Category		Title
NFR:	**1.A.3.a, 1.A.5.b ***	**Civil and military aviation**
SNAP:	**080501** **080502** **080503** **080504** **080100**	**Domestic airport traffic (LTO cycles — < 3000 ft (914 m))** **International airport traffic (LTO cycles — < 3000 ft (914 m))** **Domestic cruise traffic (> 3000 ft (914 m))** **International cruise traffic (> 3000 ft (914 m))** **Military aviation**
ISIC:		
Version	**Guidebook 2013**	
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Contents

1 Overview

The scope of the emissions to be included comprises the civil aviation portion of combustion emissions from mobile sources that concerns the movement of people and/or freight by air. The activities comprise:

1. international airport traffic (LTO-cycles < 3 00 ft (914 m) ([1]);
2. international cruise traffic (> 3 000 ft (914 m));
3. domestic airport traffic (LTO-cycles < 3 000 ft (914 m));
4. domestic cruise traffic (> 3 00 ft (914 m)).

The scope of the emissions to be included comprises civil commercial use of airplanes, including scheduled and charter traffic for passengers and freight, air taxiing and general aviation. The international/domestic split should be determined on the basis of departure and landing locations for each flight stage and not by the nationality of the airline. Fuel used at airports for ground transport should be excluded from these NFR codes, and are reported under 1.A.5.b, Other Mobile. Fuel for stationary combustion at airports should also be excluded and reported under the appropriate stationary combustion category.

The importance of this sector ranges from negligible to quite significant for some pollutants' contribution to the inventories for many countries. Importantly, emissions from this sector are often increasing at a higher rate than for many other sources. The major pollutants generated from these activities are CO_2 and NO_x, but with important contributions of CO, hydrocarbons and SO_2.

Reporting

Inventory compilers should note that differences exist for the reporting of domestic LTO and cruise (SNAP codes 080501 and 080503, respectively) and international LTO and cruise (SNAP codes 080502 and 080504, respectively) between a) the Long-Range Transboundary Air Pollution (LRTAP) Convention and National Emissions Ceiling (NEC) Directive, and b) EU-MM and United Nations Framework Convention on Climate Change (UNFCCC). Specifically, these instruments contain different definitions concerning whether the domestic and international LTO/cruise elements should be included within the reported national totals, or should be reported as additional 'memo items'. The UNECE Reporting Guidelines ([2]) provide the definitions for reporting of emissions to the LRTAP Convention. Any questions concerning reporting of emissions to the Convention should be addressed to the European Monitoring and Evaluation Programme **(**EMEP) Centre on Emission Inventories and Projections (CEIP).

([1]) LTO is an abbreviation for the Landing and Take-Off cycle. International Civil Aviation Organisation (ICAO) defines the LTO cycle as those activities occurring below a height of 3 000 feet (914 m)
([2]) Available at http://www.ceip.at

2 Description of sources

2.1 Process description

Exhaust emissions from aviation arise from the combustion of jet fuel (jet kerosene and jet gasoline) and aviation gasoline. They arise during the two activities illustrated in Figure 2-1.

