	100
Climb	2.2	85

A1.1.12 This reference emissions LTO cycle is intended to address aircraft operations below the atmospheric mixing height or inversion layer. Whilst the actual mixing height can vary from location to location, on average it extends to a height of approximately 915 meters (3,000 feet), the height used in deriving airborne times-in-mode. Pollutants emitted below the mixing height can potentially have an affect on local air quality concentrations, with those emitted closer to the ground having possibly greater effects on ground level concentrations.[17]

A1.1.13 The certification LTO cycle characteristics selected were derived from surveys in the 1970s. They reflected peak traffic operations (i.e. typical adverse conditions), rather than average LTO operations. The justification for using these for aircraft emission standards was largely based on protecting air quality in and around large metropolitan air terminals during high operational or adverse meteorological conditions.

A1.1.14 It was recognized that even for aircraft of the same type there were large variations in actual operating times and power settings between different international airports, and even at a single airport there could be significant variations day-to-day or throughout a single day. However the use of a fixed LTO cycle provided a constant frame of reference from which differences in engine emissions performance could be compared.

A1.1.15 Thus, the reference emissions LTO cycle is of necessity an artificial model that is subject to many discrepancies when compared to real world conditions at different airports. It was designed as a reference cycle for technology comparison purposes for certification compliance.

A1.1.16 This LTO cycle was, and still is, acceptable for certification purposes. It may also be adequate for simple emissions inventory calculations. However, in light of its generic assumptions, use of this cycle typically would not reflect actual emissions. Thus, if more precise data on operations are available, these data should be used instead.

A1.1.17 As stated elsewhere in the guidance, ICAO aircraft engine emissions standards cover emissions of CO, HC, NO_x and smoke. They apply only to subsonic and supersonic aircraft turbojet and turbofan engines of thrust rating greater than or equal to 26.7 kN [*Annex 16 Volume II – Aircraft Engine Emissions*]. ICAO excluded small turbofan and turbojet engines (thrust rating less than 26.7 kN), turboprop, piston and turboshaft engines, APU and general aviation aircraft engines from ICAO standards on the grounds of the very large number of models, the uneconomic cost of compliance and small fuel usage compared to commercial jet aircraft.

A1.1.18 Emissions Certification Data

A1.1.19 Emissions certification testing is carried out on uninstalled engines in an instrumented and calibrated static test facility. Engine emissions and performance measurements are made at a large number of power settings (typically greater than ten) covering the whole range from idle to full power and not just at the prescribed four ICAO LTO modes. The measured data are corrected to reference engine performance conditions and reference atmospheric conditions of ISA at sea level and humidity of 0.00634 kg water/kg of air, using well established procedures (See *ICAO Annex 16, Volume II* for additional information).

A1.1.20 The ICAO engine emissions certification data for CO, HC, and NO_x, together with associated fuel flow rates, are reported at a set of four reference power settings defined as “take-off”, “climb”, “approach”, and “taxi/ground idle”, respectively and for prescribed times at each of these power settings

[17] ICAO recognizes that different States may have different standards or thresholds for designating whether a pollutant as emitted has a local effect. In many cases, this is expressed in terms of a maximum altitude up to which a particular pollutant is emitted. Some States may specify a specific altitude for such purposes. Others may direct that modeling be undertaken to identify the altitude at which pollutants may have local effect in a particular area. This is often referred to as the “mixing height” within the atmospheric “boundary layer.” In basic terms, the “mixing height” is the height of the vertical mixing of the lower troposphere. Also in basic terms, the “boundary layer” is that part of the troposphere that is directly influenced by the presence of the earth's surface. States that specify a mixing height is determined for purposes of local air quality assessment typically have accepted models for such analyses and/or specify a default height for the mixing height, such as 3,000 feet.

(i.e. “times-in-mode”). However, smoke emissions are only required to be reported as a maximum value of SN for each engine, irrespective of the power setting (although for some certified engines, mode-specific smoke numbers have been reported).

A1.1.21 The emissions certification values previously described are provided in the ICAO *Engine Emissions Databank*, both as individual engine datasheets and also as a spreadsheet containing the data for all certified engines for which manufacturers have made data available. This databank is publicly available on the worldwide web at www.caa.co.uk/srg/environmental and is periodically updated. An example of an *Engine Emissions Datasheet* is presented in Appendix A.

A1.2 Main Engine Emissions in the Vicinity of Airports

A1.2.1 Emissions from an individual aircraft-engine combination are primarily a function of three parameters: TIM, main engine emission indices (EI), and main engine fuel flows. Aggregate emissions from a fleet serving an airport also include two additional parameters; fleet size/type and number of operations. In the calculation of aircraft emissions at a given airport, the desired accuracy of the emissions inventory will dictate the values and methodology (e.g. Simple, Advanced, or Sophisticated approach) used for determining each of these parameters. The following information provides basic descriptions of each of these parameters:

A1.2.2 Aircraft fleet is a generic description to describe the various aircraft and engine combinations that serve an airport. In its simplest form, the aircraft fleet can be generally characterised according to descriptors such as, for example, heavy, large, small, turboprop, and piston. For aircraft emissions inventory purposes, however, it is typically necessary to identify fleets more accurately (for example, by aircraft type).

A1.2.3 Aircraft can be generically labelled according to manufacturer and model. For example, “A320” is an Airbus model 320 or a “B737” represents the Boeing 737, though it should be noted that a generic aircraft type may contain significant variations in engine technology and widely differing emissions characteristics between different types and their engine fits.

A1.2.4 A more descriptive labelling for an aircraft type would also include the series number for each model, such as B747-400 for a 400 series Boeing 747 aircraft. This helps to establish the size and technology used in the aircraft engine and is necessary for a more accurate emissions inventory.

A1.2.5 Finally, the most accurate representation of aircraft is to identify the aircraft model, and series along with the actual engines fitted on the aircraft and modifications that affect its emissions performance (e.g. B777-200IGW with GE90-85B engines with DAC II combustors). As the aircraft itself does not produce emissions, having detailed information on engines installed on the aircraft fleet is an essential component of an accurate emissions inventory.

A1.2.6 Time-in-mode (TIM) is the time period, usually measured in minutes, that the aircraft engines actually spends at an identified power setting; typically pertaining to one of the LTO operating modes of the operational flight cycle.

A1.2.7 Emission Index (EI) and Fuel Flow: An emission index is defined as the mass of pollutant emitted per unit mass of fuel burned for a specified engine. The ICAO *Engine Emissions Databank* provides the EI for certified engines in units of grams of pollutant per kilogram of fuel (g/kg) for NO_x, CO, and HC, as well as the mode-specific fuel flow in units of kilogram per second (kg/s), for the four power settings of the engine emissions certification scheme. Multiplying the mode-specific EI TIM-specific fuel flow yields a mode-specific emission rate in units of grams per LTO. For more accurate inventories, adjustments are necessary to these values to take account of, for instance, different power settings, installation effects, etc.

A1.2.8 Operations are the sum of the LTO (two aircraft movements) for each aircraft/engine combination over the period of interest; typically, though not necessarily a calendar year.

A1.3 Emissions Calculation Approaches

There are various approaches, or methodologies, to quantify aircraft emissions – each with a degree of accuracy and an inverse degree of uncertainty. The purpose and need for quantifying aircraft emissions drive the level of accuracy needed in an inventory, which in turn, determines the appropriate approach. A secondary factor is data availability. Although an analysis may warrant a high degree of accuracy, it may not be possible for certain elements of the analysis due to lack of available data.

A1.3.1 This section currently covers three approaches to quantifying aircraft engine emissions: two in detail and one in overview.

1. Simple Approach is the least complicated approach, requires the minimum amount of data, and provides the highest level of uncertainty often resulting in an over estimate of aircraft emissions; and
2. Advanced Approach reflects an increased level of refinement regarding aircraft types, EI calculations and TIM.
3. Sophisticated Approach is provided in overview, will be further developed in an update of this guidance (e.g. CAEP/8) and is expected to best reflect actual aircraft emissions. However, in many instances, this approach requires the use of propriety data or models that are not normally available in the public domain.

A1.3.2 The alternate methodologies afford a progressively higher degree of accuracy and an inverse degree of uncertainty. The purpose and need for quantifying aircraft emissions drive the level of accuracy needed in an inventory, which in turn, determines the appropriate methodology. A secondary factor is data availability. Although an analysis may warrant a high degree of accuracy, it may not be possible for certain elements of the analysis due to lack of available data.

A1.3.3 It is also important to note that, although at its simplest level it may be possible for individuals to construct an emissions inventory, the advanced and sophisticated methods likely necessitate some form of collaboration with other aviation resources. For example, the identity of actual aircraft and engine types, realistic and accurate times in mode, and actual engine power settings used in the analysis requires data that is often difficult to obtain. In general, the more sophisticated the method, the greater the level of collaboration will be required.

A1.3.4 ICAO stresses the importance for airports and States to use the best data available when assembling an aircraft engine emissions inventory. The ICAO emission inventory methodologies increase in accuracy moving from the Simple to the Advanced and eventually to the Sophisticated Approach. ICAO recommends selecting an approach, or portions thereof, to reflect the desired, or required, fidelity of the results. The air quality practitioner can reference these approaches as ICAO Simple Approach, Advanced Approach, or Sophisticated Approach. It should also be noted that the methods can be combined and that just because a Simple Approach is used for one part of an inventory, that this does not preclude the use of more precise other approaches being employed for the remaining parts of the emissions inventory.

A1.3.5 As a prelude to the details involved in each approach, ICAO wishes to establish the general concept within each method. In summary, the inventory starts with an individual aircraft/engine combination(s), and generally applies the operational and emission parameters in a two-step process, as follows:

Step One: Calculate emissions from a single aircraft/engine combination by summing the emissions from all the operating modes which constitutes an LTO cycle, where emissions from a single mode are expressed as:

Modal emissions for an aircraft/engine combination = TIM x fuel used (at the appropriate power) x EI (at the appropriate power) x number of engines

The emissions for the single LTO operational flight cycle are then a summation of the individual parts of the cycle. In more sophisticated methods, EI and fuel flows may not be constant throughout the time in mode.

Step Two: Calculate total emissions by summing over the entire range of aircraft/engine combinations and number of LTO cycles for the period required.

A1.3.6 The following table provides an overview of the calculation approaches. It lists each of the four primary parameters (e.g. fleet mix, TIM, EI, and movements) along with other contributing factors. Also included are explanations of how each of these parameters are determined using the three approaches (e.g. Simple, Advanced, and Sophisticated).

Aircraft Main Engine Emissions Inventory Methodology Factors			
Key Parameters	**Simple Approach**	**Advanced Approach**	**Sophisticated Approach**
Fleet (aircraft/engines combinations)	Identification of aircraft types	Identification of aircraft and Corresponding engine types	Actual fleet composition in terms of aircraft types and engine combinations
Time in Mode	N/A (indirectly accounted for via United Nations Framework Convention for Climate Change (UNFCC) LTO Emission Factors)	ICAO Databank Certification Values, adjusted if possible to reflect airport-specific information	Refined values (e.g. with consideration of performance)
Emission Indices and Fuel Flow	UNFCC LTO Emission Factors by Aircraft Type	ICAO Databank Certification Values	Refined values using actual performance and operational data
Movements	Number of aircraft movements by aircraft type	Number of aircraft movements by aircraft-engine combination	Number of actual aircraft movements by aircraft-engine combination

A1.3.7 Simple Approach

A1.3.8 This is the most basic approach for estimating aircraft engine emissions provided in the guidance. The only airport-specific data required are the number of aircraft movements (over a certain period such as a year) and the type of each aircraft involved in each movement.

A1.3.9 This Simplified Approach should only be used as means of conducting an initial assessment of the aircraft engine emissions at an airport. For most pollutant species, the approach is generally conservative, meaning that the outcome will often overestimate the total level of aircraft engine emissions. However, for some emission species and less common aircraft, the resultant emissions may be underestimated. As such, it is unclear how accurately the Simple Approach accounts for actual aircraft engine emissions at a given airport.

A1.3.10 ICAO urges that if an emissions inventory involves policies that will affect aircraft operations at a particular airport, then the calculations should be based on the best data available, and the simple approach should not normally be used. Where further information on the aircraft operations at an airport is available, then a more advanced approach is more appropriate.

A1.3.11 As previously described, there are usually four parameters used for the calculation of aircraft emissions. The Simple Approach utilizes only three of these: fleet mix, emissions index, and operations. The method does not require TIM, thrust or fuel flow data as all these assumptions have already has been incorporated into the EI. It is also important to note that this approach does not utilize engine-specific emissions data but uses the most common type of engine in operation internationally for that aircraft type.

A1.3.12 Aircraft Fleet

A1.3.13 For the Simple Approach, the two primary elements of the aircraft fleet (e.g. aircraft and engine types) have been simplified in a list of the types of aircraft for which pre-calculated emission data is provided. For each aircraft, the engine type has been assumed to be the most common type of engine in operation internationally for that aircraft type[18], and emissions from that engine type are reflected in the associated emission factors. Appendix B contains Table B-1 which lists 52 aircraft and provides emission data for each of their engine types.[19]

A1.3.14 If the fleet servicing an airport includes aircraft that are not contained in Table B-1, then Table B-3 should be used to determine an appropriate generic aircraft. (Refer to the column headed "IATA aircraft in group" to locate the aircraft type shown in the column headed "Generic Aircraft Type".)

A1.3.15 If an aircraft is not contained in either Table B-1 or B-3, then it is recommended to use supplementary information such as weight, number of engines, size category, range, etc. to identify a suitable equivalent aircraft that is in Table B-1 or B-3, recognising that this will introduce additional assumptions that may affect the accuracy of any result. In the case of an airport primarily served by regional jets, business jets and/or turboprops, it is unlikely that the range of aircraft will yield a reliable result. In these cases, a more advanced method is recommended.

A1.3.16 Emissions Indices

A1.3.17 In the Simple Approach, the EI is replaced with an emissions factor and Table B-1 in Appendix B provides these emissions factors for five pollutant species for each of the listed aircraft.

A1.3.18 The emissions factor is provided in terms of kg of each emission species per LTO cycle per aircraft. These have been calculated based on the representative engine type for each generic aircraft type and using ICAO TIM, thrust settings and other basic assumptions. Other assumptions are described in the notes in Table B-1 in Appendix B.

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[18] As of 30 July 2004 emissions data for the B747-300 is based on proportioned emissions for the two most common engine types.

[19] CAEP developed this data at the request of the UNFCCC in connection with UNFCCC guidelines for national greenhouse gas inventories, which are used for global emissions issues rather than local air quality. It therefore includes data for greenhouse gas emissions that are not relevant to local air quality. These may be disregarded for purposes of inventories assembled for local air quality assessments (though some locations may wish to inventory CO_2 emissions for other purposes). The data included in this document was current at the time of writing. The UNFCCC will provide updates to this table on an on-going basis and the most current table should be used whenever possible [www.ipcc-nggip.igs.or.jp]. If using new data from the UNFCCC website, CH4 and NMVOC data will require summing in order to obtain a value for HC. Since the UNFCCC's main focus was on greenhouse gas emissions over the entire course of flight, the data for LTO emissions is based on ICAO certification standards, and therefore will not accurately reflect actual emissions in an operating setting. In most cases, use of the refinements discussed in the Advanced and Sophisticated Approaches will help to achieve a more accurate inventory for the relevant pollutants.

A1.3.19 Aircraft Movements

A1.3.20 For the Simple Approach, it is necessary to know (or to have an estimate of) the number of aircraft movements or operations (e.g. LTO) and type of aircraft at an airport over a specified period (e.g. hour, day, month, or year).

A1.3.21 Most airports levy user charges for provision of facilities and services typically collected as a landing fee. In these cases airport operators have accurate records of landing movements; including the number of landings and the type of aircraft. Some airports also record the number of take-offs, although the landing records usually provide more reliable data. For this reason, at larger airports, published data on the annual aircraft movements is often available.

A1.3.22 An LTO cycle contains one landing and one take-off, and so the number of landings and takeoffs at an airport should be equal. The total number of either landings or takeoffs may be treated as the number of LTO. Any difference in the number of landings and the number of take-offs will usually indicate an error in the records; if there is no explanation for this discrepancy, then the greater number should be used.

A1.3.23 If no data is available, it will be necessary to conduct a survey of the number of aircraft movements and the types of aircraft over a short- or medium-term period (e.g. one to six months), noting that there are normally seasonal differences in the number of movements at most airports.

A1.3.24 Emissions Calculation

A1.3.25 For NO_x, HC, CO, SO_2 and CO_2 there is a standard method for calculating aircraft engine emissions using the Simple Approach. For each aircraft type, multiply the number of LTO cycles of that aircraft (over the assessment period) by the emissions factor in Table B-1 for each of the pollutant species and then add up the values for all the aircraft to get the amount of total emissions (in kg) for each pollutant. See the following generic equation:

$$\underset{\text{(in kg)}}{\text{Emission of Species X}} = \sum_{\text{All Aircraft}} \left(\underset{\text{of Aircraft Y}}{[\text{Number of LTO cycles})} \times \underset{\text{for Species X}}{(\text{Emissions Factor})} \right) \qquad \text{Eq. A1-1}$$

A1.3.26 Notably, this equation does not account for specific engine types, operational modes or TIM as it assumes that the conditions under study are the same or similar to the default data being used.

A1.3.27 If required for the inventory, a similar process is used for fuel consumption over the period under consideration using fuel consumption data in Table B-1:

$$\underset{\text{(in kg)}}{\text{Fuel consumption}} = \sum_{\text{All Aircraft}} \underset{\text{of Aircraft Y}}{[\text{Number of LTO cycles}]} \times [\text{Fuel Consumption}] \qquad \text{Eq A1-2}$$

A1.3.28 There is no provision for the calculation of PM emissions in the Simple Approach.

A1.3.29 Advanced Approach

A1.3.30 The Advanced Approach represents a more accurate estimation of aircraft engine emissions compared to the Simple Approach because it attempts to account for the specific engine model on the aircraft under study. Further, because each mode of the LTO cycle (see Annex A1.1.9) will be calculated individually, the practitioner has the option to add aircraft-specific operating times for the taxi/idle mode according to the unique taxi-way characteristics linking the terminal area with the runway ends. As stated above, these improvements result in a more accurate reflection of main engine emissions over the Simple

Approach, yet the total emissions are still considered conservative, given the reliance on certification data to represent LTO emissions (see discussion in Annex A1.1.9 through A1.1.17).

A1.3.31 Aircraft Fleet

A1.3.32 Like the Simple Approach, the first step of the Advanced Approach is to quantify the aircraft operations or LTO by aircraft type and specific to the airport. Typically, this information can be obtained directly from airport records, thereby reflecting the most accurate form of this information (see Annex A1.3.12). However, because no database is entirely accurate and changes due to aircraft engine fits, temporary intermixes, and other considerations over time can introduce inaccuracy, it is important to gather as much information as close to the source of the operation as is possible. If access to this information is not possible, then national traffic statistics can be accessed if available. Another source of data is from air navigation service providers such as EUROCONTROL or the U.S. FAA.

A1.3.33 The Advanced Approach then tries to match the various aircraft types operating at the study airport with the engines that are fitted to them. Airports typically have lists with aircraft type/engine combinations obtained from the carriers that service the airport. However, if this information is unavailable, States have access to several publicly available databases that enable the matching of aircraft types with specific engines. Annex A1.3.34 through A1.3.37 describes these important databases that can assist practitioners in identifying the aircraft/engine combinations that characterize fleet mix at a particular the airport.

A1.3.34 Other sources of information include the International Official Airline Guide (IOAG) Database which contains data that identifies the type of aircraft, carrier, and frequency of scheduled flights. In addition, the IOAG lists scheduled passenger flights by participating airlines, which are updated on a monthly basis. IOAG provides the main components in determining the fleet mix at a specific airport such as airport, aircraft type, carrier, and frequency of aircraft arrivals and departures. However, the IOAG does not include unscheduled and charter flights, or general aviation flights including business jets. The IOAG covers the flights of all U.S. scheduled airlines and the majority of scheduled worldwide airlines. Specifically, Appendix C provides a description of the useful fields contained in the IOAG database. The most important IOAG airport-specific parameters are the flight number, aircraft type, carrier, and schedule when determining the number of operations at a specific airport.

A1.3.35 BACK's World Fleet Registration Database (BACK) contains additional airline fleet information such as all worldwide commercial aircraft currently in use and other various aircraft parameters (see Appendix C for a list of useful fields). For emissions inventory purposes, the most important parameters from the BACK database (or other similar databases) are the aircraft identifiers, tail number, engine model, number of engines, and aircraft type.

A1.3.36 Bucher & Company's JP Airline-Fleets International Database (JPFleets) is another publicly-available database that provides aircraft type/engine combinations for major commercial airlines worldwide.

A1.3.37 Airline Service Quality Performance (ASQP) Database is available from the U.S. Department of Transportation's (U.S. DOT) Bureau of Transportation Statistics (BTS). This database consists of performance and flight data for approximately 20 of the largest U.S. carriers. Appendix C lists the useful fields in the ASQP database. The practitioner should note the ASQP database provides good coverage for the fleet flying in the U.S. and their associated markets abroad.

A1.3.38 Depending upon the reasons for assembling an emissions inventory, a different method of assigning engines to aircraft can be used. One approach is to identify the specific engines used for the aircraft operations. This is achieved by collecting aircraft type information, scheduled flight numbers, and arrival/departure data for a specific airport (e.g. using IOAG), then finding the specific engine types assigned to the identified aircraft using the available databases described above. If this degree of accuracy is not necessary, then an alternative approach can be used to estimate the engine.

A1.3.39 This alternative is based upon the popularity of engines within the worldwide fleet. If the data available does not allow the identification of specific aircraft-engine combinations at a particular airport, these might be estimated. One way of doing this is to extrapolate the information on aircraft-engine combinations from a larger fleet database, such as a worldwide fleet database. For example, if the reference database shows that X percent of the B777 in the worldwide fleet have Y engines, and then it might be assumed for purposes of an airport inventory that X percent of the B777 that operate into that airport have Y engines. States should be aware that a single aircraft type may be fitted with more than one type or subtype of engine, which in turn can have differing emissions characteristics, in an airline's worldwide inventory. For these cases, databases such as BACK, JPFleets, and others can be used to develop distributions of engines based on reported airline and aircraft categories.

A1.3.40 It should be remembered that no database is entirely accurate, and changes due to aircraft engine fits, temporary intermixes, cross-referencing between databases, and other considerations over time can introduce even greater levels of inaccuracy. It is therefore important to gather as much information as close to the source of the operation as is possible in order to minimise uncertainties.

A1.3.41 Aircraft Time-in-mode

A1.3.42 As discussed previously, the reference TIM used as part of the ICAO engine emissions certification process (and contained in the ICAO *Aircraft Engine Emissions Databank*) are only appropriate for the engine certification process, and are not representative of actual TIM aircraft spend in real world operations (see Annex A1.1.9 through A1.1.17). Nonetheless, the ICAO default TIM can provide a conservative estimate of aircraft emissions at an airport when airport-specific taxi/ground idle TIM data or refined methods of estimating takeoff, climb, and approach times are not available. Sensitivity analyses conducted by CAEP determined that conducting an aircraft emissions inventory using the ICAO certification TIM (as well as the fuel flow and EI) normally yields an overestimation of total aircraft emissions across the entire LTO cycle.

A1.3.43 Airports are encouraged to take measurements of the typical taxi times unique to the taxiway structure for both taxi-in from runway to the terminal and vice versa for taxi-out times, including possible queuing times at departure runways. Using the measured taxi time values for the study airport can be better reflect emissions for the taxi/idle mode of the LTO cycle.

A1.3.44 Emissions Indices and Fuel Flow

A1.3.45 Aircraft engines with rated power greater than 26.7 kN are emissions-certified by ICAO for emissions of NO_x, CO, and HC and maximum SN, based upon the standardised LTO cycle as set out in *ICAO Annex 16, Volume II* and published originally in Document 9646-AN/943 (1995) and website amendments. ICAO provides the emissions certification data on the worldwide web at www.caa.co.uk. Updates to the Aircraft Engine Emissions Databank are made as new engines are certified. An example of the ICAO Engine Emissions Databank can be found in Appendix A.

A1.3.46 When ICAO engine data are used to calculate aircraft emissions, it is important to select the pollutant measured average value and not the pollutant characteristic level, which also is reported in the ICAO databank. The characteristic level of a gaseous pollutant or smoke is derived for certification purposes and contains statistical coefficients corresponding to the number of engines tested.

A1.3.47 For the vast majority of commercial aircraft engines operated at major airports, fuel flow and EI values are reported in the *ICAO Aircraft Engine Emissions Databank*, at the four certification thrust settings. Aircraft engine EI are reported in grams of pollutant per kilogram of fuel consumed (g/kg) and the fuel flow rates for each mode are reported in kilograms per second (kg/s). The reported EI and fuel flow values are recommended by ICAO to be used to calculate emissions from main aircraft engines.

A1.3.48 There are other databases available that address EI and fuel flow information for aircraft engines that are not certified nor regulated by ICAO. The following are two of the primary non-ICAO databases.

A1.3.49 The *Swedish Defence Research Agency* (FOI) is the keeper of a database of EI for turboprop engines supplied by the manufacturers for the purposes of developing emissions inventories. Although the database is publicly available only through FOI, *International Coordinating Council of Aerospace Industries Associations* (ICCAIA) closely monitors who requests the use of the database to ensure the data is not misused. The FOI database is not endorsed by ICAO because the data are not certified and may have inaccuracies resulting primarily from the unregulated test methodologies. There is also a significant issue of an appropriate idle setting for turboprops. Therefore, whilst this data is not ICAO-certified aircraft engine emission data, this information is included in this guidance document recognizing that the FOI turboprop database may assist airports in conducting emission inventories. Currently, documentation of how the EI were derived and the types of turboprop engines is unavailable. Information about turboprop engines, suggested TIM and how to obtain the data from FOI can be found at www.foi.se/FOI/templates/Page 4618.aspx.

A1.3.50 *Switzerland's Federal Office of Civil Aviation* (FOCA) has developed a methodology and a measurement system to obtain emissions data from piston-powered aircraft. For these engine types, there is no requirement for emissions certification; hence the FOCA data is one of the few sources of data available for conducting emission inventories with respect to aircraft with these engines. However, the FOCA data has not been corroborated by ICAO, and is not endorsed by ICAO. Therefore, whilst this data is not ICAO-certified aircraft engine emission data, this information is included in this guidance document recognizing that FOCA data may assist airports in conducting emission inventories for certain aircraft for which they otherwise might not have any data sources. The reader is referred to FOCA website to obtain documentation of the emissions measurement system, the consistent measurement methodology, recommendations for the use of their data to conduct simple emission inventories using suggested TIM. All material is openly available for download at

www.aviation.admin.ch/fachleute/lufttechnik/entwicklung/00653/00764/index.html?lang=en .

A1.3.51 Emissions Calculation Methodology for NO_x, CO, and HC

A1.3.52 Identification of the aircraft type will enable the determination of the number of engines and the appropriate engine models. In turn, the engine model will determine the proper EI to calculate aircraft emissions.

A1.3.53 To determine the NO_x, CO, or HC emissions for a unique aircraft/engine combination, the following formula may be used. This method is repeated for each aircraft/engine type representing each TIM to establish a complete aircraft emissions inventory.

$$E_{ij} = \sum (TIM_{jk} * 60) * (FF_{jk}/1000) * (EI_{jk}) * (NE_j) \qquad \text{Eq A1-3}$$

where:

- E_{ij} = Total emissions of pollutant *i* (e.g. NO_x, CO, or HC), in grams, produced by aircraft type *j* for one LTO cycle
- EI_{jk} = The emission index for pollutant *i* (e.g. NO_x, CO, or HC), in grams per pollutant per kilogram of fuel (g/kg of fuel), in mode *k* (e.g. takeoff, climb out, idle and approach) for each engine used on aircraft type *j*

FF_{jk} = Fuel flow for mode *k* (e.g. takeoff, climb out, idle and approach), in kilograms per second (kg/s), for each engine used on aircraft type *j*

TIM_{jk} = Time-in-mode for mode *k* (e.g. idle, approach, climb out, and takeoff), in minutes, for aircraft type *j*

NE_j = Number of engines used on aircraft type *j*

A1.3.54 If the actual measured TIM for one or more of the operating modes exists and is used, then the different flight phases have to be calculated separately and the total emissions for each species have to be summed to give the total emissions for each aircraft/engine type.

A1.3.55 ICAO does not have emissions certification standards for SO_x. However, SO_x emissions are a function of the quantity of sulphur in the fuel. The U.S. EPA conducted a survey of sulphur content for commercial aviation jet fuel, which resulted in a U.S. average of 1 gram per 1,000 grams of fuel consumed (EI_{SOx} = 1 g/kg of fuel). This average should not be relied upon where validated data is needed, but can be used to perform an emissions inventory of SO_x emissions using the following equation:

$$E_k = \sum (TIM_k * 60) * (ER_k) * (NE_k) \qquad \text{Eq A1-4}$$

where:

E_k = Total emissions of SO_x, in grams, produced by aircraft type k for one LTO cycle

NE_k = Number of engines used on aircraft type *k*

$ER_k = 1 * (FF_k)$

where:

ER_k = emission rate of total SO_x in units of grams of SO_x emitted per second per operational mode for aircraft k

FF_k = the reported fuel flow by mode in kilograms per second (kg/s) per operational mode for each engin used on the aircraft type k.

A1.3.56 ICAO does not have emissions certification standards for PM emissions. However, CAEP has developed and approved the use of an interim First Order Approximation (FOA) method to estimate total PM emissions from certified aircraft engines. At the time of this document, FOA version 3 is the most up-to-date and is provided in Appendix D of this section. FOA3 provides expressions of volatile PM from fuel organics and sulphur content, as well as a relationship between SN and non-volatile PM mass. CAEP is committed to continually updating the interim FOA methodology as data and scientific advancements become available, until such time as it can be replaced for fully validated and verified measurement data. The FOA methodology is to be used for emissions inventory purposes only within the vicinity of airports. The FOA methodology should not be relied upon where accurate, validated data is required.

A1.3.57 Aircraft Movements

A1.3.58 The requirements for aircraft movements needed for the Advanced Approach is nearly identical to the Simple Approach: it is necessary to know the number of aircraft movements or operations by type of aircraft *and engine* for the advanced approach. The reader is referred to Annex A1.3.19 for more information. When the emissions for the single LTO are calculated for each aircraft/engine combination using the above inputs and equations, the total emissions are calculated by multiplying the single LTO emissions for each aircraft/engine by the corresponding number of movements and summing over the entire range of aircraft/engine combinations and movements for the period required.

A1.3.59 Sophisticated Approach

A1.3.60 When a greater level of accuracy is required in the estimation of aircraft engine emissions inventories at airports, a more sophisticated approach, beyond that described in the Advanced Approach, may be employed. This Sophisticated Approach goes beyond LTO certification data and TIM and utilizes actual engine/aircraft operational performance data. Use of this approach requires a greater knowledge of aircraft and engine operations and in certain instances will require the use of proprietary data or data or models that are normally not available in the public domain and in most instances require the users to perform higher levels of analysis.

A1.3.61 Emission Parameters

A1.3.62 Under the Sophisticated Approach, the actual and refined data required for the analysis is obtained from real-time measurements, reported performance information and/or complex computer modeling outputs. At a high level, these data and information characterize the actual fleet composition in terms of aircraft types and engine combinations, TIM, thrust levels, fuel flows and possibly, combustor operating conditions for all phases of ground-based and take-off operations. In some cases, correction of engine operating conditions to reference conditions, using accepted methods will also be required.[20]

A1.3.63 Listed below are the data and information typically required for computing aircraft engine emissions using the Sophisticated Approach.

- Times-in-mode measurements for different aircraft/engine types under different load, route and meteorological conditions.
- Reverse thrust deployment measurements for different aircraft/engine types under different meteorological conditions.
- Airport meteorological conditions, where modelling of aircraft/engine performance accounts for variation in meteorological conditions.
- Frequency and type of engine test runs.
- Frequency of operational aircraft towing.
- Airport infrastructure and constraints (e.g. runway length).

A1.3.64 Similarly, data measured by operators may be made available, including:

- Typical or actual throttle settings used during reverse thrust operation.
- Actual aircraft/engine configuration data.
- Actual fuel flow data.
- Actual idle engine-type idle speeds.
- Typical or actual throttle settings for approach take off and climb out (e.g. reduced thrust take-off procedures).
- Approach and climb profiles.
- Frequency of less than-all-engine taxi operation.

A1.3.65 This measured and actual operator data may supplement or replace elements of modeled data.

[20] Sources for correcting and obtaining these data will be the airlines, engine manufacturers, ICAO Annex 16 Volume II, SAE AIR 1845, BADA, and ETMS, ETFMS and FDR data.

A1.3.66 Using actual performance and operational data, engine emissions factors can be calculated using programs such as the Boeing Fuel Flow Method 2 or the Deutsches Zentrum für Luft- und Raumfahrt Method.

A1.3.67 Emissions Calculation

A1.3.68 Once the actual fleet engine emissions factors, times-in-mode and fuel flows are known, the LTO emissions are calculated using the same equation used in the Advanced Approach; however with the refined input values.

$$E_{ij} = \sum(TIM_{jk}*60) * (FF_{jk}/1000) * (EI_{jk}) * (NE_j)$$

where:

E_{ij} = Total emissions of pollutant *i* (e.g. NOx, CO, or HC), in grams, produced by aircraft type *j* for one LTO cycle

EI_{jk} = Performance based emission index for pollutant *i* (e.g. NOx, CO, or HC), in grams per pollutant per kilogram of fuel (g/kg of fuel), in mode *k* (e.g. takeoff, climb out, idle and approach) for each engine used on aircraft type *j* [21]

FF_{jk} = Fuel flow for mode *k* (e.g. takeoff, climb out, idle and approach), in kilograms per second (kg/s), for each engine used on aircraft type *j* [22]

TIM_{jk} = Time-in-mode based on aircraft operational performance for mode *k* (e.g. idle, approach, climb out, and takeoff), in minutes, for aircraft type *j*

NE_j = Number of engines used on aircraft type *j*

A1.4 Auxiliary Power Unit Emissions

A1.4.1 An auxiliary power unit (APU) is a small gas-turbine engine coupled to an electrical generator and is used to provide electrical and pneumatic power to aircraft systems when required. It is normally mounted in the tail cone of the aircraft, behind the rear pressure bulkhead, and runs on kerosene fed from the main fuel tanks. Not all aircraft are fitted with APU, and though their use on transport category jet aircraft is now almost universal, some turboprops and business jets do not have an APU fitted.

A1.4.2 Emissions Calculation Methodology

A1.4.3 Unlike aircraft main engines, APU are not certificated for emissions and the manufacturers generally consider information on APU emissions rates as proprietary. As a result, little data are publicly available to serve as a basis for calculating APU emissions.

A1.4.4 Simple Approach

A1.4.5 If very little information is known about the aircraft types operating at the study airport, then the Simple Approach for APU emissions may be used. However, the results are likely to have a large order of uncertainty associated with their use and emissions. Generalised emissions for APU have been made public. The information is recommended for use as the Simple approach uses averaged proprietary engine-specific values obtained from APU manufacturers

A1.4.6 Where the level of detail of aircraft fleet does not allow for this process to be used, the following values are considered representative of the APU emissions for each aircraft operation at the airport under study (other values may be used if deemed more appropriate):

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[21] EI may vary during the time in mode

[22] Fuel flow may vary during the time in mode

Aircraft Group	Short-haul	Long-haul
Duration of APU operation	45 min.	75 min.
Fuel burn	80 kg	300 kg
NO_x emissions	700 g	2400 g
HC emissions	30 g	160 g
CO emissions	310 g	210 g
PM_{10} emissions	25 g	40 g

A1.4.7 The previous fuel burn and emission values are based on averaged manufacturer APU-specific proprietary data; though do not represent any specific APU type. The operational times noted are based on average operating times experienced by a number of operations and do not necessarily represent any specific airport operation. It should be noted that APU operating times vary considerably at different airports due to a number of factors, and can be significantly different to the default values listed in the previous table. If information on actual APU operating times is available, either from surveys or as maximum durations from local airport restrictions, then the APU fuel burn and emissions may be adjusted by factoring these values in the table by the ratio of the survey times with the default values outlined.

A1.4.8 For example, APU NO_x emissions for a short-haul aircraft operating for 60 minutes would be calculated as follows:

NO_x (g/LTO) = (60 minutes per LTO)) x (700 g/ 45 minutes) = 933 g/LTO

A1.4.9 In addition, publicly distributed manufacturer information is available showing aircraft and APU combinations including duty cycle average APU EI and fuel burn rates.[23] Air Transport Association (ATA) estimates of APU operating times also are available; based on a limited, informal survey concerning APU usage. Use of the manufacturer APU emissions data, along with the ATA estimates on APU operating times will provide a more accurate estimate of APU emissions. The ATA estimates on APU operating times provide estimates for narrow and wide-body aircraft with and without gate power. As examples, these estimates are provided in the following table (other values may be used if deemed more appropriate):

	ATA Operating Time (hours/cycle)	
Aircraft Type	**With Gate Power**	**Without Gate Power**
Narrow Body	0.23 to 0.26	0.87
Wide Body	0.23 to 0.26	1.0 to 1.5

A1.4.10 APU and aircraft combinations can be found in 1995 FAA technical report entitled, *Technical Data to Support FAA Advisory Circular on Reducing Emissions from Commercial Aviation*. This document provides an accurate summary of which major APU family is used on different aircraft. The document also provides modal EI and fuel flow for specific APU; all of which would provide additional detail to the APU emissions calculation.

A1.4.11 For example, APU NO_x emissions for a wide body aircraft utilizing a 331-200ER without gate power, where the time at load is 1.5 hours, the NO_x EI is 9.51 lb per 1000 lb fuel, and the fuel flow is 267.92 lb per hour.

NO_x (lb/LTO) = (1.5 hours per LTO)) x (9.51 lb/1000 lb fuel)(267.92 lb fuel/hour) = 3.82 lb/LTO = 3,466 g/LTO*

[23] Correspondence from Honeywell Engines & Systems to U.S. EPA Assessment and Standards Division, APU Emissions, September 29, 2000.

A1.4.12 Advanced Approach

A1.4.13 APU emissions can be estimated from knowledge of the actual aircraft/APU combination and APU running time, with EI assigned to individual APU types. Emissions can be calculated at three suggested APU operating load conditions of

- Start-up (No load),
- Normal running (Max Environmental Control System [ECS]), and
- High load (Main engine start),

to represent the operating cycle of these engines.

A1.4.14 For each of these loads, the emissions can be calculated from the following formulas:

NO_x = NO_x rate x Time at Load,
HC = HC rate x Time at Load,
CO = CO rate x Time at Load, and
PM_{10} = PM_{10} rate x Time at Load.

A1.4.15 Where data for actual time at load cannot be identified accurately, it is recommended that the following times be used. These times are provided as examples (other values may be used if deemed more appropriate). The times are based on the experience of a number of airlines and represent averaged values. If additional specific information is available for operations at the airport under study, they should be used in preference to those outlined.

Activity	**Mode**	**Two-engine aircraft**	**Four-engine aircraft**
APU start-up and stabilisation	Start -up	3 minutes	3 minutes
Aircraft preparation, crew and passenger boarding	Normal running	(Total pre-departure running time) – 3.6 min	(Total pre-departure running time) – 5.3 min
Main Engine Start	High Load	35 seconds	140 seconds
Passenger disembarkation and aircraft shutdown	Normal running	15 minutes (default) or as measured	15 minutes (default) or as measured

A1.4.16 To calculate NO_x and PM_{10} emissions, current aircraft types have been assigned to one of six groups that characterize their NO_x emissions, and three groups that characterize their PM_{10} emissions:

A1.4.17 APU NOx, HC, and CO emission can then be calculated by multiplying the time at load by the appropriate emission factor from the following tables (other values may be used if deemed more appropriate). These values are averaged emission rates for a number of APU fitted to aircraft in the classes listed. The data use information supplied by the manufacturer for actual APU suitably combined to ensure that the confidentiality required by the manufacturer such that the performance of specific APU is not compromised.

APU NO_x Group	**Start-up No Load (kg/hr)**	**Normal Running Max ECS (kg/hr)**	**High Load Main Engine Start (kg/hr)**
Business Jets/Regional Jets (<100 seats)	0.274	0.452	0.530
Smaller (>200,>100 seats), newer types	0.364	0.805	1.016
Smaller (>200>100 seats), older types	0.565	1.064	1.354
Mid-range (>300,>200 seats), types	0.798	1.756	2.091

Larger (>300 seats), older types	1.137	2.071	2.645
Larger (>300 seats), newer types	1.210	2.892	4.048

APU HC Group	Start-up No Load (kg/hr)	Normal Running Max ECS (kg/hr)	High Load Main Engine Start (kg/hr)
Business Jets/Regional Jets (<100 seats)	0.107	0.044	0.042
Smaller (>200,>100 seats), newer types	2.662	0.094	0.091
Smaller (>200>100 seats), older types	0.105	0.036	0.036
Mid-range (>300,>200 seats), types	0.243	0.070	0.059
Larger (>300 seats), older types	0.302	0.153	0.125
Larger (>300 seats), newer types	0.180	0.078	0.076

APU CO Group	Start-up No Load (kg/hr)	Normal Running Max ECS (kg/hr)	High Load Main Engine Start (kg/hr)
Business Jets/Regional Jets (<100 seats)	1.019	0.799	0.805
Smaller (>200,>100 seats), newer types	3.734	0.419	0.495
Smaller (>200>100 seats), older types	1.289	0.336	0.453
Mid-range (>300,>200 seats), types	0.982	0.248	0.239
Larger (>300 seats), older types	5.400	3.695	2.555
Larger (>300 seats), newer types	1.486	0.149	0.192

A1.4.18 The relevant equations of the three curves for PM_{10} emission rate (g/hr) as a function of NO_x emission rate (g/hr) are shown in the following. These values are averaged emission rates for a number of APU fitted to aircraft in the classes listed in a manner similar to the previous tables.

APU PM_{10} Group	Equation for PM_{10} calculation (g/hr)
Regional jet (<100 seats), all types/ Smaller (>200>100 seats), older types/ Larger (>300 seats), newer types	$PM_{10} = 12.2278 \times (NO_x)^{0.09336}$
Business Jets/ Smaller (>200,>100 seats), newer types	$PM_{10} = 0.0000045 \times (NO_x)^{2.64169}$

Mid-range (>300,>200 seats), types/ Larger (>300 seats), older types	$PM_{10} = 19.0611 \times (NO_x)^{0.17304}$

A1.4.19 From knowledge of the NO_x, HC, and CO emissions rate identified previously, the PM_{10} emission rate can then also be determined for any APU and operating mode. For aircraft types that are not included in the previous list and for future developments, the classes listed in the following table, are provided as examples (other values may be used if deemed more appropriate):

Aircraft Type	**APU NO_x, HC and CO Group**	**APU PM_{10} Group**
Developments of current aircraft	same as current type	same as current type
Business jets, piston and turboprop powered aircraft	n/a*	n/a*
Small aircraft up to 100 seats	Smaller (>200,>100 seats), newer types	Business Jets/ Smaller (>200,>100 seats), newer types
Medium aircraft between 100 and 300 seats	Smaller (>200>100 seats), older types	Regional jet (<100 seats), all types/ Smaller (>200>100 seats), older types/ Larger (>300 seats), newer types
Large jets above 300 seats	Larger (>300 seats), newer types	Mid-range (>300,>200 seats), types/ Larger (>300 seats), older types
Note: Some turboprops may have an APU fitted in which case NO_x class 'a' and PM_{10} class 'B' should be used.		

Suggested APU NO_x and PM_{10} groups for aircraft types not listed.

A1.4.20 The total APU emissions of NO_x and PM_{10}, for each turnaround cycle, can be calculated from a summation of the emissions for each mode over the whole cycle.

A1.4.21 Sophisticated Approach

A1.4.22 Emissions indices for APU have been made available from the manufacturers to some airport and aircraft operators; however due to the proprietary nature of the data, their widespread use has not been authorised. As a result, the sophisticated approach may only be available to a few specialist inventory builders.

A1.4.23 The sophisticated approach requires a detailed knowledge of the APU type, operating modes and times in these modes, aircraft operations and fuel burn and associated emissions factors. As noted, many of these may not be available publicly and the APU manufacturers would have to be approached. TIM data is another factor that would need to be carefully researched and collected. It may be that only typical values are available for specific operators/aircraft types, and in this case, it may be necessary to use the default values of the advanced approach, but coupled with more accurate EI from the manufacturers to give a more reliable result.

A1.4.24 The APU emissions for each aircraft APU mode of operation can then be calculated from the following formula:

Emission mass = Time in mode x Fuel flow x EI, for each mode and each emissions species *Eq A1-6*

A1.4.25 The mass of each emissions species can then be calculated for each operation by summing the emissions masses for the different power loads. Finally by summing up the emissions calculated for each aircraft APU operation, the total mass of each emissions species can be calculated for the emissions inventory.