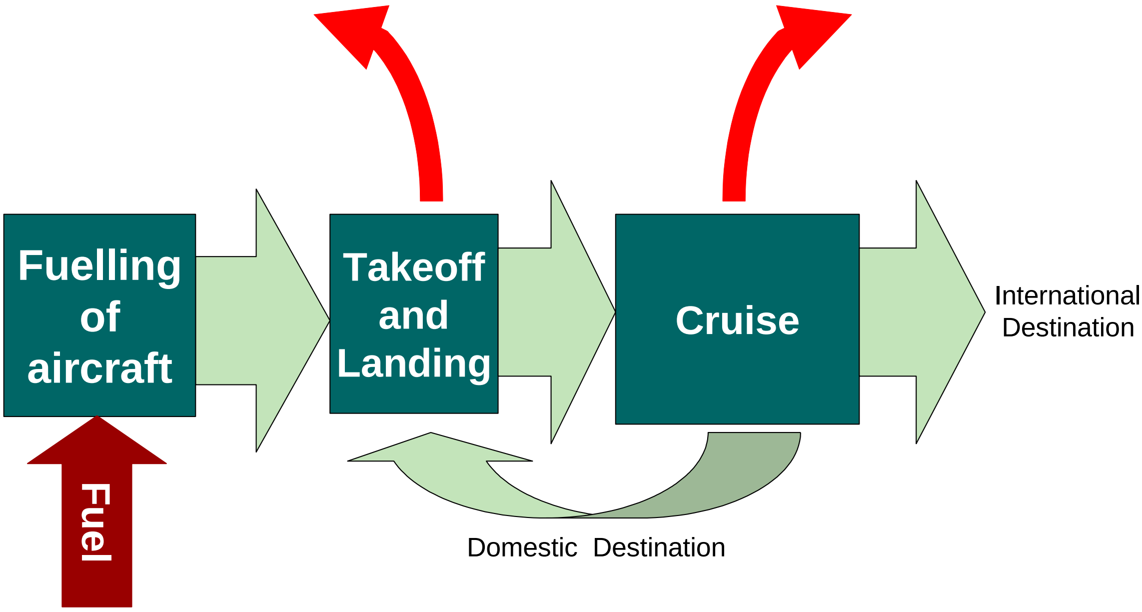

Figure 2-1 Flow diagram for the contribution from aviation to mobile sources combustion emissions

The landing and take-off cycle includes all activities near the airport that take place below a height of 3 000 ft (914 m). This therefore includes taxi-in and -out, take-off, climb-out and approach-landing.

Cruise is defined as all activities that take place above 3 000 ft (914 m). No upper limit of height is given. Cruise in this handbook includes climb from the end of climb-out in the LTO cycle to the cruise altitude, cruise and the descent from cruise altitude to the start of LTO operations of landing. Figure 2-2 below illustrates the standard flying cycles.