Chapter 2
Emissions Inventory
Annex 1
Aircraft Emissions
Appendix A
Example ICAO Engine Emissions Datasheet

ICAO ENGINE EXHAUST EMISSIONS DATA BANK

SUBSONIC ENGINES

ENGINE IDENTIFICATION: Trent 895
UNIQUE ID NUMBER: 5RR040
ENGINE TYPE: TF

BYPASS RATIO: 5.7
PRESSURE RATIO (π_{oo}): 41.52
RATED OUTPUT (F_{oo}) (kN): 413.05

REGULATORY DATA

CHARACTERISTIC VALUE:	HC	CO	NOx	SMOKE NUMBER
D_p/F_{oo} (g/kN) or SN	1.7	23.1	78.6	6.9
AS % OF ORIGINAL LIMIT	8.6 %	19.6 %	63.9 %	42.8 %
AS % OF CAEP/2 LIMIT (NOx)			79.9 %	
AS % OF CAEP/4 LIMIT (NOx)			87.3 %	

DATA STATUS

- \- PRE-REGULATION
- x CERTIFICATION
- \- REVISED (SEE REMARKS)

TEST ENGINE STATUS

- \- NEWLY MANUFACTURED ENGINES
- x DEDICATED ENGINES TO PRODUCTION STANDARD
- \- OTHER (SEE REMARKS)

EMISSIONS STATUS

x DATA CORRECTED TO REFERENCE (ANNEX 16 VOLUME II)

CURRENT ENGINE STATUS

(IN PRODUCTION, IN SERVICE UNLESS OTHERWISE NOTED)
- \- OUT OF PRODUCTION
- \- OUT OF SERVICE

MEASURED DATA

MODE	POWER SETTING (%F_{oo})	TIME minutes	FUEL FLOW kg/s	EMISSIONS INDICES (g/kg) HC	CO	NOx	SMOKE NUMBER
TAKE-OFF	100	0.7	4.03	0.02	0.27	47.79	-
CLIMB OUT	85	2.2	3.19	0	0.19	34.29	-
APPROACH	30	4.0	1.05	0	0.54	11.39	-
IDLE	7	26.0	0.33	0.89	14.71	5.11	-
LTO TOTAL FUEL (kg) or EMISSIONS (g)			1357	462	7834	28029	-
NUMBER OF ENGINES				1	1	1	1
NUMBER OF TESTS				3	3	3	3
AVERAGE D_p/F_{oo} (g/kN) or AVERAGE SN (MAX)				1.1	18.8	67.81	5.34
SIGMA (D_p/F_{oo} in g/kN, or SN)				-	-	-	-
RANGE (D_p/F_{oo} in g/kN, or SN)				0.95 - 1.24	17.71 - 19.67	65.76 - 69.5	4.7 - 6.0

ACCESSORY LOADS

POWER EXTRACTION 0 (kW) AT - POWER SETTINGS
STAGE BLEED 0 % CORE FLOW AT - POWER SETTINGS

ATMOSPHERIC CONDITIONS

BAROMETER (kPa)	100.2
TEMPERATURE (K)	287
ABS HUMIDITY (kg/kg)	.0053 - .0089

FUEL

SPEC	AVTUR
H/C	1.95
AROM (%)	16

MANUFACTURER: Rolls-Royce plc
TEST ORGANIZATION: Rolls-Royce plc
TEST LOCATION: SINFIN, Derby
TEST DATES: FROM Sep 94 TO -

REMARKS

1. Data from certification report DNS59304

This document was prepared on 1 October 2004
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Chapter 2

Emissions Inventory
Annex 1
Aircraft Emissions
Appendix B
Simplified Aircraft Emission Indices

Table B-1 LTO Emission Factor by Aircraft

			LTO emissions factors/airplane (kg/LTO/aircraft)[10]					Fuel consumption (kg/LTO/aircraft)
		Aircraft[11]	CO_2[9]	HC	NO_x	CO	SO_2[8]	
Source: ICAO (2004)[1]	Large Commercial Aircraft[2]	A300	5450	1.25	25.86	14.80	1.72	1720
		A310	4760	6.30	19.46	28.30	1.51	1510
		A319	2310	0.59	8.73	6.35	0.73	730
		A320	2440	0.57	9.01	6.19	0.77	770
		A321	3020	1.42	16.72	7.55	0.96	960
		A330-200/300	7050	1.28	35.57	16.20	2.23	2230
		A340-200	5890	4.20	28.31	26.19	1.86	1860
		A340-300	6380	3.90	34.81	25.23	2.02	2020
		A340-500/600	10660	0.14	64.45	15.31	3.37	3370
		707	5890	97.45	10.96	92.37	1.86	1860
		717	2140	0.05	6.68	6.78	0.68	680
		727-100	3970	6.94	9.23	24.44	1.26	1260
		727-200	4610	8.14	11.97	27.16	1.46	1460
		737-100/200	2740	4.51	6.74	16.04	0.87	870
		737-300/400/500	2480	0.84	7.19	13.03	0.78	780
		737-600	2280	1.01	7.66	8.65	0.72	720
		737-700	2460	0.86	9.12	8.00	0.78	780
		737-800/900	2780	0.72	12.30	7.07	0.88	880
		747-100	10140	48.43	49.17	114.59	3.21	3210
		747-200	11370	18.24	49.52	79.78	3.60	3600
		747-300	11080	2.73	65.00	17.84	3.51	3510
		747-400	10240	2.25	42.88	26.72	3.24	3240
		757-200	4320	0.22	23.43	8.08	1.37	1370
		757-300	4630	0.11	17.85	11.62	1.46	1460
		767-200	4620	3.32	23.76	14.80	1.46	1460
		767-300	5610	1.19	28.19	14.47	1.77	1780
		767-400	5520	0.98	24.80	12.37	1.75	1750
		777-200/300	8100	0.66	52.81	12.76	2.56	2560
		DC-10	7290	2.37	35.65	20.59	2.31	2310
		DC-8-50/60/70	5360	1.51	15.62	26.31	1.70	1700
		DC-9	2650	4.63	6.16	16.29	0.84	840
		L-1011	7300	73.96	31.64	103.33	2.31	2310
		MD-11	7290	2.37	35.65	20.59	2.31	2310

		MD-80	3180	1.87	11.97	6.46	1.01	1010
		MD-90	2760	0.06	10.76	5.53	0.87	870
		TU-134	5860	35.97	17.35	55.96	1.86	1860
		TU-154-M	7040	17.56	16.00	110.51	2.51	2510
		TU-154-B	9370	158.71	19.11	190.74	2.97	2970
	Regional Jets/Business Jets > 26.7 kN thrust	RJ-RJ85	950	0.67	2.17	5.61	0.30	300
		BAE 146	900	0.70	2.03	5.59	0.29	290
		CRJ-100ER	1060	0.63	2.27	6.70	0.33	330
		ERJ-145	990	0.56	2.69	6.18	0.31	310
		Fokker 100/70/28	2390	1.43	5.75	13.84	0.76	760
		BAC111	2520	1.52	7.40	13.07	0.80	800
		Dornier 328 Jet	870	0.57	2.99	5.35	0.27	280
		Gulfstream IV	2160	1.37	5.63	8.88	0.68	680
		Gulfstream V	1890	0.31	5.58	8.42	0.60	600
		Yak-42M	1920	1.68	7.11	6.81	0.61	610
Source: FAEED222 (3)	Low Thrust Jets (Fn < 26.7 kN)	Cessna 525/560	1060	3.35	0.74	34.07	0.34	340
Source: FOI (4)	Turboprops	Beech King Air (5)	230	0.64	0.30	2.97	0.07	70
		DHC8-100 (6)	640	0.00	1.51	2.24	0.20	200
		ATR72-500 (7)	620	0.29	1.82	2.33	0.20	200

Notes:

(1) ICAO (International Civil Aviation Organization) Engine Exhaust Emissions Data Bank (2004) based on average measured certification data. Emissions factors apply to LTO cycle only. Total emissions and fuel consumption are calculated based on ICAO standard time in mode and thrust levels.

(2) Engine types for each aircraft were selected on a basis of the engine with the most LTOs as of 30 July 2004 (except 747-300 - see text). This approach, for some engine types, may underestimate (or overestimate) fleet emissions which are not directly related to fuel consumption (eg NOx, CO, HC).

(3) U.S. Federal Aviation Administration (FAA) Emissions and Dispersion Modeling System (EDMS) non-certified data

(4) FOI (The Swedish Defense Research Agency) Turboprop LTO Emissions database non-certified data

(5) Representative of Turboprop aircraft with shaft horsepower of up to 1000 shp/engine

(6) Representative of Turboprop aircraft with shaft horsepower of 1000 to 2000 shp/engine

(7) Representative of Turboprop aircraft with shaft horsepower of more than 2000 shp/engine

(8) The sulphur content of the fuel is assumed to be 0.05% [Same assumption as in 1996 IPCC NGGIP revision]

(9) CO2 for each aircraft based on 3.16 kg CO2 produced for each kg fuel used, then rounded to the nearest 10 kg.

(10) Information regarding the uncertainties associated with the data can be found in the following references:

QinetiQ/FST/CR030440 “EC-NEPAir: Work Package 1 Aircraft engine emissions certification – a review of the development of ICAO Annex 16, Volume II”, by D H Lister and P D Norman

ICAO Annex 16 “International Standards and Recommended Practices Environmental Protection”, Volume II “Aircraft Engine Emissions”, 2nd edition (1993)

(11) Equivalent aircraft are contained in Table B-3

Table B-2 Engine Designations by Aircraft		
Aircraft	**ICAO Engine**	**Engine UID**
A300	PW4158	1PW048
A310	CF6-80C2A2	1GE016
A319	CFM56-5A5	4CM036
A320	CFM56-5A1	1CM008
A321	CFM56-5B3/P	3CM025
A330-200/300	Trent 772B-60	3RR030
A340-200	CFM56-5C2	1CM010
A340-300	CFM56-5C4	2CM015
A340-500/600	TRENT 556-61	6RR041
707	JT3D-3B	1PW001
717	BR700-715A1-30	4BR005
727-100	JT8D-7B	1PW004
727-200	JT8D-15	1PW009
737-100/200	JT8D-9A	1PW006
737-300/400/500	CFM56-3B-1	1CM004
737-600	CFM56-7B20	3CM030
737-700	CFM56-7B22	3CM031
737-800/900	CFM56-7B26	3CM033
747-100	JT9D-7A	1PW021
747-200	JT9D-7Q	1PW025
747-300	JT9D-7R4G2(66%) RB211-524D4(34%)	1PW029(66%) 1RR008(34%)
747-400	CF6-80C2B1F	2GE041
757-200	RB211-535E4	3RR028
757-300	RB211-535E4B	5RR039
767-200	CF6-80A2	1GE012
767-300	PW4060	1PW043
767-400	CF6-80C2B8F	3GE058
777-200/300	Trent 892	2RR027
DC-10	CF6-50C2	3GE074
DC-8-50/60/70	CFM56-2C1	1CM003
DC-9	JT8D-7B	1PW004
L-1011	RB211-22B	1RR003
MD-11	CF6-80C2D1F	3GE074
MD-80	JT8D-217C	1PW018
MD-90	V2525-D5	1IA002
TU-134	D-30-3	1AA001
TU-154-M	D-30-KU-154-II	1AA004
TU-154-B	NK-8-2U	1KK001
RJ-RJ85	LF507-1F, -1H	1TL004
BAE 146	ALF 502R-5	1TL003
CRJ-100ER	CF34-3A1	1GE035
ERJ-145	AE3007A1	6AL007
Fokker 100/70/28	TAY Mk650-15	1RR021
BAC111	Spey-512-14DW	1RR016
Dornier 328 Jet	PW306B	7PW078
Gulfstream IV	Tay MK611-8	1RR019
Gulfstream V	BR700-710A1-10	4BR008
Yak-42M	D-36	1ZM001
Cessna 525/560	PW545A or similar	FAEED222
Beech King Air	PT6A-42	PT6A-42
DHC8-100	PW120 or similar	PW120
ATR72-500	PW127F or similar	PW127F

Table B-3 Representative Aircraft		
Generic Aircraft	**ICAO**	**IATA aircraft in group**
Airbus A300	A30B	AB3
	A306	AB4
		AB6
		ABF
		ABX
		ABY
Airbus A310	A310	310
		312
		313
		31F
		31X
		31Y
Airbus A319	A319	319
	A318	318
Airbus A320	A320	320
		32S
Airbus A321	A321	321
Airbus A330-200	A330	330
	A332	332
Airbus A330-300	A330	330
	A333	333
Airbus A340-200	A342	342
Airbus A340-300	A340	340
	A343	343
Airbus A340-500	A345	345
Airbus A340-600	A346	346
Boeing 707	B703	703
		707
		70F
		70M
Boeing 717	B712	717
Boeing 727-100	B721	721
		72M
Boeing 727-200	B722	722
		727
		72C

		72B
		72F
		72S
Boeing 737-100	B731	731
		732
		73M
Boeing 737-200	B732	73X
		737
		73F
		733
Boeing 737-300	B733	73Y
		737
Boeing 737-400	B734	734
		737
Boeing 737-500	B735	735
Boeing 737-600	B736	736
		73G
Boeing 737-700	B737	73W
		738
Boeing 737-800	B738	73H
Boeing 737-900	B739	739
	B741	74T
	N74S	74L
	B74R	74R
Boeing 747-100	B74R	74V
		742
		74C
Boeing 747-200	B742	74X
		743
Boeing 747-300	B743	74D
		747
		744
		74E
		74F
		74J
		74M
Boeing 747-400	B744	74Y
		757
		75F
Boeing 757-200	B752	75M
Boeing 757-300	B753	

		762
Boeing 767-200	B762	76X
		767
		76F
		763
Boeing 767-300	B763	76Y
Boeing 767-400	B764	
		777
Boeing 777-200	B772	772
Boeing 777-300	B773	
		773
		D10
		D11
		D1C
Douglas DC-10	DC10	D1F
		D1M
		D1X
Douglas DC-10	DC10	D1Y
	DC85	D8F
	DC86	D8L
		D8M
		D8Q
		D8T
		D8X
Douglas DC-8	DC87	D8Y
	DC9	DC9
	DC91	D91
	DC92	D92
	DC93	D93
	DC94	D94
		D95
		D9C
		D9F
Douglas DC-9	DC95	D9X
		L10
		L11
		L15
Lockheed L-1011	L101	L1F
		M11
		M1F
McDonnell Douglas MD11	MD11	M1M
McDonnell Douglas MD80	MD80	M80
	MD81	M81

	MD82	M82
	MD83	M83
	MD87	M87
	MD88	MD88
McDonnell Douglas MD90	MD90	M90
Tupolev Tu134	T134	TU3
Tupolev Tu154	T154	TU5
Avro RJ85	RJ85	AR8
		ARJ
BAe 146	B461	141
	B462	142
	B463	143
		146
		14F
		14X
		14Y
		14Z
Embraer ERJ145	E145	ER4
		ERJ
Fokker 100/70/28	F100	100
	F70	F70
	F28	F21
		F22
		F23
		F24
		F28
BAC 111	BA11	B11
		B12
		B13
		B14
		B15
Donier Do 328	D328	D38
Gulfstream IV / V		GRJ
Yakovlev Yak 42	YK42	YK2

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Appendix C
Definition of Publicly Available Databases for Use in the Matching Aircraft Type with Engine Type

Useful data fields in the IOAG Database:

LveTime	=	time flight is scheduled to depart origin in local time
LveGMT	=	time flight is scheduled to depart origin in Greenwich Mean Time (GMT)
ArrCode	=	number representing arrival airport
Arrive	=	arrival airport alphabetic code (e.g. JFK)
ArrTime	=	time flight is scheduled to arrive in local time
ArrGMT	=	time flight is scheduled to arrive in GMT
Equip	=	type of aircraft, in code (e.g. B738)
FAACarr	=	abbreviation for air carrier name
FltNo	=	flight number
Freq	=	1/0 code showing days of the week that that flight flies that time slot and city pair
ATACarr	=	carrier name in Air Transport Association Code
IOAGCARR	=	air carrier company in 2-letter IOAG code
CarrType	=	commuter or carrier company
ATAEquip	=	aircraft type in ATA code
EqType	=	J for Jet, T for Turboprop, P for propeller-driven aircraft
CarrName	=	air carrier company name spelled out
LveCity	=	origin city and country/state, spelled out
ArrCntry	=	destination country or state if the destination is in the US
LveCntry	=	origin country or state if the origin is in the US
YYMM	=	year and month of the current schedule
Eday	=	0/1 code indicating whether this flight flies on each day of the month given by the schedule
FPM	=	number of times (days) this fight is flown between this city-pair at this time slot in a month

Useful data fields in the BACK World Fleet Registration Database:

- Aircraft Type
- Aircraft Serial Number
- Aircraft Manufacturer
- Registration\Tail Number
- Engine Manufacturer
- Engine Model
- Number f Engines
- Aircraft Noise Class (Stage)
- Equipment Category

- Equipment Type (LAR Code)
- Equipment Type (IOAG Code)
- Aircraft Equipment Model
- Operator Category
- Operator Name
- Operator IATA Code
- Operator ICAO Code
- Wing Span (meters)
- Wing Area (square meters)
- Overall Length (meters)
- Belly Volume (cubic meters)
- Fuel Capacity
- Maximum Takeoff Weight (kilograms)
- Maximum Payload (kilograms)
- Maximum Landing Weight (kilograms)
- Range with Maximum Fuel (kilometres)
- Range with Maximum Payload (kilometres)

Useful data fields in the ASQP Database:

- IATA carrier code
- Flight number
- Depart airport
- Arrival airport
- Date of operation
- Day of week
- IOAG depart time
- Actual depart time
- IOAG arrival time
- CRS arrival time
- Actual arrival time
- Wheels off time
- Wheels on time
- Aircraft Tail number
- Taxi out time
- Taxi in time

Useful data fields in the JP Airline Fleets Database:

- Operator Name
- Operator IATA Code
- Operator ICAO Code
- Aircraft Tail number
- Aircraft type and subtype
- Month and year of manufacturing
- Construction number

- Previous identity
- Number of engines
- manufacturer of engines
- exact type of engines
- Maximum Takeoff Weight (kilograms)
- Seat configuration (or other use than for passenger services)

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Appendix D
First Order Approximation v3.0 Method for Estimating PM Emissions from Aircraft Engines

The development of detailed Particulate Matter (PM) inventories from aircraft is in its infancy. Data on specific engine emission levels are sparse and the test methods are still being refined.[24] However, there is an immediate need to estimate PM for airport planning and regulatory requirements. To this end, a First Order Approximation (FOA) has been developed as an interim method to estimate PM emissions from jet turbine aircraft in the vicinity of airports. The need for an FOA method will become obsolete at a time when engine-specific validated and verified PM EI are available.

By way of a brief historical introduction, in 2003 the original version, FOA 1.0,[25] was made publicly available based on the ICAO reported maximum smoke number (SN), estimated only the non-volatile fraction of PM. Based on feedback from scientific and regulatory reviewers in 2005, scaling to accommodate both the volatile and non-volatile components was included in FOA 2.0.[26] In November 2005, WG3-AEMTG concluded that more in-depth procedures were needed to improve the fidelity and usefulness of the FOA. This resulted in the creation of the FOA ad hoc group within WG3/AEMTG to further develop the next version of FOA (FOA3) taking into account available information addressing the individual drivers of aircraft PM formation.[27]

The FOA ad hoc group operates in an open forum, inviting all information pertaining to the development of aircraft PM emissions. Through face-to-face meetings, teleconferences, and other correspondence a new FOA3 methodology was developed. The non-volatile portion was estimated the same way using the ICAO SN but new data was introduced to the analysis. The volatile component was estimated by breaking down the total volatile emissions into the various contributing species and estimating each, namely fuel sulphur content, fuel-based organics, and lube oil. Nitrates were not considered to be an important contributor to PM formation based on available measurement information.

The breakdown by component led to a new general form of the FOA3 of:

PMvols = ∑(Fuel Sulphur Content) + ∑(Fuel Organics) + ∑(Lubrication Oil) [1]
PMnvols = based on SN-to-Mass Relationship [2]
TOTAL PM = PMvols + PMnvols [3]

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[24] SAE E-31 Position Paper on Particle Matter Measurements.

[25] Wayson, R.L., G. Fleming, B. Kim, A Review of Literature on Particulate Matter Emissions From Aircraft, DTS-34-FA22A-LR1, Federal Aviation Administration, Office of Environment and Energy, Washington, D.C. 20591, December, 2003.

[26] A First Order Approximation (FOA) for Particulate Matter, Working Paper prepared for CAEP/7-WG2/TG4-4th Meeting, Athens, Greece, June 2005.

[27] To date, the participants of the WG3/AEMTG FOA Ad Hoc Group have been Ralph Iovinelli (FAA) (lead), Roger Wayson (Volpe), Chris Eyers (QinetiQ), Chris Hurley (QinetiQ), Curtis Holsclaw (FAA), David Lee (MMU), David Lister (CAA), Dom Sepulveda (Pratt), John Rohde (NASA), Paul Madden (Rolls), Anuj Bhargava (Pratt), Rick Miake-Lye (Aerodyne and WG3 LAQ RFP), Will Dodds (GE), and Chowen Wey (NASA).

Fuel Sulphur Content as a driver for volatile PM: Sulphur emissions are assumed to be primarily a function of the amount of sulphur in the fuel and the conversion efficiency from elemental sulphur (S^{IV}) to an oxidized sulphate (S^{VI}), such as sulphuric acid or some other form of sulphate. Fuel sulphur contents change from location to location and should remain a variable during the estimation process. A fleet wide conversion efficiency can be assumed. A molecular weight of 96 is used for sulphur volatile PM emissions to reflect the sulphate component of the measured aerosol.

$$\boxed{EI_{PMvols-FSC}\left[\frac{mg}{kgfuel}\right] = 1x10^{6}\left(\frac{FSC(\varepsilon)MW_{out}}{MW_{S}}\right)} \qquad [4]$$

where: FSC = fuel sulphur content (%)
ε = S^{IV} to S^{VI} conversion rate (%)
MW_{out} = 96 ([SO_4] sulphate in exhaust)
MW_S = 32 (sulphur)

Equation [4] simplifies to:

$$EI_{PMvols-FSC}\ [mg/kgfuel] = 3x106 * (FSC) * (\varepsilon) \qquad [5]$$

Fuel sulphur content can be ideally obtained at the time the jet fuel is delivered to the airport, typically reported in mass percent. If the actual FSC is not known, other references provide typical FSC values ranging from 0.005 to 0.068 weight percent (Coordinating Research Council, 2004) with a global average of 0.03 weight percent (IPCC, 1999).

True understanding of the S^{IV} to S^{VI} conversion process is not completely known and must be estimated, as well as assumed to be a constant for all FSC ranges. Non-linear production of S^{VI} occurs with FSC but can be approximated. Literature suggests that the conversion fraction (ε)of fuel sulphur to sulphuric acid is measured in the range 0.34 to 4.5%for an older engine (Mk501) and 3.3 +/- 1.8% for a modern engine (CFM56-3B1) (Schumann, 2002). The practitioner is advised to chose a sulphur conversion rate that best suits the purpose and need for conducting an aircraft PM emissions inventory.

Fuel Organics as a driver for volatile PM: HC EI are assumed to be statistically related to PM gaseous organic emissions. That is, if unburned HC gaseous emissions increase, so do the overall organic volatile PM emissions in a related fashion. Measurement data separating the organic fraction from the overall PM emissions from in-situ engines are very limited, with information from APEX1 as the most recently published, addressing only one engine (CFM56-2-C1) at this time. It is assumed that the pollutant trends shown in Figure 1 are consistent for all commercial jet turbine engines in the ICAO database. As such, ICAO HC EI can be related to the fuel organic emissions. The data used is for a probe 30 meters behind the aircraft. It is assumed that at this distance, volatile organic PM emissions are representative of those in the atmospheric in the vicinity of airports.

The overall estimation of volatile PM from fuel organics is a complex, multi-faceted issue, and many details are not well known. As such, the fuel organics methodology implemented at this time must be simplistic. Currently the only data available are from the CFM56 and it is not yet clear whether the variation in the $V_{component}$ with engine type or power setting is significant. Therefore, two equally acceptable methods, one mode-specific based and the other LTO-mass based, are offered as part of the FOA3 methodology.

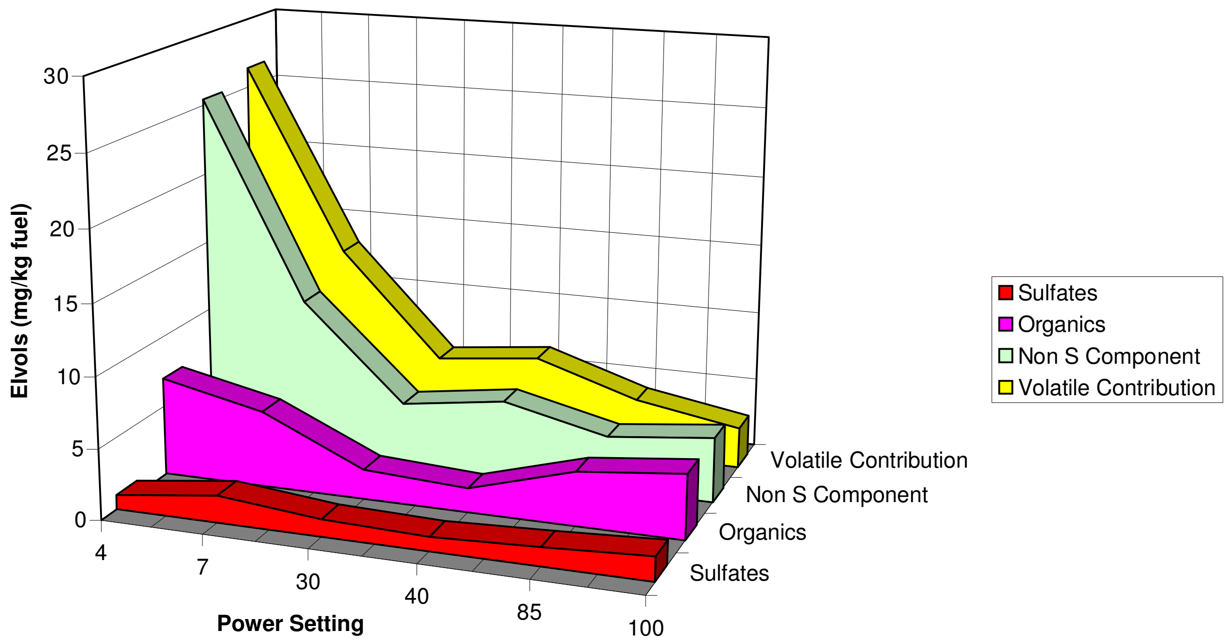

Figure 1. Trends From APEX 1 for CFM56-2-C1 Engine

METHOD 1: From the APEX 1 measurements, Figure 1 shows curves that represent the sulphate fraction, the organics fraction, and the volatile contribution by power setting. The volatile contribution was measured using a thermal denuder, and the sulphate component is a subset of the volatile contribution. Therefore, the sulphate component must be subtracted from the volatile contribution to avoid double counting sulphate emissions as a driver for volatile PM. This resulted in the curve derived for this work labelled the non-sulphur component in Figure 1 and is assumed to be the total organic component of the volatile PM emissions. However, this component should never be less than the measured organic component which used other techniques. This problem occurs for the two higher power settings (85% and 100%) when simple subtraction is used. To avoid this possible error, the reported value for the organic component was used for the two higher power settings resulting in the final non-sulphur component as shown in Figure 1. This component is then thought to represent the fuel organic volatile fraction of the volatile PM emissions. If it is assumed the CFM-56-2-C1 is representative of other engines in the fleet, as done in this methodology, a ratio of the organic component can be determined and applied to other engines in the ICAO Aircraft Engine Emissions Databank to allow determination for each engine and each mode. This results in the expression as shown in Equation [6].

$$EI_{vol-FuelOrganics} = \delta\left[EI_{HC(Engine)}\right] \qquad [6]$$

where:
$EI_{vol\text{-}FuelOrganics}$ = volatile PM emissions of fuel organics (mg/kg)

$$\delta = \left(\frac{V_{component}}{EI_{HC(CFM56-2-C1)}}\right) \text{ by mode}$$

$V_{component}$ = a ratio based on the trends shown in Figure 1
$EI_{HC(CFM56\text{-}2\text{-}C1)}$ = mode-specific ICAO gaseous HC EI for CFM56-2-C1 engine
$EI_{HC(Engine)}$ = mode-specific ICAO gaseous HC EI for the engine of concern

If equation [6] is used, the mode-specific values for δ are shown in Table 1. It should be noted that the $PM_{vol\text{-}FuelOrganics}$ value for the entire LTO cycle is greatly influenced by the amount of time an engine spends in idle mode, given that the HC EI is greatest in idle mode and the potential for engines to spend extended time in idle mode. Applying this mode-specific method for all engines in the ICAO Aircraft Engine Emissions Databank yields a volatile PM contribution from fuel organics as 1.3% of the total LTO HC emissions, based on certification time in mode.

Table 1. Values of δ (the ratio of the $V_{component}$ and the $EI_{HC(CFM56)}$)

Mode	δ Numeric Value
Takeoff	115
Climb	84
Approach	56.25
Idle	6.17

METHOD 2: A second simplistic method is offered based on applying the $V_{component}$ across the entire LTO cycle. This method is based on the ratio of total $V_{component}$ across the entire LTO cycle

versus the total LTO HC emissions for the CFM56 engine. Equation [7] provides the formula to calculate the volatile PM created by fuel organic emissions:

$$PM_{vol\text{-}FuelOrganics}\ (\text{grams}) = (0.0085) \times (\text{Total LTO HC emissions}_{(Engine)}) \qquad [7]$$

Lubrication Oil as a driver for volatile PM: Lubrication oil emissions are believed to have an effect on volatile PM formation. The physical and chemical makeup of lube oil is known. Yet, there are many variables that require further investigation to determine the magnitude of influence on volatile PM formation, the least of which is addressing different configurations of venting lube oil emissions. As a result, work is ongoing on lubrication oil. Too little is known to justify the development of a direct quantification methodology at this time. It should be noted that, for now, lube oil's influence on the formation of volatile PM whilst in the exhaust plume is assumed to be included in the organic fraction estimate described.

Non-volatile PM (soot) Estimation: Multiple researchers have proved that SN correlates to non-volatile PM mass emissions. Average air-to-fuel ratios (AFR) per power setting can be assumed for all commercial turbine jet aircraft as shown in Table 2. Error in SN measurement by different researchers is estimated to be ± 3 and measurements also have errors. These errors form upper and lower bounds to the estimate. Analysts may chose to use the average, or for conservatism the maximums. Minimum mass emissions, based on the error analysis, should not be used to estimate PM_{nvol} emissions, yet are included here to bound the uncertainty. A difference in the trends for SN and mass occur for those ≤ 30 and those > 30. Most modern engines have SN < 30 but older engines remain in the fleet and a method is necessary. As such, there must be a correlation for SN to mass for each of the four ICAO power settings as well as less than and greater than a SN of 30, resulting in the use of eight equations.

Table 2. Average Air-to-Fuel Ratios by Power Setting

Power Setting	AFR
7% (idle)	106
30% (approach)	83
85% (climb)	51
100% (takeoff)	45

Non-volatile PM methodology: The methodology is based on the available mass data at this time and is related to the reported SN so that emissions from the majority of jet turbine engines can be approximated by using the ICAO databank. Additionally, the data shows different trends for the lower SN as compared to the higher SN. A break point of ≤ 30 and >30 was selected based on the data and also that most modern engines in the fleet now have a SN of 30 or less.

For the estimation of PM_{nvol} emissions for SN less than 30, laboratory experimental data developed by QinetiQ of the United Kingdom was used to establish a relationship between SN and PM_{nvol} mass. These data seemed to be quite reasonable when compared to engine measurement data reported by DLR[28] and UMR[29]. The analysis of these data, based on mass per volume of exhaust, yielded an equation to predict the PM_{nvol} concentration index (CI) as compared to the SN. The general equation is:

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28 [Petzold, 1999] Petzold, A., A. Dopelheuer, C.A. Brock, and F. Schroder, In situ observations and model calculations of black carbon emission by aircraft at cruise altitude, Journal of Geophysical Research, Vol 104, No. D18, September 27, 1999, pgs. 22.171 – 22.181.

29 [Whitefield, 2001] Whitfield, P.D., D.E. Hagen, G. Siple, J. Pehrson, Estimation of Particulate Emission indexes as a Function of Size for the LTO Cycle for Commercial Jet Engines", Proceedings of the Air & Waste Management Association Annual Meeting Orlando, Florida, June, 2001.

$$CI = \exp(1.23357\ln(SN) - 2.6679) \quad [8]$$

where: CI = concentration index (mg/M^3)
SN = smoke number

For SN > 30 a different approach was utilized. In this case, data from UMR[30] as well as Hurley were used in the analysis. The resulting correlation was as follows and applied for all engines with SN > 30:

$$CI = 0.0297(SN)^2 - 1.802(SN) + 31.94 \quad [9]$$

Final calculation of the non-volatile estimation of PM is based on two other derivations. The first is the calculation of the exhaust volumetric core flow rate based on the air-to-fuel ratio (AFR). This term is needed as a multiplier for the concentration index to derive an emission index directly tied to fuel usage as is customary. Whilst details are presented in the working paper by Eyers[31], the reduced equation is:

$$Q_{core} = 0.776(AFR) + 0.733 \quad [10]$$

Where: Q_{core} = Core exhaust volumetric flow rate (M3/kg fuel)
AFR = modal air-to-fuel ratio

In some cases the SN may be measured under mixed flow conditions. Different methods may be employed to adjust for this condition. One possible way, is shown in Equation [11].[32]

$$Q_{mixed} = 0.776AFR(1 + B) + 0.877 \quad [11]$$

Where: B = bypass ratio

From this the EI for PM_{nvol} may be calculated from:

$$EI = Q * CI \quad [12]$$

Where: EI = PM_{nvol} Emission Index (mg/kg fuel)
CI = emission concentration index

Based on the assumptions made, Table 3 lists the volumetric core and mixed engine flows predicted for each mode.

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30 [Whitefield, 2001] Whitfield, P.D., D.E. Hagen, G. Siple, J. Pehrson, Estimation of Particulate Emission Indexes as a Function of Size for the LTO Cycle for Commercial Jet Engines", Proceedings of the Air & Waste Management Association Annual Meeting Orlando, Florida, June, 2001.

31 Eyers, C., CAEP/WG3/AEMTG/WP5, Improving the First Order Approximation (FOA) for Characterizing Particulate Matter Emissions from Aircraft Engines, Alternative Emissions Methodology Task Group (AEMTG) Meeting, Rio De Janeiro, Brazil. November, 2005.

32 Ibid.

Table 3. Engine Volumetric Flow Rates By Mode

Mode	Core Volumetric Flow Rate (M^3/kg fuel)	Mixed Volumetric Flow Rate (M^3/kg fuel)
Idle	83.0	83.133 + 82.256(B)
Approach	65.1	65.285 + 64.408(B)
Climb-Out	40.3	40.453 + 39.576(B)
Take Off	35.7	35.797 + 34.920(B)

B = bypass ratio

Figure 2 shows a sample plot of the idle EI that will occur from this new methodology for SN ≤ 30 while Figure 3 shows a sample plot for the idle mode for SN > 30. It should be noted that the y intercept was adjusted during implementation of the equations for SN > 30 so that a smooth transition occurs between the two equations to avoid a sudden change in predicted EIs. Similar plots could also be presented for the other three ICAO modes based on the AFR.

Figures 2 and 3 illustrate the uncertainties that bound the equations relating SN to PM non-volatile mass. These bounds or limits reflect the error of ± 3 in SN measurements that could occur from analyst to analyst, test to test, and is well accepted among the measurement professionals. The curve labelled "conservative" would represent an upper bound to the EI for a given SN. From this type of analysis, the ICAO Aircraft Engine Emissions Databank can be used to estimate the "best estimate" and "conservative" EIs for all certified engines. Only the "best estimate" and "conservative" equations were illustrated since practitioners would not chose the lower bounds, based on the inaccuracies in this approximation methodology.

Figure 2. Plot of EI for the Idle Mode for Smoke Number ≤ 30

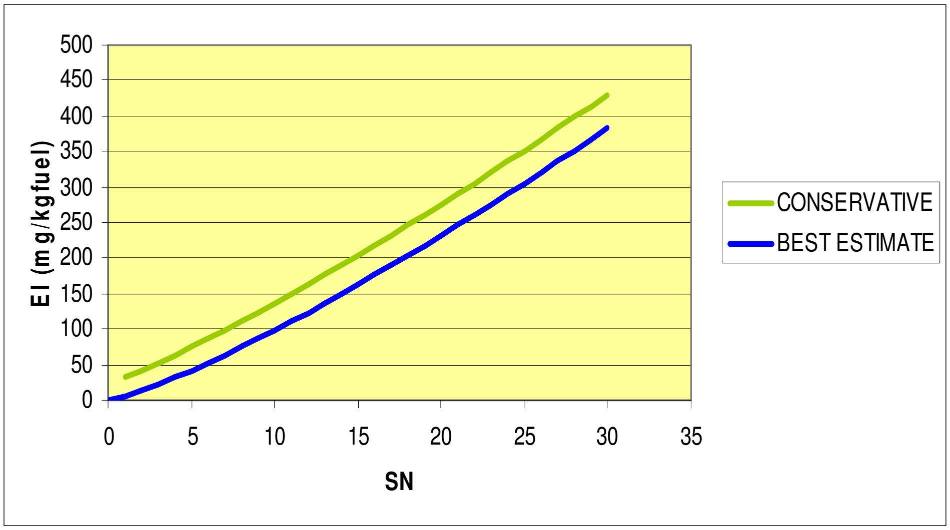
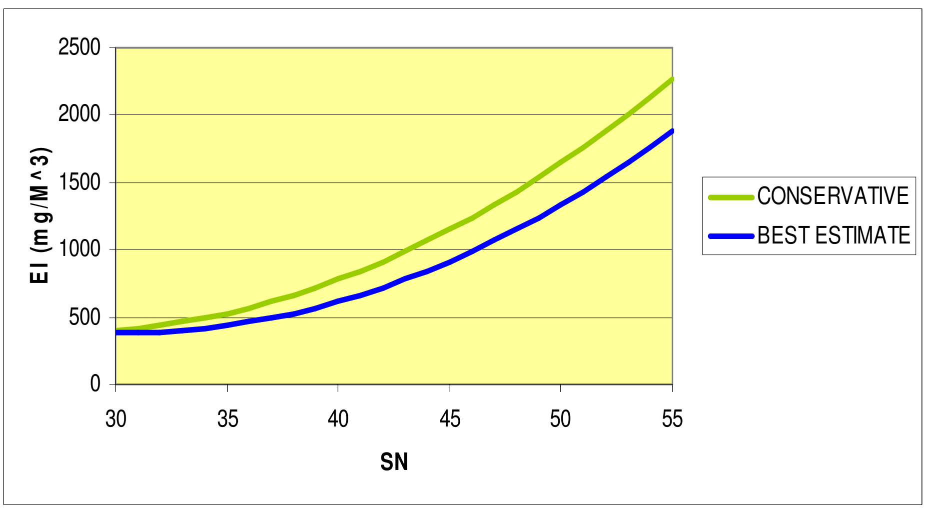


Figure 3. Plot of EI for the Idle Model for Smoke Number >30



The ICAO Aircraft Engine Emissions Databank does not always contain complete SN information for all modes and all engines. To fill in the missing SN information, a procedure[33] was brought forward to the FOA ad hoc group and was accepted as the method to be used based on dividing aircraft into groups by combustor technology and using the trends of each group to fill in the missing SN. The results allow calculation of the non-volatile EI for all engines listed in the ICAO database for each of the four modes.

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[33] Calvert, J.W, Revisions to Smoke Number Data in Emissions Databank, Gas Turbine Technologies, QinetiQ, 23 February 2006.

FOA3 Implementation: In summary, the component calculation approach for FOA3 is as follows:

PMvols = [13]
F(Fuel Sulphur Content) [Equation 5] + F(Fuel Organics) [Equation 6 or Equation 7] + F(Lubrication Oil) [no recommended methodology at this time]

PMnvols = [14]
SN vs. Mass relationship [Equation 8 for SN≤30 or Equation 9 for SN>30];
Calculate Volumetric Flow [Equation 10 for core or Equation 11 for mixed];
Calculate EI_{nvol} [Equation 12]

TOTAL PM = PMvols + PMnvols [15]

All EI calculations should be multiplied by fuel flow for the respective mode and summed to get total PM mass emissions. The FOA3 results are to be used strictly for inventory purposes only.

FOA3 Conclusions: The development of an interim first order approximation method fulfills the need to estimate jet turbine aircraft PM emissions in the vicinity of airports for airport planning and regulatory requirements. The participants of CAEP emissions technical working group are committed to continually improving the FOA methodology as new information becomes available and scientific understanding on the formation of engine PM emissions improves. It is important to keep in mind that the need for an FOA method will become obsolete at a time when engine-specific validated and verified PM EI are available.

APPENDIX
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A2.1 Introduction

A2.1.1 Ground handling of aircraft during operational turn around or for maintenance is an important airport-related emission source. The type and number of vehicles and equipment used for ground handling depends on several factors including aircraft size and type; aircraft stand properties and layout; and the technological and operational characteristics of the ground handling equipment. There are two general types of emissions comprised of four distinct sources in this category: (1) ground support equipment (GSE) and airside vehicle emissions (emissions of engine exhaust) and (2) aircraft refuelling and aircraft de-icing (evaporative emissions of volatile organic compounds (VOC) :

Exhaust Emissions	
▪ Ground Support Equipment	Emissions from vehicles and machinery used to service the aircraft on the ground at the aircraft stand or maintenance area.
▪ Airside Vehicles	Service vehicles and machinery operating on service roads within the airport property (other than GSE).
Evaporative Emissions	
▪ Aircraft Refuelling	VOC evaporation emissions during fuelling processes of aircraft.
▪ Aircraft De-icing	VOC evaporation emissions during de-icing of aircraft (where applicable).

A2.1.2 Vehicle refuelling, fuel farm and surface de-icing emissions are described in the Stationary and Infrastructure-related sources Annex of this guidance.

A2.2 Ground Support Equipment Emissions

A2.2.1 Operations

A2.2.1.1 The operation of GSE is a function of several parameters that can vary considerably from airport to airport (See Figure A2-1). However, in terms of spatial and temporal resolution, GSE emissions can be related to the aircraft operations, as follows:

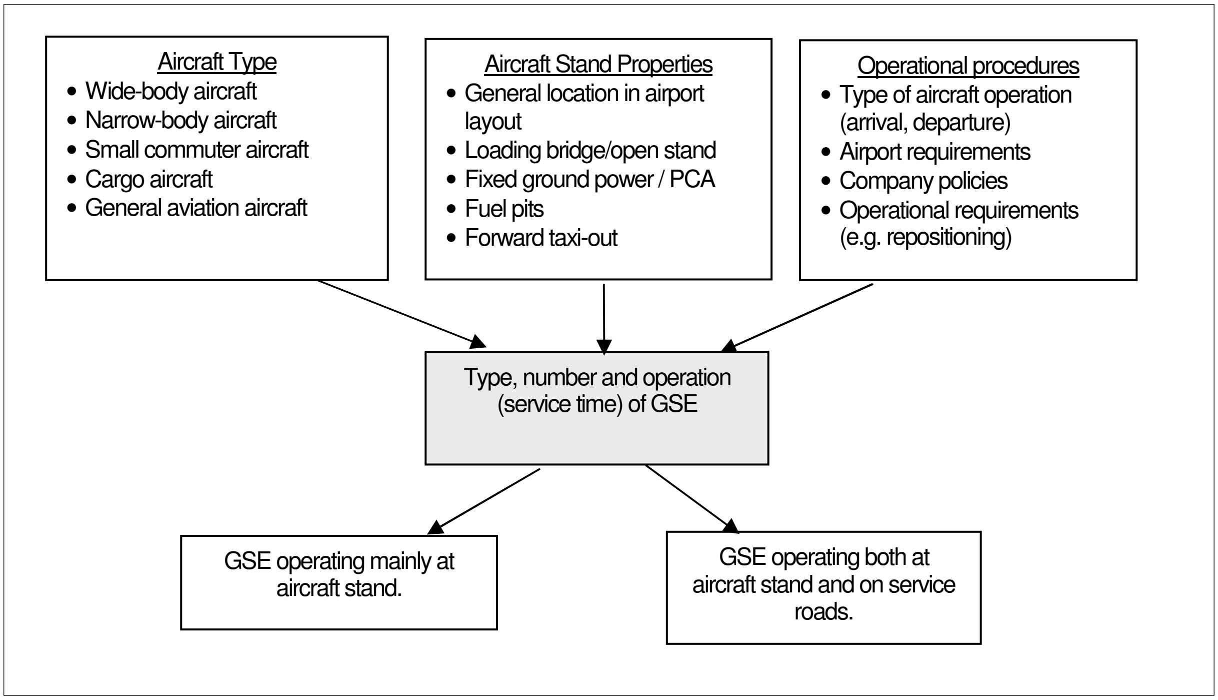

Figure A2-1: Characterization of GSE operations.

A2.2.1.2 Many of the GSE are "non-road" vehicles that have been specially designed to provide services required for aircraft (e.g. cargo loaders, baggage belts, aircraft tugs). They are geared for low-speed, high-torque duties and are built to manoeuvre in tight locations around parked aircraft. They may move across the airport, but generally service a limited number of specific locations. They are generally powered by internal combustion engines of various kinds, but other technologies are sometimes used. Some GSE units, however, operate on an aircraft stand for some time and then use service roads to return to specific facilities (e.g. catering trucks, lavatory, trucks, baggage tugs). They may also be equipped with on-road certified engines. The following table lists the GSE most frequently used to provide ground support services to aircraft with suggested default values for engines and service times.