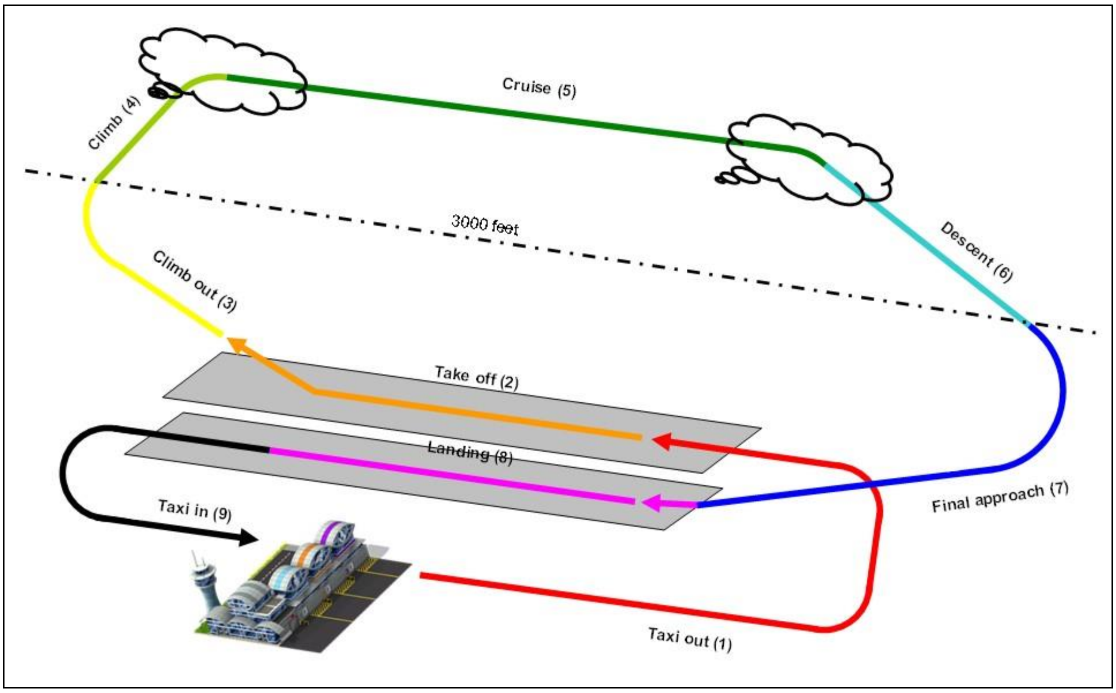

Figure 2-2 Standard flying cycles

In principle, the activities include all flights in a country. Civil air traffic (which includes general aviation) is often divided into three categories with operational military flights making a fourth category:

category 1 — Civil instrument flight rule (IFR) flights;

category 2 — Civil visual flight rule (VFR) flights, also called general aviation;

category 3 — Civil helicopters;

category 4 — Operational military flights.

Flight data are often recorded for category 1 only, and most emissions will originate here. Category 2 contains small aircraft used for leisure, agriculture, taxi flights, etc.

Data are mostly available for turbofans, but estimates also have to be made from turboprop and piston engine aircraft (which are currently not subject to any emissions regulation).

Aircraft in category 1 can be classified into types and engines as outlined in Table 2-1. This table presents aircraft and engines most frequently used in European and American aviation, although other engines may be used in significant numbers. Also note that some large long-distance planes not on this list may be important for fuel consumption (e.g. DC10, A340). In addition, emissions from turboprop aircraft may be significant in national aviation in some countries. More types and engines exist and jet engines can be seen in International Civil Aviation Organisation (ICAO) (1995) or in the ICAO online databank hosted by the UK Aviation Authority (www.caa.co.uk/default.aspx?catid=702&pagetype=90).

Military aircraft activities (category 4) are in principle included in the inventory. There may, however, be some difficulties in estimating these due to scarce and often confidential military data. One should also be aware that some movements of military aircraft might be included in category 1, for example non-operational activities.

Other emissions arise from the following activities:

start up of engines,

auxiliary power operation,

fuel dumping in emergencies,

fuelling and fuel handling,

maintenance of aircraft engines,

painting of aircraft,

service vehicles for catering and other services,

anti-icing and de-icing of aircraft with much of the substances used flowing off the wings during idle, taxi, and take-off and evaporates.

Emissions from start up of engines

There is currently little information available to estimate emissions from start up of engines and these are not included in the LTO cycle. This is not of great importance for total national emissions, but they may have an impact on the air quality in the vicinity of airports.

Auxiliary power operations

Auxiliary Power Units (APUs) are used where no other power source is available for the aircraft and may vary from airport to airport. This is the case, for example, when the aircraft is parked away from the terminal building. The APU fuel use and the related emissions should be allocated on the basis of aircraft operations (number of landings and take-offs). However, no methodology has currently been developed. The use of APUs is being severely restricted at some airports to maintain air quality, and therefore this source of fuel use and emissions may be declining. In total terms, the fuel consumption and emission contribution from this source is regarded as very small (Winther et al., 2006).

Fuel dumping in emergencies

From time to time aircraft will have to dump fuel before landing so that they do not exceed a certain maximum landing weight. This is done at a location and altitude where there will be no local impact at ground level. Only large long-range aircraft will dump fuel. Non-methane volatile organic compounds (NMVOC) emissions might become significant at very large airports with frequent long distance flights. However, since the most probable altitude of these emissions will be above 1 000 m, these are currently not relevant for United Nations Economic Commission for Europe (UNECE) reporting. The airport authorities and airline companies might give information on the extent (frequency and amount) of dumping and the altitude at particular airports.