Typical Ground Support Equipment				
Ground Support Equipment	**Function**	**Engine Type / Equipment**	**Service time per turn**	**Comments**
Ground Power Unit (GPU)	Provides electrical power to aircraft	100-150 kW diesel or gasoline, 15%-50% load	Depends on schedule	Electric system may be integrated into gate / bridge
Air Conditioning/ Heater Unit	Provides pre-conditioned air and/or heat to aircraft	150 kW diesel or gasoline; 50% load	Depends on schedule and weather conditions	Electric PCA may be integrated into gate / bridge
Air Starter Unit	Provides high pressure air flow for starting main engines	150 kW diesel; 90% load	3-5 minutes	Generally not used if aircraft is equipped with an on-board APU
Narrow-body push out tractor	Push back and maintenance towing	95 kW diesel; 25% load	5-10 minutes	Electric powered units available
Wide-body push out tractor	Push back and maintenance towing	400 kW diesel; 25% load	5-10 minutes	
Passenger stairs	Provides easy ramp access	30-65 kW diesel or gasoline; 25% load	2-10 minutes	Non-powered and electric units available
Belt loader	Transfers bags between carts and aircraft	33 kW diesel, gasoline or CNG; 25% load	10-50 minutes	Electric units available
Baggage tug	Tows loaded carts to exchange baggage	30 kW diesel, CNG or gasoline; 50% load	10-50 minutes	Electric units available
Cargo and Container Loader	Lifts heavy cargo and containers to assist transfer	60 kW diesel or gasoline with lift devices; 25% load	10-50 minutes	Different types
Cargo Delivery	Transfers cargo from dollies to loader	30 kW diesel or gasoline; 25% load	10-50 minutes	Different types
Bob tail Truck	Misc. towing and heavy services	90 kW diesel truck; 25% load	Variable	Highly variable
Catering and Service Truck	Cleans and restocks food and supplies	85-130 kW diesel with scissors lift; 10-25% load	10-30 minutes	May use on-road certified engines
Lavatory, Potable Water Truck	Empties aircraft toilet storage, refills aircraft water storage	120 kW diesel with tank and pumps; 25% load	5-20 minutes	May use on-road certified engines
Fuel Hydrant Truck	Delivers fuel from pits to aircraft	70-110 kW diesel with pumps; 10-50% load	10-40 minutes	May use on-road certified engines
Fuel Tanker Truck	Pumps fuel from truck to aircraft	200 kW diesel with pumps; 10-50% load	10-40 minutes	May use on-road certified engines
De-icing Truck	Sprays de-icing fluid on aircraft prior to departure	180 kW diesel with tank, pumps, sprayers; 10-60% load	5-15 minutes	May use on-road certified engines
Maintenance Lift	Provides access to outside of aircraft	70-120 kW diesel, CNG or gasoline; 25% load	Variable, little used	May use on-road certified engines
Passenger buses	Transports passengers to and from aircraft	100 kW diesel, CNG or gasoline; 25% load	Variable (distance rather than time)	May use on-road certified engines
Fork lift	Lifts and carries heavy objects	30-100 kW diesel; 25% load	Highly variable	Electric units available; mostly cargo-related use
Misc. Vehicles (cars, vans, trucks)	Misc. services	50-150 kW diesel, CNG or gasoline; 10-25% load	Highly variable (distance rather than time)	Usually on-road certified engines

A2.2.1.3 As shown, the size of the aircraft sometimes influences the stand allocation and often the handling procedures (e.g. number, types and operating time) involving GSE.

Aircraft Group Characterization	
Aircraft-Group	**Characterisation**
Wide-body Aircraft	• Passenger baggage pre-loaded in containers • Large cargo volume • Passenger stairs with busses or boarding bridge required • Turn around time could include moving aircraft (day-parking)
Narrow-body Aircraft	• Passenger baggage is free-loaded (e.g. not in a container) • Small cargo volume • Passenger stairs with busses or boarding bridge required • Short turn around times
Small Commuter Aircraft	• Passenger baggage open • carry some cargo (very small volume) • Short turn around times • Built-in passenger stairs
Cargo Aircraft	• No '"comfort"' needs (busses, baggage, air-conditioning) • Specialised cargo-handling equipment and vehicles
General Aviation Aircraft	• No baggage, cargo, stairs • Limited handling activities

A2.2.1.4 At most airports, the two following types of aircraft stands can be found:

- Pier stands where a passenger boarding bridge connects the aircraft to the building and
- Remote/open stands where an aircraft is parked free of direct building connections (for passenger and/or cargo operations).

A2.2.1.5 The stands themselves can exhibit considerable differences in terms of location and technical equipment available which influence the number and operations of GSE and thus emissions from this source. Stands may also differ for reasons of dedicated usage, (e.g. whether a stand is used for cargo aircraft or for passenger aircraft).

Properties of Aircraft Stands		
Stand Properties	**GSE and Operational Consequences**	**Notes**
Stand equipped with passenger boarding bridge	• Aircraft doesn't require passenger stairs;	May require Pre-conditioned Air (PCA), heating, and/or GPU
Stand equipped with fixed 400 Hz	• Aircraft doesn't require GPU; • Aircraft might need air conditioning unit (ACU)	
Additionally equipped with PCA (stationary) or through Aircraft Climate Unit (ACU))	• Aircraft doesn't require GPU or ACU;	Stationary only together with 400 Hertz (Hz)
Stand equipped with kerosene pipeline	• Aircraft doesn't require refuelling tanker truck;	Aircraft requires hydrant fuel truck
Proper layout for self powered break away	• Aircraft doesn't require push-back tractor.	Not possible on stands with bridge

A2.2.1.6 Operational procedures also determine the types and amounts of GSE services required; described as follows:

- The type of GSE used varies widely across applications. For example, different GSE types are required for servicing aircraft after landing than are used prior to departure, and for servicing passenger and cargo operations;
- Government regulations (e.g. safety, operational requirements) and airport operator requirements (e.g. airport-specific procedures or restrictions) may limit or preclude the use of certain GSE;
- The airline operator, in cooperation with the handling agent, might follow specific procedures that influence the emissions of GSE,
- Airport infrastructure can affect the feasibility of alternative fuel types or other factors that can affect emissions; and
- Airport stand layout and flexibility in operations may also be a factor (relocating GSE from stand to stand or to remote stands during operations).

A2.2.1.7 Operational data can be obtained in different ways (e.g. bottom-up, by assessing individual pieces of GSE or top-down; by using global operating times; or fuel consumption over the total GSE population). Each alternative provides advantages and the choice among them will depend on factors such as the purpose and design of the emission inventory, the availability of data and their accuracy. Operational data could include:

- Total fuel burn by all GSE (by different fuel types);
- Total hours of operation for each GSE type and number of units per type (again, with distinction by fuel type); and
- Operating time for each GSE unit for specific or individual aircraft operations (e.g. LTO in general or arrival and departure separately). Spatial and temporal information might be also included. The accuracy of GSE service time in this case is very important as even small deviations can yield large errors. For example, if a tug was used 8 minutes per cycle (instead of 6 minutes) and the handling cycles were 25,000, the error would be 843 operating hours.

A2.2.2 Emission Factors

A2.2.2.1 Emission factors for GSE are not uniform for all regions of the world. Depending on regional or national standards or local operational requirements, the same type of equipment might be equipped with different engines (e.g. size and technology). Emission factors are also often reported as off-road vehicle or non-road mobile machinery emission factors. They are dependent on fuel type, engine size, load factor, technology, age (or deterioration factor) and additional emission reduction devices. It is recommended that the analysts obtain industry specific data first or to check with the proper authorities for other available emission factors if they are not otherwise available.

A2.2.3 Emission Calculation

A2.2.3.1 The calculation of GSE emissions can be done by following either of the two following Simple Approaches, as well as the Advanced and Sophisticated Approaches:

A2.2.3.2 Primary Simple Approach

A2.2.3.3 In a very simple method using the aircraft-based approach, emissions can be calculated using the number of aircraft arrivals, departures or both and default emission factors. With this approach, there is no analysis of the GSE fleet and GSE operation necessary. Examples of emissions factors representative of Switzerland's Zurich Airport that could be used for this approach follow. As aircraft handling equipment varies by State, airport, and aircraft operator, an analysis should be performed using emission factors appropriate for the GSE fleet being assessed.

Example Default Emission Factors Representative of Zurich Airport for Aircraft Handling[34]			
Pollutant	Unit	Narrow body Aircraft (single aisle fixed wing jet)	Wide body Aircraft (double aisles fixed wing jet)
NO_x	kg/cycle	0.400	0.900
HC	kg/cycle	0.040	0.070
CO	kg/cycle	0.150	0.300
PM_{10}	kg/cycle	0.025	0.055
CO_2	kg/cycle	18	58

A2.2.3.4 For this application, emissions are calculated by multiplying the number of movements (by aircraft category, or the total if no differentiation is available) with the respective emission factor (or the average of both factors if no aircraft differentiation is available).

A2.2.3.5 For example, at an airport with 23,450 narrow body aircraft movements and 9,600 wide body aircraft movements and assumed NO_x emission factors of 0.4 kg/cycle and 0.9 kg/cycle, the total amount of NO_x is:

*0.4 kg/cycle * (23,450 movements) [Narrow Body] + 0.9 kg/cycle * (9,600 movements) [Wide Body] = 9,010 kg NO_x*

A2.2.3.6 Secondary Simple Approach

A2.2.3.7 An alternate, more simplified, method involves the fuel use by GSE. In this approach, emissions are calculated by obtaining actual fuel use data for GSE (or estimating such data) and then combining these data with average emission factors, independent of equipment number, size or technology. Examples of emissions factors representative of Europe that could be used for this approach

[34] Unique (Flughafen Zürich AG).

follows. As aircraft handling equipment varies by State, airport, and aircraft operator, an analysis should be performed using emission factor values appropriate for the GSE fleet being assessed.

$$Emission_{Pollutant}\,[g] = \sum_{fuel\ types} (total\ fuel\ type\ used\ [kg] \times average\ emission\ factor\ [g/kg\ fuel\ type]) \qquad \text{Eq A2-1}$$

Example European Emissions Factors for Aircraft Handling (2)[35]		
Pollutant	**Diesel (g/kg)**	**Gasoline (g/kg)**
NOx	48.2	9.6
HC	10.5	45.5
CO	15.8	1193.0
PM	5.7	--
CO_2	3150	3140

A2.2.3.8 For example: if the total amount of diesel fuel used for GSE is 128,500 kg, and an average emission factor of 48.2 g NO_x/kg fuel is assumed, the total amount of NO_x emissions is: 6,194 kg.

A2.2.3.9 Advanced Approach

A2.2.3.10 Following this approach, emissions are calculated for the entire GSE population as a whole or individually according to aircraft-specific GSE requirements. In both cases, the actual operating time or fuel usage during a defined period of time (e.g. one year) for each type of GSE is used. To apply this calculation method, it is necessary to obtain or estimate the population for fleet of GSE by category and associated activity (hours/year, fuel usage /year) for each piece of GSE. There are two alternatives using the total fuel usage or the total operating hours over the population of a specific GSE model. When using the total operating hours, emissions can be calculated using the specific fuel flow or the size and load factor of the GSE model. If available, a deterioration factor can be considered as well.

$$\text{Emission}_{\text{Pollutant}}\,[\text{g/GSE}] = \text{fuel flow [kg/h]} \times \text{emission factor}_{\text{Pollutant}}\,[\text{g/kg fuel}] \times \text{time [h]}\ (\times\ \text{DF}) \qquad \text{Eq A2-2}$$

Or

$$\text{Emission}_{\text{Pollutant}}\,[\text{g/GSE}] = \text{power [kW]} \times \text{load [\%]} \times \text{emission factor}_{\text{Pollutant}}\,[\text{g/kW}] \times \text{time [h]}\ (\times\ \text{DF}) \qquad \text{Eq A2-3}$$

Or

$$\text{Emission}_{\text{Pollutant}}\,[\text{g/GSE}] = \text{fuel flow [kg/a]} \times \text{emission factor}_{\text{Pollutant}}\,[\text{g/kg fuel}]\ (\times\ \text{DF}) \qquad \text{Eq A2-4}$$

where:

power = size of engine [kW, sometimes bhp]

emission factor = based on engine type, fuel type, age, and reflecting design and emission control technology of GSE

time [h] = total annual operating time

DF = Deterioration Factor

A2.2.3.11 For this application, GSE emissions are then summed for all individual pieces of a specific equipment type and over the whole GSE population.

[35] Diesel and Gasoline: CORINAIR (other values may be used if deemed more appropriate).

A2.2.3.12 For example, if all passenger stairs at the airport with diesel engines of 95 kW, an EI of 6.0 g NO_x/kWh and a load factor of 25 percent total 3,500 operating hours, and a deterioration factor of 3 percent are assumed, the total amount of NO_x emissions is:

95 kW × 0.25 load factor × 6.00 g/kW-hr × 3,500 hours × 1.03 deterioration factor

= 513,712.5 g (514 kg NO_x).

A2.2.3.13 Sophisticated Approach

A2.2.3.14 Under this approach, all GSE emissions are calculated for each individual aircraft operation (e.g. arrival, departure or maintenance). This operational distinction is relevant when linking the aircraft handling activities to flight tables where an arriving and departing flight does not have the same flight number or arrival and departure are not in a timely sequence (e.g. for night stops).

$$\text{Emission}_{\text{Pollutant}}\ [g] = \text{power}\ [kW] \times \text{load factor}\ [\%] \times \text{emission factor}_{\text{Pollutant}}\ [g/kWh] \times \text{time}_{\text{A/C-Ops}}\ [h] \times DF \quad \text{Eq A2-5}$$

where:

time $_{\text{A/C-Ops}}$ [h] = average time for GSE unit operation, dependent on type of operation (arrival, departure or Maintenance), stand property and aircraft size

DF = Deterioration Factor (reflecting age and maintenance of GSE)

A2.2.3.15 GSE emissions are again tallied up for all individual pieces of a specific equipment type and all individual aircraft handling (including maintenance) operations.

A2.2.3.16 For example, a passenger stair is operated 10 minutes for a B-737 size aircraft at an open (e.g. remote) stand upon arrival. The stair has a 45 kW engine, operated at 25 percent load, with a NO_x EI of 6.0 g/kW-hr and a deterioration factor of 3 percent. The total NO_x of this GSE operation is:

45 kW × 0.25 load factor × 6.0 g/kW-hr × 1.03 deterioration factor × 10 minutes x 1-hour/60 minutes = 11.61 g NOx.

A2.3 Airside Vehicle Traffic

A2.3.1 Airside vehicle traffic is considered to be all machinery and vehicles that operate on airside service roads within the airport perimeter as opposed to on aircraft stands only. As such, emissions are considered to be generated while travelling over distances rather than during periods of time. Airside vehicles do not include GSE as defined previously. Also, passenger and employee traffic operating on the landside is described separately in the chapter on Vehicle Traffic Emissions of this guidance.

A2.3.2 Most airside vehicles are "on-road equivalent vehicles" and calculation of their emissions can be done the same way as for landside road vehicles. The guidance to do so is given in Annex A4.

A2.4 Aircraft Refuelling

A2.4.1 At most airports, aircraft are either refuelled through an underground pipeline system with fuel hydrant trucks or from individual fuel tanker trucks. In both cases, fuel vapour (remaining from flight fuel mixed with air) emitted from aircraft fuel tanks during the fuelling process. Vapours are also emitted when the tanker truck is being filled with fuel at the fuel farm or equivalent storage facility. Any emission caused by the handling of the fuel during delivery to the fuel farm or storage facility is not considered to be part of this procedure, but described separately in the Stationary Sources Annex of the guidance.

A2.4.2 The operational data that is required for computing aircraft refuelling emissions include:

- Amount of fuel, by fuel type (e.g. kerosene or aviation gasoline), delivered to aircraft by fuel hydrant truck [kg], and/or
- Amount of fuel delivered to aircraft by fuel tanker truck [kg].

A2.4.3 The average emission factors (also called emission indices (EI) that are needed include:

- Emissions in g VOC/kg fuel for refuelling with kerosene, and
- Emissions in g VOC/kg fuel for refuelling with aviation gasoline.

A2.4.4 Typical emission factors for Zurich Switzerland follow. An analysis should be performed using emission factor values appropriate for the State and/or airport being assessed.

Aircraft Refuelling[36]	Unit	Value
Refuelling with kerosene	g VOC/kg fuel	0.01
Refuelling with aviation gasoline	g VOC/kg fuel	1.27

A2.4.5 From this information, the emission calculation is conducted using the following general equation:

$$\text{Emissions [g VOC]} = \sum_{\text{fuel types}} \left((\text{fuel}_{\text{hydrant delivered}}\ [\text{kg}] + 2\times \text{fuel}_{\text{tanker delivered}}\ [\text{kg}]\,) \times \text{emission factor [g/kg]e} \right) \quad \text{Eq A2-6}$$

A2.4.6 For example, if a total of 1,500,000 kg of Jet-A1 (EI of 0.01 g VOC/kg) are delivered, of which 85 percent by a hydrant system and 500 kg of AVGAS (EI of 1.27 g VOC/kg) all by truck, the total amount from aircraft refuelling is:

(1,500,000 kg Jet A-1 x 0.85 x 0.01 gVOC/kg Jet A-1)+(1,500,000 kg Jet A-1 x 0.15 x 2 connections x 0.01 gVOC/kg Jet A-1)+(500 kg Avgas x 2 connections x 1.27 gVOC/kg Avgas) = 18,520 kg VOC

A2.5 Aircraft De-icing

A2.5.1 Deicing operations for aircraft and airfield facilities can be a source of VOCs and other compounds. Comprised of both propylene- or ethylene-glycol and water, the mechanical application of deicing and anti-icing agents to aircraft results in some loss to the atmosphere due to evaporation and overspray. However, because of growing concerns over the effects of deicing chemicals on water quality, conservation and recovery processes are now commonly used which also reduce the potential air quality impacts.

A2.5.2 VOC emissions from deicing/anti-icing activities[37] are generally based on the amount of deicing fluid used, the percentage of the deicing chemical (i.e. ethylene glycol) in the mixture and an emission factor. A U.S. source of VOC emission rate data for deicing/anti-icing activities for aircraft and for runways, taxiways, etc., is provided within the following. An analysis should be performed using emission factor values appropriate for the State and/or airport being assessed.

Sources of Emission Data – Deicing/Anti-icing Activities

Substances	Source(s)
Propylene glycol/ethylene glycol	FAA's Air Quality Handbook, Section H3.3.2.4 (Emission Indices)

A2.5.3 For demonstration purposes, the following formula for calculating VOC emissions from deicing/anti-icing activities is provided:

$$E_{VOC} = DF \times DS \times W_{DS} \times EF \qquad \text{Eq A3-6}$$

where

[36] KIGA (Cantonal Office for Trade and Industry) Zurich, Switzerland, 1994 (other values may be used if deemed more appropriate).

[37] At airports, there are two types of de-icing activities that are disconnected: aircraft de-icing, as part of the handling activities of an aircraft and surface de-icing as part of the maintenance of the airport (irrespective of traffic volume or size of aircraft).

E_{VOC} = emissions of VOC (e.g. kilograms)

DF = amount of deicing fluid (e.g. litres)

DS = amount of deicing substance in deicing fluid (percentage)

W_{DS} = weight of deicing substance (e.g. kilograms/litre)

EF = emission factor (e.g. kilograms/kilograms of deicing chemical)

A2.5.4 Using this formula, the following example is given for deicing operations at an airport: Assume an airport uses 5 kilolitres of a deicing mixture to deice aircraft and 65 percent of the deicing mixture is ethylene glycol. The weight (or density) of the ethylene glycol is approximately 2 kilograms/kilolitre and the emission factor is 0.11 kilogram of VOC per kilogram of ethylene glycol used. Therefore, the amount of VOC emissions produced would be:

5 kilolitres x 0.65 x 2 kilogram/kilolitre x 0.11 kilograms VOC/kilogram of deicing agent = 0.65 kilograms of VOC

A2.5.5 Future emission levels can be based on a projected increase in aircraft operations and/or on the total area of runways/taxiways/roadways, if applicable.

Chapter 2
Emissions Inventory
Annex 3
Infrastructure Related and Stationary Source Emissions

Table of Content

A3.1 Introduction

A3.1.1 Airports are typically viewed as an assemblage of moving or "mobile" sources of emissions (i.e. aircraft, GSE, and motor vehicles). However, most airports also include "stationary" sources of emissions (i.e. boilers, emergency generators, incinerators, etc.) as part of their infrastructure and support facilities. In contrast to mobile sources, stationary sources are "non-mobile" and remain "fixed" or "motionless", discharging the emissions through an assortment of conveyances such as smokestacks, chimneys, flues and/or vents.

A3.1.2 Other airport infrastructure-related sources of air emissions are classified as "area" sources. In concept, these sources discharge emissions directly to the atmosphere and can be either mobile or stationary in nature. Typically, area sources at airports include fuel storage/transfer facilities, live-fire training facilities, deicing operations and construction activities. Also categorized as "off-road" or "non-road" sources of emissions, the construction activities comprise a wide variety of trucks, earth movers, excavators, pavers and other heavy equipment. Construction activities involving the storage/transportation of raw materials, the disposal of construction debris and the production of asphalt or concrete are also considered area sources.

A3.1.3 The information presented in this section provides guidance on preparing emission estimates for stationary and area sources at airports and for the pollutants of CO, THC, NMHC, NO_x, SO_x, and PM_{10}.

A3.1.4 There are a wide range of data bases for emission factors which can be used to calculate the types and amounts of emission releases from stationary sources at airports. However, the two which are most commonly cited in Europe and North America are those produced by the U.S. EPA and the European Environment Agency such as:

1. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources (AP-42)*, Fifth Edition and Supplements, 1995 (with supplements through 2004)
2. *Coordinated Information on the Environment in the European Community – Air (Corinair) – CORINAIR Atmospheric Emissions Inventory Guidebook* 2005.

   http://reports.eea.eu.int/EMEPCORINAIR4/en/tab_abstract_RLR

A3.1.5 However, the methodological approaches set out in the documents cited are broadly similar to those used in other Countries and Regions and it is beyond the scope of this guidance manual to list all national sources of information. Within this chapter, a number of worked examples are put forward using data from the U.S. EPA but the authors could have chosen others. It is the responsibility of the airport officials who are tasked with developing emission inventories to use the most appropriate emission factors.

A3.2 Power/Heating Plants, Boilers and Generators

A3.2.1 Emissions from power/heating plants (i.e. boilers and space heaters) and emergency generators are largely contained in the exhaust of burning hydrocarbon-based fuels. These include emissions of CO, NO_x, HC, SO_x and PM_{10}. A variety of fuels are used in power/heating generating plants including coal, fuel oil, diesel fuel, gasoline, natural gas as well as liquid petroleum gas (LPG) and each one has it's own emission characteristics.

A3.2.2 For existing stationary sources that have operating permits, the types and amounts of air pollutant emissions can usually be obtained from the appropriate regulatory agency files and/or the operating permit itself. In the absence of such a permit or supporting information, emissions are typically based on the time period (i.e. horsepower-hours) of actual or estimated equipment usage (i.e. activity rates), the fuel type and any applicable emission control or reduction technologies. For new or expanded boilers/space heaters, future activity rates can be based on the increase in airport terminal area in cases where gross estimates are sufficient for the analysis.

A3.2.3 Commonly-used sources of available emissions rate data for boilers/space heaters (by fuel type and pollutant) are provided and emission data for emergency generators follow.

Sources of Emission Data – Boilers/Space Heaters

Fuel		Source(s)
Coal	Anthracite	1985 National Acid Precipitation Program
		AP-42, Vol.1, Tables 1.2-1 and 1.2-2
		EPA's Factor Information Retrieval (FIRE) Data System
		USGS COALQUAL database
		CORINAIR Emissions Inventory Guidebook - 2005
	Bituminous	AP-42, Vol.1, Tables 1.1-3, 1.1-4 and 1.1-19
		EPA's Factor Information Retrieval (FIRE) Data System
		USGS COALQUAL database
		CORINAIR Emissions Inventory Guidebook - 2005
	Bituminous/ Subbituminous	AP-42, Vol.1, Tables 1.1-3, 1.1-4 and 1.1-19
		LIFAC Sorbent Injection Desulfurization Demonstration Project findings.
		USGS COALQUAL database
		CORINAIR Emissions Inventory Guidebook - 2005
	Subbituminous	AP-42, Vol.1, Tables 1.1-3, 1.1-4 and 1.1-19
		EPA's Factor Information Retrieval (FIRE) Data System
		USGS COALQUAL database
		CORINAIR Emissions Inventory Guidebook - 2005
Fuel Oil		1985 National Acid Precipitation Program
		AP-42, Vol.1, Tables 1.3-1, 1.3-3, 1.3-4, 1.3-5, 1.3-6, and 1.3-7
		EPA's Factor Information Retrieval (FIRE) Data System
		CORINAIR Emissions Inventory Guidebook - 2005
LPG		AP-42, Vol.1, Table 1.5-1
		Haneke, B.H. - A National Methodology & Emissions Inventory., pg. 4
		CORINAIR Emissions Inventory Guidebook - 2005

Natural Gas	AP-42, Vol.1, Tables 1.4-1 and 1.4-2 CORINAIR Emissions Inventory Guidebook - 2005

Sources of Emission Data – Emergency Generators

Fuel	Methodology	Source(s)
Diesel Fuel	USEPA	AP-42, Vol.1, Table 3.1-1
	USAF (Distillate Oil)	FAA's Air Quality Handbook, Table H-2 1985 National Acid Precipitation Program
Gasoline	USAF	FAA's Air Quality Handbook, Table H-2 NONROAD
	USEPA	AP-42, Vol.1, Table 3.1-1
Kerosene/Naphtha (Jet Fuel)	USAF	FAA's Air Quality Handbook, Table H-2
LPG (Propane or Butane)	USAF	FAA's Air Quality Handbook, Table H-2 NONROAD
Natural Gas	USAF	FAA's Air Quality Handbook, Table H-2
Residual/Crude Oil	USAF	FAA's Air Quality Handbook, Table H-2

A3.2.4 For demonstration purposes, estimates of emissions from power/heating plants, boilers and generators are calculated using the following general equation:

$$E = A \times EF \times (1-ER/100) \qquad \text{Eq A3-1}$$

where:

E = emissions (e.g. kilograms/day)

A = activity rate (e.g. horsepower-hour or litres/day)

EF = emission factor (e.g. kilograms/litre specific to fuel type and pollutant)

ER = control equipment emission reduction efficiency (%)

A3.2.5 In cases where fuel sulfur content is important, an alternative formula may be more appropriate. Using this formula, the following example is given for an airport emergency generator. Assume an airport has a 335 horsepower diesel engine emergency generator with an emission reduction efficiency of 75 percent. If the emission factor for NO_x is 14.0 grams/horsepower-hour and the airport operates the generator 1,000 hours annually, total NO_x emissions would be:

1,000 hours x 14.0 grams/horsepower-hour x 335 horsepower x (1-75/100) =

1,172,500 grams of NO_x

A3.3 Incinerators

A3.3.1 When located at airports, incinerators are typically used to destroy or sterilize refuse and other regulated waste products produced and transported on international aircraft. An airport may also have food preparation facilities that use incinerators to dispose of solid wastes (i.e. paper, wood, plastics and other rubbish).

A3.3.2 Combustible waste incinerators have a variety of furnace types and configurations (i.e. in-line, retort, etc.), include a single or multiple combustion chamber(s), and are typically fuelled by natural gas, oil, or LPG. Control equipment and technologies are used in both the burning process and at the stack to help reduce excess emissions.

A3.3.3 For existing incinerators that have operating permits, estimates of air pollutant emissions can be obtained from the appropriate regulatory agency files and/or the operating permit itself. In the absence of a permit, emission estimates are often based on the fuel type, the contents and amounts of refuse incinerated and appropriate emission factors for the fuel, refuse and combustion chamber design. For new and expanding facilities, the forecasted amounts of incinerated refuse can be based on the projected increase in international flights and/or increases on food service providers, if applicable.

A3.3.4 Commonly-used sources of emissions rate data for combustible waste incinerators are provided.

Sources of Emission Data – Combustible Waste Incinerators

Number of Chambers	Source(s)
Single and Multiple	AP-42, Vol.1 Table 2.1-12 EPA's Factor Information Retrieval (FIRE) software CORINAIR Emissions Inventory Guidebook – 2005 (Group 9)

A3.3.5 For demonstration purposes, estimates of emissions from a combustible waste incinerator are calculated using the following general equation:

$$E = A \times EF \times (1-ER/100) \qquad \text{Eq A3-2}$$

where:

E = emissions (e.g. kilograms/year, grams/day, etc.)

A = amount of refuse incinerated (e.g. metric tonnes or kilograms/day)

EF = emission factor (e.g. kilograms or grams/metric ton)

ER = control equipment emission reduction efficiency (%)

A3.3.6 Using this formula, the following example is given for an airport emergency generator. Assume an airport has a single chamber incinerator with an emission reduction efficiency of 80 percent. If the emission factor for CO is 1.0 kilograms/metric ton of waste and the airport incinerates 2,500 metric tonnes of waste, the total CO emissions would be:

1.0 kilograms x 2,500 metric tonnes x (1-80/100) = 500 kilograms of CO (i.e. 0.5 metric tonnes)

A3.4 Aircraft/Airport Maintenance Facilities

A3.4.1 At most large airports, aircraft maintenance facilities are typically operated by commercial airlines or other service providers and perform scheduled aircraft inspections and repairs on the aircraft fuselage, engines and other apparatus. A variety of surface treatment, coating and painting operations may also occur. At smaller airports, these maintenance services are typically offered by privately-owned fixed-based operators (FBO).

A3.4.2 Airports also often involve a variety of support facilities for the building and airfield maintenance staffs, supplies and activities. Actions and operations that generate emissions associated with these types of facilities include building painting; runway/taxiway/apron striping; asphalt/concrete repair and cleaning. Because these activities often involve liquid coatings, petroleum-based solvents and other evaporative substances, the primary pollutants of concern are VOC.

A3.4.3 In most cases, the emissions from these sources generally result from evaporation and/or over-spray of the used materials. In only a few cases are the amounts of emissions considered to be significant.

A3.4.3 Material Safety Data Sheets (MSDS) for most products and substances can be used to obtain the volatile content of the VOC (typically expressed in lbs (or grams) of VOC per gallon (or litre) of the substance used). Alternative sources of emissions rate data for surface coating and other solvents are provided.

Sources of Emission Data – Aircraft/Airport Maintenance Facilities

Activity	Substances	Source(s)
Surface Coating	Paint (solvent and water based), enamel, lacquer, primer, varnish/shellac, thinner, and adhesive	• FAA's *Air Quality Handbook*, Table H-5 (Jagielski, Kurt D., and Robert J. O'Brien, Calculation Methods for Criteria Air Pollutant Emission Inventories) • CORINAIR Emissions Inventory Guidebook – 2005 (Group 6)
Solvent Degreasers	Acetone, alcohol (ethyl and methyl), carbon tetrachloride, chloroform, ether, isopropyl alcohol, methylene chloride, perchloro-ethylene, stoddard solvent, 1,1,1-trichloroethane, trichloro-ethylene, and turpentine	• FAA's *Air Quality Handbook*, Table H-7 • CRC Handbook of Chemistry and Physics, 63rd Edition). • Occupational, Health & Safety Administration (OSHA) www.ohsah.bc.ca/index. • CORINAIR Emissions Inventory Guidebook – 2005 (group 6)

A3.4.4 For demonstration purposes, estimates of VOC emissions from surface coating can be obtained using the following general equation that considers the quantity of the coating used, the VOC content of the substance and, if applicable, an emissions reduction efficiency factor for the application process:

$$E_{VOC} = Q \times VOCC \times ER \qquad \text{Eq A3-3}$$

where

E_{VOC} = emissions of VOC (e.g. kilograms)

Q = quantity of coating substance (e.g. litres)

VOCC = VOC content of the coating substance (e.g. grams/litre)

ER = control equipment emission reduction efficiency (%)

A3.4.5 Using this formula, the following example is given for the use of a metal cleaning solvent. If an aircraft maintenance facility uses 2,500 litres of primer in a spray booth that has an emission reduction efficiency of 65 percent and the VOC content of the primer is 3.2 kilograms per litre, the amount of VOC emitted would be:

2,500 litres x 3.2 kilograms/litre x (1-65/100) = 2,800 kilograms of VOC (i.e. 2.8 metric tonnes)

A3.4.6 Another example involves the evaporation of a solvent directly to the atmosphere. In this case, it is assumed that not all of the solvent is disposed of. Therefore, as shown in the following equation, the difference in the amount of the solvent used and the amount of the solvent disposed of is multiplied by the density of the substance to derive the amount emitted to the atmosphere:

$$E_{VOC} = (QC - QD) \times D$$

where:

E_{VOC} = emissions of VOC

QC = quantity of solvent consumed (e.g. litres)

QD = quantity of solvent disposed as liquid waste (e.g. litres)

D = solvent density (e.g. kilograms/litre)

A3.4.7 Using this formula, the following example is given for an airport emergency generator. Assume an airport maintenance facility uses 950 litres of turpentine, disposes of 750 of the litres as liquid waste, and the density of turpentine is 0.87 kilograms per litre. The amount of VOC would be:

950 litres consumed – 750 litres disposed= 200 litres

200 litres x 0.87 kilograms/litre = 174 kilograms of VOC (i.e. 0.174 metric tonnes).

A3.5 Fuel Farm, Hydrant System and Vehicle Refueling Stations

A3.5.1 Airport fuel storage and transfer facilities can contain a variety of fuels with jet fuel (Jet-A, jet kerosene, JP-4), aviation gasoline (avgas) and motor vehicle fuels (gasoline and diesel) being the predominant types. These facilities and transfer operations are a potential source of evaporative hydrocarbons (e.g. VOC)

A3.5.2 Fuel storage tanks can emit VOC from both “standing” (i.e. storage) and “working” (i.e. withdrawal and/or refilling) activities. Important variables that have an affect on the amounts of emissions released include the vapor pressure of the fuel; the storage and throughput volumes; the type(s) of tank(s) (i.e. above-ground, floating roof, etc.) and climatic conditions (i.e. temperature and humidity). Importantly, the vapor pressures of jet fuel and diesel are so low that most environmental agencies do not require any controls on these emissions.

A3.5.3 A common source of emissions rate data for fuel storage tanks are provided.

Sources of Emission Data – Fuel Storage Tanks

Tank Type	Fuels	Source(s)
Horizontal, Vertical Fixed Roof, Internal Floating Roof, External Floating Roof, Domed External Floating Roof	Jet Naphtha (JP-4), Jet Kerosene, Gasoline, Distillate Fuel Oil No. 2, Residual Fuel Oil No. 6	AP-42, Fifth Edition, Volume 1, Chapter 7: Liquid Storage Tanks.

A3.5.4 For demonstration purposes, estimates of VOC emissions from fuel storage tanks can be obtained using the following general equation that considers both the standing and working losses.

$$E_{VOC} = SL + WL = (QS \times EF) + (QT + EF) \qquad \text{Eq A3-4}$$

where

E_{VOC} = emissions of VOC (e.g. kilograms)

SL = standing loss

WL = Working loss

QS = quantity of fuel stored (e.g. kilolitres)

QT = quantity of fuel throughput (e.g. kilolitres)

EF = emission factor for fuel type (e.g. kilograms/kilolitre)

A3.5.5 Using this formula, the following example is given for the storage and transfer of jet fuel in an aboveground tank. If a fuel facility stores 1,500 kilolitres of jet fuel (with a standing loss of 200 grams of VOC/kilolitre. a day) and dispenses 90 kilolitres of fuel daily (with a working loss of 100 grams of VOC/kilolitre a day), the estimated amount of VOC emitted would be:

(1,500 kilolitres x 200 grams/kilolitre) + (90 kilolitres x 100 grams/kilolitre)

= 309 kilograms of VOC (i.e. 0.31 metric tonnes)

A3.6 Fire Training

A3.6.1 At some airports, Airport Rescue Fire Fighting (ARFF) personnel conduct emergency response training using live-fire simulators. Fuelled with either jet fuel or diesel, these facilities can be a source of dense black smoke, particulate matter and VOC, when used. New, "low-smoke" fuels are also available and considered to be more environmentally acceptable as are the propane-fuelled facilities.

A3.6.2 The quantity of fuel used for ARFF "live-fire" training varies by the frequency of use, the type(s) of fires created and the fuel type.

A3.6.3 The FAA *Air Quality Handbook* is the most authoritative source of information for fire training activities and is not included within the CORINAIR publications. Available sources of emissions rate data for the most common fuels used in fire training activities are provided.

Sources of Emission Data – Fire Training

Fuel Type	Source(s)
JP-4, JP-8, Propane	FAA's Air Quality Handbook, Table H-3 (Emission Indices for Uncontrolled Fuel Burning in Training Fires)
JP-5, Tekflame	Exxon Mobil Chemical

A3.6.4 Estimates of air pollutant emissions from live-fire training exercises are based on the fuel type, quantity of fuel burned and emission rates by pollutant. These emissions can be calculated using the following equation:

$$E = QF \times EF \qquad \text{Eq A3-5}$$

where

E_{VOC} = emissions of VOC

QF = quantity of fuel (e.g. in kilolitres)

EF = emission factor (e.g. grams/kilolitre of fuel)

A3.6.5 Using this formula, the following example is given for an ARFF live-fire training facility. Assume an airport conducts live-fire training once every month and 3 kilolitres of propane is used each time (i.e. 36 kilolitres per year). Assuming a PM emission factor for propane of 18 kilograms/kilolitre of fuel, the amount of PM emitted would be:

36 kilolitres x 18 kilograms/kilolitre = 648 kilograms of PM (i.e. 0.65 metric tonnes).

A3.7 Deicing/Anti-icing Activities

A3.7.1 Deicing operations for airfield surfaces can be a source of VOCs and other compounds. Comprised of both propylene- or ethylene-glycol and water, the mechanical application of deicing and anti-icing agents results in some loss to the atmosphere due to evaporation and overspray. On runways, taxiways and aprons, urea, potassium acetate, or solutions of ethylene glycol, urea and water are used. However, because of growing concerns over the effects of deicing chemicals on water quality, conservation and recovery processes are now commonly used which also reduce the potential air quality impacts.

A3.7.2 VOC emissions from deicing/anti-icing activities are generally based on the amount of deicing fluid used, the percentage of the deicing chemical (i.e. ethylene glycol) in the mixture and an emission factor. The sources of VOC emission rate data for deicing/anti-icing activities for aircraft and for runways, taxiways, etc., are provided. An example calculation for aircraft de-icing is found in Annex A2 Section 5 of this guidance, and the calculation for airfield surface is conducted in the same manner.

Sources of Emission Data – Deicing/Anti-icing Activities

Substances	Source(s)
Propylene glycol/ethylene glycol	FAA's Air Quality Handbook, Section H3.3.2.4 (Emission Indices)

A3.8 Construction Activities

A3.8.1 Construction activities that generate air pollutant emissions include land clearing and demolition (dust emissions), the use of construction equipment and vehicles (exhaust emissions), storage of raw materials (wind erosion emissions), and paving (evaporative emissions). Construction-related vehicles include vehicles that remain on the construction site (e.g. off-road or non-road vehicles) and vehicles that travel off site (e.g. haul and dump trucks). Pollutant emissions also result from construction-related employee commute trips to and from a construction site.

A3.8.2 Common U.S. sources of emissions rate data for construction activities are provided.

Sources of Emission Data – Construction Activities

Activity/Vehicle Type	Source(s)
Land Clearing/Demolition	USEPA AP-42, Fifth Edition, Volume 1, Chapter 13: Miscellaneous Sources
Construction Equipment/Vehicles (off-road)	USEPA NONROAD model
Construction Vehicles (on-road)	USEPA MOBILE model
Material Storage Piles (standing and working)	USEPA AP-42, Fifth Edition, Volume 1, Chapter 13: Miscellaneous Sources
Asphalt Paving	USEPA AP-42, Fifth Edition, Volume 1, Chapter 4: Evaporation Loss Sources
Batch Mix Plants	USEPA AP-42, Fifth Edition, Volume 1, Chapter 11: Mineral Products Industry
Concrete Batching	USEPA AP-42, Fifth Edition, Volume 1, Chapter 11: Mineral Products Industry
Open Burning	USEPA AP-42, Fifth Edition, Volume 1, Chapter 2: Solid Waste Disposal
Vehicle Travel on Unpaved Roads	USEPA AP-42, Fifth Edition, Volume 1, Chapter 13: Miscellaneous Sources

A3.8.3 For Europe, emission factors for these activities can be found in the *CORINAIR Emissions Inventory Guidebook – 2005*.

A3.8.4 For demonstration purposes, estimates of PM emissions from the working of a storage pile can be obtained using the following general equation that considers the throughput of the operation (i.e. the quantity of material used over a given time and the number of drops the material undergoes (once during loading and once during unloading)). Notably, the emission factors for various materials vary depending on the type, particle size, silt content and moisture content of the material.

$$E_{PM} = 2 \times TH \times EF \qquad \text{Eq A3-7}$$

where

E_{PM} = emissions of PM (e.g. kilograms)

2 = number of drops material undergoes

TH = total throughput

EF = emission factor (e.g. grams)

A3.8.5 Using this formula, the following example is given for deicing operations at an airport: Assume a construction operation involves the movement of 100 metric tonnes of limestone. Given a moisture content of approximately 0.2 percent, an aerodynamic particle size of 0.45 micrometers and an average wind speed of 20 kilometers per hour, the amount of PM generated would be as follows based on an emissions factor of 54 grams/metric ton:

2 x 100 metric tonnes x 54 grams/metric ton = 10,800 grams (i.e. 0.01 metric tonnes)

A3.8.6 Another common example of construction emissions involves the use of an off-road vehicle. The equation used to obtain pollutant estimates from this type of construction activity consider the type of equipment (i.e. bulldozer, articulated truck), the size of the equipment (i.e. horsepower), the load factor placed on the equipment (i.e. the ratio of the load over a designated period of time to the peak load), and the period (i.e. hours) of operation.

A3.8.9 For demonstration purposes, estimates of exhaust emissions from construction vehicles and equipment can be derived from the following formula.

$$E = H \times EF \times LF \times T \qquad \text{Eq A3-8}$$

where:

E = emissions (e.g. grams/day)

H = horsepower of the equipment

EF = emission factor (e.g. grams/horsepower-hour)

LF = load factor (percent)

T = total period of operation (hours)

A3.8.9 Using this formula, the following example is given for the use of a bulldozer. Assume an airport contractor uses a 400 horsepower bulldozer 3 hours each day, 15 days a month, for a period of one year and the average load factor for the equipment is 59 percent. If the emission factor for the bulldozer is 9.6 grams per horsepower-hour, the amount of NO_x would be:

400 hp x 9.6 grams/hp-hr x 0.59 x 540 hours = 1,223,424 grams (i.e. 1.2 metric tonnes)

Chapter 2
Emissions Inventory
Annex 4
Vehicle Traffic Emissions

Table of Content

A4.1 Introduction

A4.1.1 Emissions from airport-related surface transportation can constitute a significant portion of the total emissions associated with airport activities. The guidance provided in this section focuses on approaches and methods to prepare an inventory of emissions from both landside and airside “on-road” motor vehicles. The data and other supporting information required to prepare these estimates is also discussed. Airports may need to include in the inventory other surface transportation systems whose emissions may be attributed to airport operations (e.g. diesel trains on an airport rail link).

A4.1.2 On-road landside vehicles include taxis, vans, buses and privately owned cars; light- and heavy-duty goods vehicles; motorbikes and scooters travelling on the airport’s internal roadway network and within the airport’s parking facilities. On-road airside vehicles are the vehicles that travel primarily within an airport’s secured area (i.e. the area where aircraft arrive and depart). These vehicles can include airline crew and passenger buses, aircraft/airport service vehicles, and other vehicles for which emission estimates are calculated in the same way as for landside vehicles (i.e. the vehicles are designed around chassis that are used on public roads and they are driven airside in a manner similar to public road driving) Approaches of estimating emissions from GSE are discussed in Annex 2 - Aircraft Handling.

A4.1.3 In the following sections, three approaches to calculating motor vehicle emissions are discussed—a Simple Approach, an Advanced Approach, and a Sophisticated Approach--each requiring increasingly comprehensive levels of input data and calculation complexity.

A4.1.4 All three approaches are based on the “vehicle-average-speed” method which is commonly used for road traffic emissions calculations for meso- (i.e. district) and macro- (i.e. city or region) scale inventories, to which the airports emissions must be integrated and compared. It is recognised that average speed models may have limitations at low vehicle speeds due to varying transient speeds. Output from these models is also influenced by the availability of supporting data from outside sources.

A4.2 Parameters

A4.2.1 Depending on the approach (i.e. Simple, Advanced, or Sophisticated), some or all of the parameters in the following discussion are necessary in different levels of detail to prepare an estimate of vehicle traffic emissions.

A4.2.2 Although the purpose of this guidance is for preparing an emissions inventory, the reader should note that ultimately an air quality study using dispersion modeling may also be required. In this context air quality models often incorporate road traffic models which contain only a few of the input parameters needed and so analysts’ are required to estimate the missing parameters by other means.

A4.2.3 Clearly, certain parameters will have more effect on the results than others. To this end, the notion of parameter ranking may be used to identify the relative importance of each parameter. The ranking system may be used to prioritize the input data collection for the inventory.

A4.2.4 The following is an example of a ranking system, based on experiences at London Heathrow Airport.[38] The list shows, in order of importance, the parameters that are judged to influence inventory results. The basic ranking is summarized in the list in order of importance. Some of the issues for each rank are also discussed in the following sections

Rank 1 - Road network extent;

Rank 2 - Traffic flow (periods modeled - profiles);

Rank 3 - Fleet and composition;

Rank 4 - Road traffic speeds;

Rank 5 - Road traffic queues;

Rank 6 - Trip ends; and

Rank 7 - Other traffic parameters.

A4.2.1 Geographic Scope – Road Network Extent

A4.2.1.1 The geographic scope defines the road network and road types that are included in a vehicle traffic emissions inventory. The geographic scope is also used in conjunction with the chosen approach to identify the type of input data required for the inventory.

A4.2.1.2 The geographic scope can be limited to the roadways and parking lots inside an airport's property boundary (both airside and landside) or, in some cases, be expanded to include public roads and parking lots that "feed" an airport and have a significant amount of airport-related traffic. The choice of the geographical scope for a project depends on the purpose of the study, the type of available input data and the chosen approach; discussed as follows:.

- The Simple Approach aggregates all roads together to provide an overall inventory based on "total distance travelled" (or vehicle-miles-traveled (VMT) with broad assumptions on vehicle fleet mix, age and speed. The Simple Approach may be limited to the airport perimeter with no link to regional vehicle emissions.
- The Advanced Approach will disaggregate the results into individual roads according to the level of detail of the input data. Each road segment will require average traffic volumes or VMT and typical vehicle speed.
- The Sophisticated Approach should capture as much detail as possible about the road network in the study, with sufficient detail to give an inventory that is highly sensitive to changes in infrastructure and use. For example road network should be divided to give portions of constant gradient to allow for compensation of uphill and downhill emissions.

A4.2.1.3 The Advanced and Sophisticated approaches may include off-airport traffic that are related directly to airport activities but are located off-site. Whichever approach is used, to avoid double-counting vehicle emissions, the analysis must not include vehicles in the vicinity of the airport that are inventoried by other parties (i.e. such as vehicles from non-airport-related transit traffic on nearby roads). These non-airport vehicle emissions may also be relevant to assessing the air quality in the vicinity of the airport, depending on the purpose of the study and/or regulatory requirements of the state, regional or local agencies.

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[38] Department for Transport (UK). *Project for the Sustainable Development of Heathrow: Air Quality Technical Report*. 19 July 2006. www.dft.gov.uk/stellent/groups/dft_aviation/documents/divisionhomepage/612123.hcsp

A4.2.2 Time Scope – Traffic Flow

A4.2.3.1 The time (i.e. temporal) scope defines the averaging period over which a vehicle traffic emissions inventory is to be calculated (e.g. an hour, a day, a season, a year). Conventionally periods of one calendar year are chosen and, amongst other reasons, this simplifies alignment with emissions indices data and national vehicle databases.

- For a Simple Approach, it is sufficient to calculate the total annual amounts of the emissions of each pollutant, based upon annual traffic volumes, travel distances, average operating speeds and representative fleet mix.
- For the Advanced Approach, the temporal resolution should allow for estimates or measurements of the daily and/or hourly variations in traffic conditions (e.g. morning and evening peak periods) and fleet mix (see vehicle fleet and composition).
- For the Sophisticated Approach the temporal resolution should use time-dependent profiles to provide hourly fleet mix on all the roads in the study that are judged to make significant contributions to the inventory.

A4.2.3 Vehicle Fleet and Composition

A4.2.3.1 As previously stated, the motor vehicle categories typically included in an airport-related emissions inventory include passenger cars and vans, light- and heavy-duty goods trucks, buses, taxis, and other motorised vehicles. Separate inventories may be prepared for the landside and airside vehicles. Landside vehicle emissions can also be further categorised so that emissions are segregated by type of road or facility (i.e. access roads, car parks, passenger terminal curb sides, etc.). Generally, each type of vehicle can be defined by one of the four categories:

- Passenger cars,
- Other light duty vehicles (i.e. taxies, vans, limos) ,
- Heavy duty vehicles (including urban buses and coaches) and
- Two-wheel vehicles (scooters and motor cycles).

A4.2.3.2 Within these categories, there is a wide diversity of type and age of the vehicles, fuel type, and operational characteristic. For this reason, the categories cited previously are often sub-classified by vehicle size and type, level of emission control, fuel type, engine type, and operational purpose.

A4.2.3.2 Similarly, urban buses and coaches may be put in a separate category if suitable emissions and operational load factors are available. As discussed previously, airside vehicles will need careful attention to avoid double-counting of traffic associated with landside vehicles and some GSE.

A4.2.3.3 The alternatives for obtaining data for the vehicle fleet mix are summarized as follows:

- The Simple Approach derives vehicle data from available national average vehicle fleet mix/age databases. The Advanced Approach may also derive vehicle data from national records, but the fleet mix/age is typically reflective to that operating at the airport. Notably, under the Advanced Approach, the vehicle fleet mix may also be defined using time-dependant profiles for different road segments (e.g. to allow for morning/evening increases in private cars and buses when airport staff arrives and departs).
- The Sophisticated Approach may employ techniques to measure the actual type and age of vehicles – either as source data for the study or to validate national data. Using measured data in the airport context may be attractive since national data may not represent the typical age of vehicles using the roads in the study. An example of this technique uses video recordings of vehicle licence plates and correlation with licence records to provide exact vehicle/engine type, fuel

type and age. Classification of vehicle traffic should be made according to passengers, airport personnel, maintenance, construction and freight.

A4.2.4 Average Speed and Queues

A4.2.4.1 As discussed previously, the alternative approaches to calculating vehicle emissions provided in this guidance rely on average speed as an input to the analysis. Vehicle queues are a special case characterized by very low average speeds and may include evaporative emissions during idling. Both conditions are addressed as follows:

- The Simple Approach may use an overall average speed. Queue emissions may be factored in as a coefficient of the total traffic.
- The Advanced Approach requires an estimate of the average speeds for each road segment coupled with queuing time profiles for major segments that exhibit delays.
- The Sophisticated Approach may augment the data used for the Advanced Approach with measured data. However, road segments should be further defined to give segment-specific average speed. For each segment the average speed of each vehicle category may be defined. Traffic queue times should be assigned to separate segments.

A4.2.5 Trip ends and Other Traffic Parameters

A4.2.5.1 Trip end emissions are the emissions associated with the “cold start” that occurs at the start of a trip; the similar “hot soak” emissions which occur at the end of a trip once the vehicle engine has been switched off; and the evaporative emissions (mostly VOC) from the fuel system during use and while the vehicle is stationary. These vehicle emissions are accounted for as additional emissions and mainly apply to parking lots and curbsides outside the airport terminals.

A4.2.6 Other Vehicle Emissions

A4.2.6.1 Other vehicle emissions include non-engine emissions of particulate matter (i.e. $PM_{10)}$ from road vehicles that occur as a result of the application of braking systems and tyre wear, from road surface wear, and from the re-suspension of previously deposited particles. The spatial distribution of these fugitive sources of emissions will be relatively constant and consistent with the layout of the road network. However, there will be increases where there is routinely the most intensive stop-and-go traffic, such as either side of stop lines at road junctions and on corners. Temporal variations will occur on a diurnal and seasonal basis as road and driving characteristics vary according to traffic density and road conditions.

A4.2.6.2 The Simple Approach would not make any allowance for fugitive emissions.

A4.2.6.3 The Advanced Approach may include values at dense traffic zones, major junctions and construction sites. The road network should be divided to allocate a default value to each segment.

A4.2.6.4 The sophisticated approach will include trip end and non-engine emissions on a road segment basis and disaggregate the data to show separate inventories for staff vehicles and passengers.

A4.3 Vehicle Emission Factors

A4.3.1 For road vehicles, emission factors represent the unit quantities of a pollutant emitted when a vehicle traverses a length of roadway (typically expressed as grams or milligrams per kilometre) and/or when a vehicle is idle with the engine running a certain length of time (typically expressed as grams or milligrams per minute).

A4.3.2 Traffic emission factors are obtained from computer models and other databases specifically designed to generate such factors. These resources provide local vehicle emission factors that vary as functions of ambient temperature, travel speed, vehicle operating mode (e.g. idle, cruise, deceleration, acceleration, cold start, hot start, and stabilized), fuel type/volatility, vehicle technology, age, inspection/maintenance condition, and mileage accrual rates (km/year).

A4.3.3 Typically for the average speed models, emissions factors are used to calculate an aggregate emissions factor for a segment of road (g/km) for each class of vehicle using the road and for an average speed. In the case of parking lots, emission factors expressed as g/event such as with engine start are also used. In a sophisticated approach, emission factors may vary as the time of day/week based on local climatological factors.

A4.3.4 For airport-related vehicles, emission factors are available from the following sources:

- U.S. EPA MOBILE6.
- California's EMFAC2002.
- CITEPA method based on COPERT-II.
- EUROCONTROL ALAQS method based on COPERT-III.

A4.3.5 Other sources of vehicle emission factors include vehicle manufacturers test results, and research papers. But such sources of information should be used with due caution as they may be relevant to very specific situations and not to the vehicles found on an airport road network.

A4.4 Model Variations of Pollutant Emission Factors

A4.4.1 The vehicle emissions models cited are provided as sources of current and future road vehicle emission factors, but were originally designed for the purpose of monitoring the effect of national and/or local air quality legislation [MOBILE6, CITEPA]. These models estimate a number of exhaust pollutants including CO, HC, NO_x, PM, SO_x, select HAP and carbon dioxide CO_2. Evaporative emissions from fuel and PM emissions from brake- and tire-wear are also provided in many cases.

A4.4.2 The pollutants relevant to road vehicle emissions are divided in legislated and non-legislated groups. The pollutant species modelled by a selection of local air quality models are shown in the following table. The table shows only the pollutants typically modelled. Among other pollutants that are not included, lead may need to be calculated if leaded fuel is still in use and if a leaded fuel emissions factor is available.

Pollutant	ALAQS	CITEPA	EDMS	LASPORT
CO	X	X	x	x
HC	X		x	x
NO_x	X	X	x	x
SO_x			x	
PM_{10}	X		x	x
Benzene			X	x
VOC		X		
CH_4		X		
CO_2		X		
N_2O		X		
NH_3		X		
SO_2		X		
MTBE			X	
1.3 Butadiene			X	
CHCO			X	
Acetaldehyde			X	
Acrolein			X	

A4.5 Calculations

A4.5.1 The following discusses the three approaches (Simple, Advanced, and Sophisticated) and presents formulas that can be used to obtain total emission estimates from vehicles operating on airport-related roads, parking lots, and curb sides.

A4.5.2 Whilst many different vehicle emission calculation methods exist, the three approaches in this guidance are based on the ”vehicle average speed’ method as they are most appropriate to the airport context. However, the eventual choice of calculation method will depend on the scope of the inventory and the available input data.

A4.5.4 The selection of a calculation approach depends on the purpose of the analysis and the complexity of the input data available for the study.

Simple	Suitable for what can be termed a “top down” approach. The Simple Approach aggregates the total emissions from the total number of vehicle-kilometres travelled over the total length of all roads within a defined study area using a published national fleet mix, reference year, and annual average mileage per vehicle class.
Advanced	Using the Advanced Approach, road segments are defined individually by length, average speed, and fleet mix. Activity profiles may be used to describe the diurnal flow (e.g. time variation) of traffic on each road segment.
Sophisticated	The Sophisticated Approach requires the most data (a “bottom up” approach). Emissions are aggregated by road segment by hour and independently calculated for the actual (e.g. measured) number of vehicles of each vehicle type travelling on the road segment, together with their age and engine details. Full details of the road network including gradients, road surface may be included. The emissions from the traffic on each road segment can then be aggregated for the period of interest (i.e. one hour, one week, and one year).

A4.5.5 Simple Approach

A4.5.6 For demonstration purposes, emission estimates using the Simple Approach can be calculated using the following general equation:

$$E = RL \times NV \times EF \qquad \text{Eq A4-1}$$

where

E = emissions (e.g. grams)

RL = road length (e.g. kilometres)

NV = number of vehicles by class, age and speed on the road

EF = emission factor considering vehicle class, age, and speed (e.g. grams/vehicle-kilometre travelled)

A4.5.7 Using this formula, the following example calculates the level of emissions using the Simple approach: Assume a roadway is 5 kilometres in length. Over a 24-hour period, 100,000 vehicles traverse the roadway at an average travel speed of 35 kilometres-per-hour. The vehicle fleet mix consists of 80 percent passenger cars, 10 percent light duty vehicles, 5 percent heavy duty vehicles and 5 percent two-wheeled vehicles. Further, for the period of interest, (e.g. 24-hours) the average temperature is 21 degrees Celsius. Assuming the CO emission factor is 30 grams per kilometre, total CO emissions from the roadway are calculated as follows:

5 kilometres x 100,000 vehicles x 30 gram per kilometre =15,000,000 grams of CO (i.e. 15 metric tonnes)

A4.5.8 Advance Approach

A4.5.9 For demonstration purposes, urban driving emission estimates using the Advanced Approach can be calculated using the following equation:

$$E_{total} = (RL_1 \times NV_1 \times EF_1) + (RL_2 \times NV_2 \times EF_2) + (RL_n \times NV_n \times EF_n) \quad \text{Eq A4-2}$$

where:

E_{total} = total emissions for all roadway segments (e.g. grams)

$RL_{1..n}$ = road length (e.g. kilometres)

$NV_{1..n}$ = number of vehicles by class, age and speed on the road

$F_{1..n}$ = emission factor considering vehicle class, age, and speed (e.g. grams/vehicle-kilometres travelled)

A4.5.10 Using this formula, the following example calculates the level of emissions using the Advanced Approach: Assume there are two roadways within a defined study area. One roadway is 2.4 kilometres in length and the other roadway is 2.6 kilometres in length. Over a 24-hour period, 60,000 vehicles traverse the shorter roadway and 40,000 vehicles traverse the longer roadway. The average travel speed on either roadway is 35 kilometres-per-hour.

A4.5.11 On the shorter roadway, the vehicle fleet mix consists of 80 percent passenger cars, 10 percent light duty vehicles, 5 percent heavy duty vehicles and 5 percent two-wheeled vehicles. On the longer roadway, the vehicle fleet consists of 75 percent passenger cars, 15 percent light duty vehicles, and 10 percent heavy duty vehicles. For the period of interest (24-hours), the average temperature is 21 degrees Celsius.

A4.5.12 Assuming the CO emission factor for the shorter roadway is 30 grams per kilometre and the CO emission factor for the longer roadway is 35 grams per kilometre, the total CO emissions from the roadway segments are calculated as follows:

(2.4 kilometres x 60,000 vehicles x 30 grams per kilometre) + (2.6 kilometres x 40,000 vehicles x 35 grams per kilometre) =7,960,000 grams of CO (i.e. 7.96 metric tonnes)

A4.5.13 Sophisticated Approach

A4.5.14 The formulae for the Advanced Approach would also be used for the Sophisticated Approach as demonstrated in the following example (the only difference being the amount and scope of required data):

A4.5.15 Assume that during the morning peak hour of a 24-hour day, 5,000 vehicles traverse a road that is 1.5 kilometres in length. During the evening peak hour, 7,000 vehicles traverse the same roadway. For each of the remaining hours of the day, 25 percent of the morning peak hour traffic (1,250 vehicles) traverses the road.

A4.5.16 The average travel speed on the road during the morning peak hour is 45 kilometres-per-hour and the average travel speed on the road during the evening peak hour is 30 kilometres-per-hour. While the volume and speed fluctuate, the vehicle fleet mix remains constant during weekdays at 80 percent passenger cars, 10 percent light duty vehicles, 5 percent heavy duty vehicles, and 5 percent two-wheeled vehicles. On weekends the ratios change to 80 percent passenger cars, 10 percent light duty vehicles, 8 percent heavy duty vehicles, and 2 percent two-wheeled vehicles. Of the 80 percent cars during weekdays; 40 percent are personnel arriving at work and 60 percent are passengers.

A4.5.17 During the morning peak hour, the average temperature is 4 degrees Celsius and during the evening peak hour, the average temperature is 21 degrees Celsius. All other hours of the day, the temperature is 10 degrees Celsius.

A4.5.18 Assuming the weighted CO emission factor (accounting for fleet mix and vehicle type, age, and fuel) during the morning peak hour is 30 grams per kilometre, the factor during the evening peak hour is 20 grams per kilometre, and the emission factor every other hour of the day is 25 grams per kilometre, the total CO emissions from the roadway segments are calculated as follows::

(1.5 kilometres x 5,000 vehicles x 30 grams per kilometre) + (1.5 kilometres x 7,000 vehicles x 20 grams per kilometre) + (22 hours x (1.5 kilometres x 1,250 vehicles x 25 grams per kilometre) =1,466,250 grams of CO (i.e. 1.47 metric tonnes)

A4.5.19 The example shown here considers one road segment. This calculation would have to be repeated for all road segments taking into consideration the fleet mix, speeds, etc. Finally, in the example the emission factors are assumed constant for each road segment. Use of the sophisticated approach assumes diurnal and seasonal variations are constant.

A4.5.20 Curb Side and Parking Lot

A4.5.21 With one exception, the formulae and approaches discussed previously for roads can also be used to estimate emissions from vehicles idling at airport curbsides and traveling/idling within airport-related parking facilities (e.g. garages and surface lots). In place of distance based emission factors these are time or event based and account for hot and cold starts, hot soak (curb side engine running) and evaporative emissions.

A4.5.22 For demonstration purposes, emission estimates for vehicles idling at curb sides and travelling/idling with parking lots can be calculated using the following general equation:

$$E_{total} = (TD_m \times NV_m \times EF_m) + (T \times NV_I \times EF_I) \qquad \text{Eq A4-3}$$

where:

E_{total}= total emissions for all moving and idling vehicles (e.g. grams)

TD_m = travel distance (e.g. kilometres)

NV_m = number of vehicles by class, age and speed on the road

EF_m = emission factor for mobile (moving) vehicles considering vehicle class, age, and speed (e.g. grams/vehicle-kilometres travelled)

T = dwell time (e.g. minutes) that the vehicle is stationary.

NV_I = number of idling vehicles by class, age, and speed

EF_I = idle emission factor considering vehicle class, age, and speed (e.g. grams/minute)

A4.5.23 Using this formula, the following example calculates the level of emissions for a curb side using the Simple approach: Assume a curb side is 0.2 kilometres in length. Over a 24-hour period, 2,000 vehicles traverse the roadway next to the curb side at an average travel speed of 25 kilometres-per-hour. The vehicle fleet mix consists of 95 percent passenger cars and 5 percent light duty vehicles. While drivers are loading/unloading passenger luggage, each vehicle idles 2 minutes. The average daily temperature is 21 degrees Celsius. Assuming a moving CO emission factor of 30 grams per kilometre (the corresponding emissions factor for the vehicle speed of 25 kilometres per hour) and an idling CO emission factor of 4 grams per minute, total CO emissions from the curb side are calculated as follows::

(0.2 kilometres x 2,000 vehicles x 30 grams per kilometre) + (2 minutes x 2,000 vehicles x 3 grams per minute) =28,000 grams of CO (i.e. 0.028 metric tonnes)

Chapter 3
Emission Temporal and Spatial Distribution

Table of Contents

3.1 Introduction

3.1.1 At an airport, emissions occur at various locations and time-periods depending on the purpose and operational characteristics of the source. For example, stationary sources, such as generators or heating plants emit from fixed locations and may be continuous or intermittent. By comparison, aircraft emissions are more mobile occurring at various locations on the airport, times of day and intensities. Aircraft emissions generated during takeoff and landing operations also occur off the airport and up to the local mixing height, which is often assumed to be 1,000 meters or 3,000 feet in height. This results in the dispersion of emissions becoming not only a temporal distribution but a spatial three-dimensional (e.g. "3-D") consideration as well[39]. Other mobile sources are usually confined to a general area but move within the area and vary by time of day. The assessment of this variability of location and emission density must be done by temporal and spatial distribution of the emissions. This is especially true if dispersion modelling is to be performed as part of the overall air quality analysis. Depending on the dispersion modelling source configuration (e.g. point, line, volume, or area) different information may be needed for the emission distribution. This section describes the emission distribution process that occurs in the general vicinity of airports.

3.1.2 In summary, the objectives of the assessment of airport-related emission distribution include:

- Determination of spatial (placement) emission densities;
- Determination of temporal (time of day and total release time) of emissions;
- Evaluation of areas of the airport that include specific pollutants;
- Determination of "hot-spot" areas on airport property; and/or,
- Development of dispersion modelling input.

3.1.3 The process of emission distribution is closely tied together with the overall emission inventory process and with dispersion modelling, if conducted. Accordingly, frequent references to Chapter 2 of this guidance will be made, rather than repeating information.

3.1.4 Emission distribution may occur at different times during the air quality analysis of airports or may not be done at all. For example, some airports complete this work as they complete the emission inventory; combining the work effort. Other airports do not complete the emission distribution until dispersion modelling begins. The reason for this is that an emission inventory includes the total mass from the entire airport, broken out by source and pollutant types, and may be all that is required. Alternately, an allocated inventory places the emissions temporally and spatially providing additional information that can be used for trend analysis, dispersion modelling input, or for mitigation emission distribution. The detailed data

[39] It should be noted that the term allocation is often used during airport analysis instead of the word distribution. However, allocation in a global sense can have a different meaning and as such is not used in this document.

needed for this analysis also may not be available during the initial emission inventory which may delay the completion of the work.

3.1.5 In general, the distribution of airport-related emissions involves the following steps:

1. Define purpose of the distribution (i.e. emission density, emission variability, or dispersion modelling);
2. Collect source-specific, detailed spatial and temporal information;
3. Perform quality assurance on spatial and temporal data;
4. Allocate sources by specific area, time of day and duration of operation;
5. Perform emission inventory as described in Section B of the guidance by source, area, and time of day; and
6. Aggregate and report results.

3.1.6 If the ultimate application of the data is for dispersion modelling, then the approach to assessing spatial and temporal distribution of the emissions is often dictated by the requirements of the dispersion model and the associated meteorological data. Typically, the concentrations at the output of the dispersion model will be required to show annual, eight and 24 hour means with number of times that the limits are exceeded in those time spans and is discussed later in this document. The geospatial representation may also need to be compatible with a regional or national assessment and care is needed to determine the correct basis so that delays do not occur.

3.2 General Emission Distribution Considerations

3.2.1 Since emission distribution determines the spatial representation of emissions, the first task is the collection of operational data and location information for each source on or near the airport. Typical airport emission source pollutant species were previously described in Chapter 2, Section 2.3 and the sources were described in Chapter 2, Section 2.4. Distribution of emissions is often done in conjunction with the initial data collection for the emission inventory as previously described in Chapter 2, but this is not always the case. The reason for performing the emission distribution as a separate task is that for an emission inventory, locations and times of release do not matter and the work can be completed without distribution. As such, distribution can be completed at a later time if needed. In some locations, such as the U.S., an overall emission inventory may be all that is needed unless increases in emissions occur or a major action (e.g. new airport, runway or taxiway) is to be undertaken. In these cases, dispersion modelling is sometimes required and emission distribution is generally completed in conjunction with the dispersion modeling task. If it is known that distribution will be required as the emission inventory is undertaken, it is generally more effective to complete this work as part of the original task.

3.2.2 The additional information needed for spatial and temporal distribution can vary considerably from airport-to-airport. For example, the taxi time for an aircraft depends on runway and taxiway configurations, queue lengths, gate configurations, and aircraft type. Because most airport operational and performance characteristics differ from one another, the time in the taxi mode will also vary and must be determined on a case-by-case. Best practice includes using airport-specific data whenever possible (i.e. use of the real taxiing time for each movement). Airport schedules also vary, resulting in the time periods that the emissions actually occur being different. This results in data collection being required for each individual airport, although simplified procedures and assumptions can be used in some cases.

3.2.3 This data collection process often requires the air quality analyst to contact multiple entities to obtain the required information. The following tables list possible entities for obtaining this information, by emission source type. To the extent possible, data must be specific by time and place for a typical operational day. Variations in these parameters occur but are sometimes difficult to quantify resulting in the assessment of “typical” or “average day” conditions being analyzed most often. At some airports seasonal variations also occur and must be considered.

Sources of Spatial Data for Emission Distribution	
Airport Runway / Taxiway / Gate Geometry	• Maps • Orthophotos • Airport Layout Plans (AIP) • Geographic Information Systems (GIS) files • Field surveys
Stationary Sources	• Maps • GIS files • Orthophotos • Airport operation office • Fixed Based Operators • Maintenance operation office • Field surveys
Airside Mobile Sources	• Master plan • Noise reports • Airport operation office • Maintenance operation office • Field surveys • Handling companies / agents
Landside Mobile Sources	• Master plan • Noise reports • Airport operation office • Maintenance operation office • Field surveys • Regional authorities
Non-standard Sources	• Master plan • Airport operation office • Maintenance operation office • Airport safety office • Airport security • Fixed Based Operator surveys • Field surveys

Sources of Temporal Data for Emission Distribution	
Stationary Sources	• Master plan • Noise reports • Fuel delivery schedules / history • Fuel use records • Airport operation office • Airport maintenance office • Fixed Based Operator surveys
Aircraft	• OAG • Airport schedules • Tower logs • Airlines • Cargo scheduling • Noise reports • Observations
Airside Mobile Sources	• Aircraft scheduling

	• Airlines • Service providers • Master plan • Airport operation office • Maintenance operation office • Observations • Handling companies
Landside Mobile Sources	• Master plan • Mass transit scheduling • Parking lot counts • Employee schedules • Cargo scheduling • Roadway traffic counts • Speed limits • Roadway speed measurement • Airport operation office • Maintenance operation office • Airport security • Observations / field survey
Non-standard Sources	• Master plan • Airport operation office • Maintenance operation office • Airport safety office • Airport security • Fixed Based Operator surveys • Field surveys

3.2.4 Each emission source is allocated to a specific time period by location on the airport. The use of one hour time periods over a 24-hour average day is most often used because of dispersion modelling requirements. The source may not operate for the entire hour and in the case of mobile sources may change locations at the airport. This must be considered during distribution. This can be done by allocating the emissions using fractions of the estimation period or by using factors. Either method will result in the same outcome.

3.2.5 When the purpose is only for emission distribution, emissions are allocated to activity areas or grids for each time increment selected. The areas, or grids, defined will depend upon the source and its typical operation area (i.e. tugs used for aircraft pushback tend to remain in specified areas around the terminal gates). Final results can be by the hour, day, week, month or year, but as previously stated one hour is used most often due to dispersion modelling input needs. The end result can then be used to estimate emission density changes on the airport, "hot-spot analysis", emission variability, or comparison of trends.

3.2.6 When the purpose is for dispersion modelling, the required inputs for the dispersion model dictate where emissions are allocated. Common practice is to predict one hour concentrations to determine the worst hour of the day or greatest consecutive period of hours depending on the pollutant and the applicable regulations. This provides local ambient concentrations that can be used to determine health or public welfare impacts. As previously stated, the most common time periods are one hour, eight-hours, 24 hours, and yearly. At EU airports, legislation requires the number of occurrences of concentration levels (over various time steps as expressed previously, e.g. 24 / eight / one hour average) per year. While this occurs during dispersion modelling, it must be considered.

3.3 Spatial Distribution

3.3.1 The overall process discussed in Chapter 2 still applies. The difference is that the overall inventory is broken into smaller inventories that are specific for a particular location. As stated by the U.S. EPA, "Because air quality modelling strives to replicate the actual physical and chemical processes that occur in an emissions inventory domain, it is important that the physical location of emissions be determined as accurately as possible. In an ideal situation, the physical location of all emissions would be known exactly. In reality, however, the spatial distribution of emissions in a modelling inventory only approximates the actual location of emissions." The approximation required is not just a U.S. problem, but occurs at all airports. This is very true for airports where activities vary day to day. However, the spatial emission density can still be determined for the overall average. The process first begins by deciding on the areas, cells, or zones where emissions are to be allocated, depending on the intended purpose of the results and the requirements of the model used. The size of the areas, cells or zones is also a function of the operational area of the source, as previously mentioned. Distribution can be done by establishing a series of similarly shaped cells over the airport or by determining activities areas for each source. Cells are often used in conjunction with emission density charts to show changes in overall emission density in the vicinity of the airport. This is a strong aid for the airport planner to evaluate where "hot spots" occur and helps to determine where control measures may be needed. Cell-based representation also fits closely with dispersion analysis where the modelled concentration levels would be used in conjunction with land-use charts, maps of population, housing type, sensitive zones, etc.

3.3.2 On the other hand, distribution by activity zones allows the airport to evaluate emissions related to those particular activities. For example, these activity zones could be the gate area, the airfield, the parking lots, a roadway network, unloading zones, etc. As before, the accuracy of allocating to each zone depends on how well the source can be characterized. Each zone emission would allow characterization of that zone and comparison of alternate programs for reducing these emissions for this specific activity. In the case of dispersion modelling the zones could be related to evaluation of methods to reduce potential health or public welfare impacts on the local level.

3.3.3 Spatial distribution is straight forward for stationary sources and can be easily developed. The stationary source emissions are determined by the time of use but do not move. Mobile sources create difficulties as the moving source may cross several delineated spatial boundaries unless an activity zone is specifically defined for this source. This is especially true for moving GSE where guidelines may be necessary to ensure a reliable and consistent spatial distribution. When the cell approach is used, the partial emissions for the operation must be computed for each cell. This results in the combination of time and space parameters. A common approach is to determine the time in a particular cell by use of the emission index and allocate the emissions for that cell. This procedure was described in Chapter 2. This process must be completed for all mobile sources entering the defined area and summed with the stationary sources in the area. The sum of all sources, for each specific pollutant, results in the emission density for that defined area.

3.3.4 It is important to remember that the spatial distribution only provides emission density information. Emission variability requires the use of temporal distribution and the two combined provide an even stronger tool for the analyst.

3.4 Temporal Distribution

3.4.1 Temporal distribution provides a measure of emission variability, by duration. As stated by the U.S. EPA, "Because air quality modelling attempts to represent the actual physical and chemical processes as they occur over a specific duration of time, it is important that the temporal distribution of emissions be as accurate as possible. Temporal distribution can be thought of as an accounting of emissions variation over time. The simplest temporal distribution is for a steady-state emissions source that continually releases emissions at the same rate all the time. Under actual conditions, however, steady-state emission sources are quite rare. Instead, under actual conditions, emissions sources may operate only in the winter, not operate on Sundays, or their activity may peak during certain hours of the day. Temporal distributions allow emissions variability to be correctly modelled during the desired modelling periods. The desired modelling periods will vary depending upon the purpose of the inventory."

3.4.2 Temporal distribution requires the time-of-day of activity to be determined. For example, a heating plant may run continuously and emissions will be constant for the entire day and can be easily allocated over the day. This would result in activity factors being the same for each hour and a constant emission density for this stationary source. However, mobile sources, such as aircraft, do not have continuous activity and often do not last for an entire hour. This makes distribution more difficult. This is compounded by the source moving from between defined areas as previously discussed. For these sources, care must be taken to define the times of use by zone or defined area. In the extreme case, activity profiles may be needed for each major taxi-route and considered as a separate zone. The time a source is in a zone can be related to the speed of the mobile source and the distance travelled in each defined area. That is:

Time in Zone = distance travelled in zone / speed of mobile source

3.4.3 If the speed varies in the zone, this process may need to be further subdivided and the total determined. Often, an average speed is assumed to simplify the process. Also, the path the mobile source traverses while in the zone must be determined. When roadways, taxiways, runways, or defined routes are involved the process is well defined. When the path is not well defined, approximations must be made. For example, a car travelling in a parking lot may be assumed to travel one-half the total possible distance on entry and then one-half the total possible distance during egress. Once time has been determined in the defined area, the emission estimation process becomes that described in Chapter 2.

3.4.4 It can be seen that other difficulties may occur for sources with no defined path at all. In these cases observation may be needed to determine a representative time. A simplified procedure could also be used based on past studies for particular types of equipment (e.g. GSE). Data of this type is presented in Chapter 2, Annex 2.

For minor stationary sources such as de-icing, fire trainings, engine testing etc. some simplifications could be made to allocate the emissions temporally and spatially. (For example, meteorological data can be used to define when possible de-icing is used)

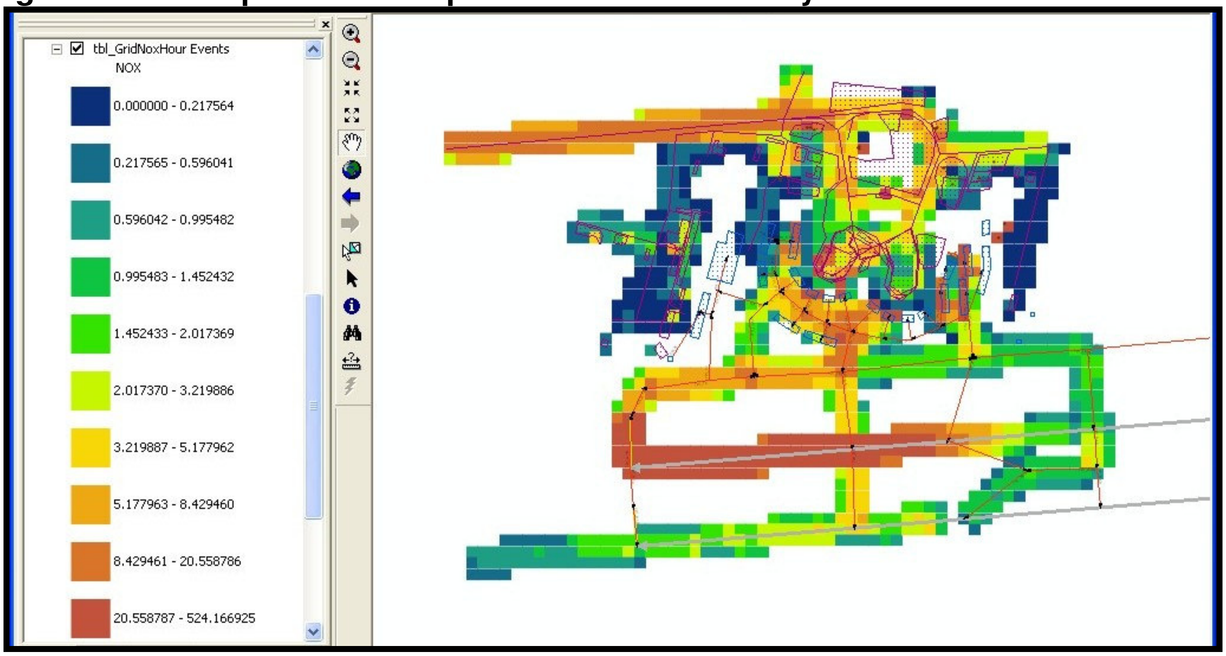
3.5 Use of Computer Models

3.5.1 Air quality computer models that have been developed for airport analyses often permit both spatial and temporal input and output as elements of the emission inventories. Such models include EDMS (U.S. FAA), LASPORT, and ALAQS-AV (Eurocontrol).

3.5.2 During the input data development for these models, the process previously described will often be needed since the models may not have algorithms for all sources to allow spatial and temporal determination. A GIS-based model should facilitate the spatial distribution process through its highly visual interface; an example is shown in Figure 3-1 taken from the Arcview based ALAQS-AV. LASPORT and EDMS also have GIS capabilities. It should be noted that any graphical user interface based program will support the spatial determination more easily and, with proper input, assist in the temporal distribution. The user should consult the appropriate model user's guide for further information.

.5.5

Figure 3-1 – Example of 2D Geospatial Emissions Inventory



3.6 Data Formatting and Reporting

3.6.1 It is often essential to use a matrix type approach when reporting spatial and temporal emission results. Figure 3-2 shows an example (USEPA). In this example figure, it can be seen that sources 23 and 24 are continuous emitting sources while source 25 represents a source with temporal emission variability. From this type of analysis, emissions for any hour can be easily determined. For example, Source 24 emits 417 pounds from 2:00 to 3:00 PM. This same matrix approach may also be used for spatial reporting or for each individual source in a single table, a combination of spatial and temporal data. In some models such matrixes can be obtained as an output.

Figure 3-2 Diurnal Profile File

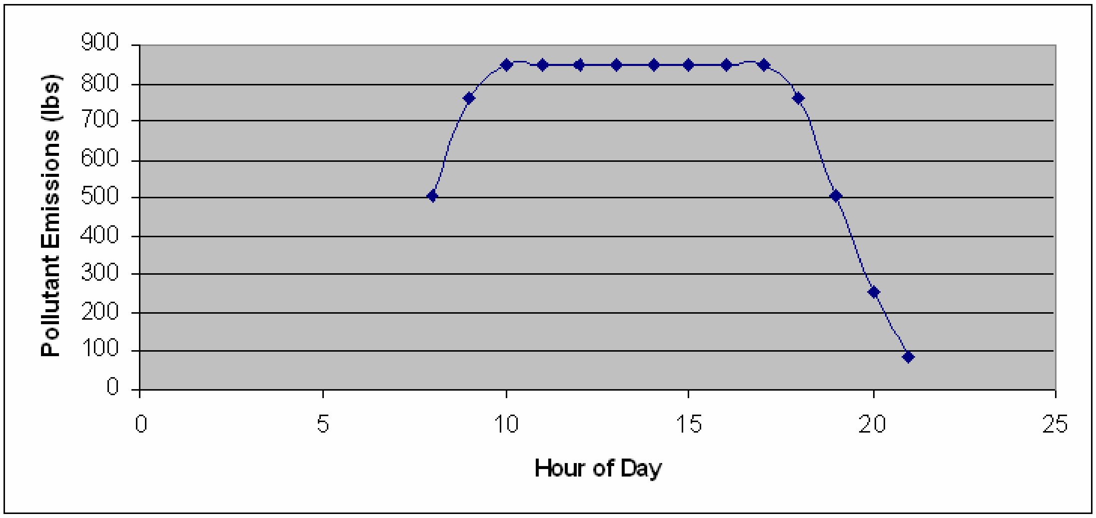
Hour	**..8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**...**	**Total**
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...		
23	... 435	435	435	435	435	435	435	435	435	435	435	435	435	435	...	10005
24	... 417	417	417	417	417	417	**417**	417	417	417	417	417	417	417	...	**10008**
25	... 508	763	847	847	847	847	847	847	847	847	763	508	254	85	...	9996
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...		

Hours of the Day

Pounds per Hour Released

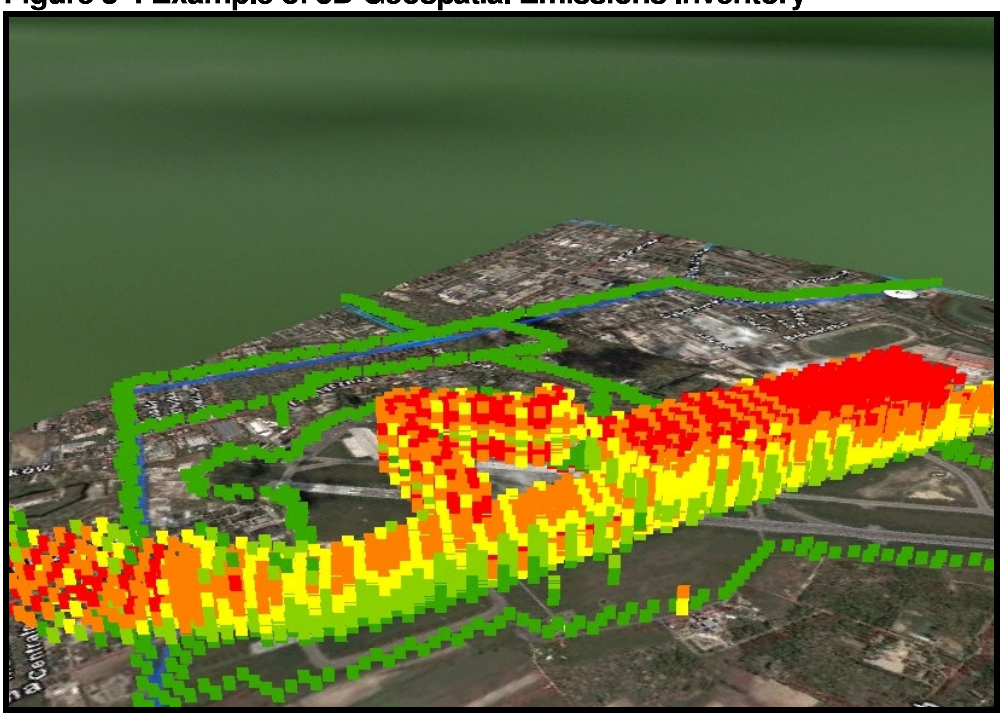
Once the data is in this format, graphics can also be used to display the results and more easily identify trends. For example, Figure 3-3 is the plot of Source 25 that was shown in Figure 3-2. It can be seen that the source is utilized in the afternoon but much less at other times of day. This could be used for spatial distribution and with 3D graphics as well, resulting in much easier comprehension by the reviewer

Figure 3-3 Diurnal Profile Plot



Graphical displays may be used to show the geo-spatial distribution, usually in 2D density grids, but careful use of 3D techniques could also be envisaged for sources such as aircraft as illustrated in Figure 3-4.

Figure 3-4 Example of 3D Geospatial Emissions Inventory



Chapter 4
Dispersion Modelling

(To be developed by ICAO for inclusion in a future update of this guidance)

Chapter 5
Airport Measurements

(To be developed by ICAO for inclusion in a future update of this guidance)

Chapter 6
Mitigation Options

(To be developed by ICAO for inclusion in a future update of this guidance)

Chapter 7
Interrelationships

(To be developed by ICAO for inclusion in a future update of this guidance)

Glossary

Symbols and Units

bhp	brake horsepower
g	grams
hp	horsepower
hr	hour
Hz	Hertz
kg	kilogram
km	kilometers
kN	kilo Newton (thrust)
kts	knots: Unit for speed, expressed in nautical miles per hours (1.85 km/h)
KVA	kilo Volt Ampères
kW	kilowatt
min	minutes
s	seconds
$\mu g/m^3$	micrograms per cubic meter
V	Volts

Abbreviations

ACARE	Advisory Council for Aeronautics Research in Europe
ACU	Air Climate Unit
AGL	Above ground level
APMA	Air Pollution in the Megacities of Asia
APU	Auxiliary Power Unit
ARFF	Airport Rescue Fire Facility
ASU	Air Starter Unit
ASQP	Airline Service Quality Performance
ATA	Air Transport Association
Avgas	Aviation gasoline
BTS	Bureau of Transportation Statistics (US)
CAEP	Committee on Aviation Environmental Protection
CH_4	Methane
CNG	Compressed Natural Gas (carburant)
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EI	Emission Indices
FES	Fixed Energy System
FESG	ICAO CAEP Forecasting and Economics Sub-Group
DEFRA	Department for Environment, Food, and Rural Affairs (UK)
DfT	Department for Transport, London (UK)
DoT	Department of Transportation (US)
ECS	Environmental Control System
EDMS	Emission and Dispersion Modelling System (US FAA)
EGT	Exhaust Gas Temperature

EPA	Environmental Protection Agency (US)
EU	European Union
FAA	Federal Aviation Administration, Washington D.C. (US)
FBO	Fixed Based Operator
FIRE	Factor Information Retrieval Data System (US EPA)
FOA	First Order Approximation
FOCA	Federal Office for Civil Aviation, Bern, Switzerland
FOI	Swedish Defence Research Agency
GIS	Geographical Information System
GPU	Ground Power Unit
GSE	Ground Support Equipment:
HAP	Hazardous Air Pollutants
HC	Hydrocarbon
HDV	Heavy duty vehicle (e.g. truck, bus)
ICAO	International Civil Aviation Organization, Montreal, Canada
ICCAIA	International Coordinating Council of Aerospace Industry Associations
IGV	Inlet Guide Valves
IOAG	International Official Airline Guide
LASPORT	LASAT for Airports (Europe)
LDV	Light duty vehicle (e.g. delivery vans)
LPG	Liquefied Propane Gas
LTO	Landing and Take-off Cycle
MSDS	Material Safety Data Sheet
MES	Main Engine Start
NAAQS	National Ambient Air Quality Standards (US)
NASA	National Aeronautics and Space Administration (US)
NMVOC	Non methane volatile organic compounds
NOx	Nitrogen oxides is a generic term encompassing nitrogen dioxide (NO_2) and nitrogen monoxide (NO).
O_3	Ozone
Pb	Lead
PM10	Particulate matter with an aerodynamic diameter of 10 micrometres or less
PM2.5	Particulate matter with an aerodynamic diameter of 2.5 micrometres or less
POV	Privately owned vehicle
PCA	Pre-conditioned Air (for cooling/heating of parked aircraft)
PM	Particulate Matter
SAE	Society of Automotive Engineers
SAEFL	Swiss Agency for Environment, Forests and Landscape, Bern, Switzerland
SN	Smoke Number
SO_x	Sulphur Oxides
SO_2	Sulphur Dioxide
TAF	Terminal Area Forecasts (US)
TIM	Time in mode
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
UK	United Kingdom
UN	United Nations

UNFCCC	United Nations Framework Convention for Climate Change
US	United States
WHO	World Health Organization

Definitions

AGL	A height above the known runway or ground elevation.
ACU	Self-driven or trailer mounted compressor unit to provide aircraft with pre-conditioned air during ground time.
Airshed	Part of the atmosphere that behaves in a coherent way with respect to the dispersion of emissions. It typically forms an analytical or management unit.
APU	Aircraft mounted kerosene fuelled turbine providing electricity and pre-conditioned air during ground times and bleed air for main engine start as well as inflight power back-up.
CO	Formed during incomplete combustion of heating and motor fuels. It's a clourless, odourless gas. Effects: Acts as a respiratory poison in humans and warm-blooded animals. It plays a role in the formation of ozone in the free troposphere,
CO_2	Is the most important greenhouse gas. It is formed during the combustion process and naturally the photochemical reactions. It's a colourless gas. The effect is in its contribution to climate change.
ECS	APU bleed air is supplied to the aircraft air conditioning packs, which supply conditioned air to the cabin – for emissions testing the bleed load condition is set for typical aircraft gate operation (depending on the aircraft type and size) - normally includes some shaft (electric) load.
FES	System at aircraft stands (remote or pier) that provide centrally produced energy (electricity and sometimes PCA) to aircraft during ground time.
GPU	Provides electrical power to aircraft during ground time.
GSE	Machinery to service aircraft during ground time.
Kerosene	Fuel for jet engines (e.g. Jet-A1)
LTO	Consisting of aircraft landing, taxi in, taxi out, and takeoff.
NOx/NO_2	Nitrogen oxides is a generic term encompassing nitrogen dioxide (NO_2) and nitrogen monoxide (NO). Because NO rapidly oxidizes to NO_2, the emissions are expressed in terms of nitrogen-dioxide (NO_2) equivalents. It is formed during combustion of heating and motor fuels, especially at high temperatures. Characteristics: NO: colourless gas, converted in the atmosphere to NO_2; NO_2: assumes a reddish colour at higher concentrations. Effects: respiratory disorders, extensive damage to plants and sensitive ecosystems through the combined action of several pollutants (acidification) and overfertilization of ecosystems.
Particulate Matter:	particulate matter is the term used to describe particles with an aerodynamic diameter of 10 micrometres or less. From a physico-chemical standpoint, dust is a complex mixture consisting of both directly emitted and secondarily formed components of natural and anthropogenic origin (e.g. soot, geological material, abraded particles and biological material) and has a very diverse composition (heavy metals, sulphate, nitrate, ammonium, organic carbon, polycyclic aromatic hydrocarbons, dioxins/furans). PM2.5 are particles with an aerodynamic diameter of 2.5 micrometer or less. They are critical in the connection with health effects. PM is formed during industrial production processes, during combustion processes, during mechanical processes (abrasion of surface materials and generation of fugitive dust) and as secondary formation (from SO_2, NOx, NH_3, VOC). Characteristics:

solid and liquid particles of varying sizes and composition. Effects: fine particles and soot: respiratory and cardiovascular disorders, increased mortality and cancer risk; dust deposition: contamination of the soil, plants and also – via the food chain – human exposure to heavy metals and dioxins/furans contained in dust.

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