2.2 Techniques

In general there are two types of engines: reciprocating piston engines and gas turbines. Reciprocating piston engines extract the energy from fuel burned in a combustion chamber using a piston and crank mechanism. This drives the propellers to give the aircraft momentum. The gas turbine engines compress air before burning fuel in a combustion chamber, thereby heating it. The major part of the energy is used for propelling the aircraft, whilst a minor portion is used to drive the turbine, which drives the compressor. Turbojet engines use only energy from the expanding exhaust stream for propulsion, whereas turbofan and turboprop engines use energy from the turbine to drive a fan or propeller for propulsion.

Table 2-1 Movements in Europe per aircraft type*, 2011

ICAO Code	Type name	Nb Engines	Engine type	Percent	Percent International	Cumulative %	Most used engine types
A320	AIRBUS A-320	2	TJ	13.3%	83.4%	13.3%	V2527-A5, CFM56-AB4/P
B738	BOEING 737-800	2	TJ	12.3%	85.1%	25.6%	CFM56-7B26, CFM56-7B27
A319	AIRBUS A-319	2	TJ	9.7%	89.9%	35.3%	CFM56-5B6/P, CFM56-5B5/P
A321	AIRBUS A-321	2	TJ	4.6%	82.4%	39.9%	V2533-A5, CFM56-5B1/2P
DH8D	DHC-8-400 DASH 8	2	TJ	3.0%	91.7%	42.9%	PW150A
B733	BOEING 737-300	2	TJ	2.9%	86.0%	45.8%	CFM56-3B2, CFM56-3C1
AT72	ATR-72-200	2	TP	2.8%	90.1%	48.6%	PW124B, PW127
B737	BOEING 737-700	2	TJ	2.4%	87.1%	51.0%	CFM56-7B22, CFM56-7B20
E190	EMBRAER ERJ-190	2	TJ	2.2%	95.1%	53.1%	CF34-10E
B735	BOEING 737-500	2	TJ	1.7%	63.4%	54.8%	CFM56-3C1, CFM56-3B1
B752	BOEING 757-200	2	TJ	1.7%	53.5%	56.5%	RB211-535E4
B734	BOEING 737-400	2	TJ	1.5%	80.6%	58.0%	CFM56-3C1, CFM56-3B2
B763	BOEING 767-300	2	TJ	1.5%	16.4%	59.5%	PW4060, CF6-80C2B6F
CRJ9	CRJ-900 REGIONAL JET	2	TJ	1.5%	95.0%	60.9%	CF34-8C5
B744	747-400,INTL.WINGLET	4	TJ	1.4%	5.5%	62.4%	CF6-80C2B1F, PW4056
CRJ2	RJ-200 REGIONAL JET	2	TJ	1.4%	88.2%	63.7%	CF34-3B1
A332	AIRBUS A-330-200	2	TJ	1.3%	7.4%	65.1%	PW4168A
E145	EMBRAER EMB-145	2	TJ	1.3%	94.4%	66.3%	AE3007A1
B772	BOEING 777-200	2	TJ	1.2%	1.3%	67.5%	GE90-94B, PW4090
E170	EMBRAER170	2	TJ	1.0%	90.4%	68.5%	CF34-8E5
MD82	BOEING MD-82	2	TJ	1.0%	97.3%	69.5%	JT8D-217C, JT8D-219

Data source: Eurocontrol - STATFOR, the Norwegian Civil Aviation Administration (personal comm.)

Notes:
TJ - turbojet, TP - turboprop
*The number of movements does not necessarily reflect the relative importance with respect to fuel use and emissions, which in addition are mostly determined by aircraft size and flight distances.

Military aircraft activities (category 4) are in principle included in the inventory. There may, however, be some difficulties in estimating these due to scarce and often confidential military data. One should also be aware that some movements of military aircraft might be included in category 1, for example non-operational activities.

2.3 Emissions

The emissions produced by aviation come from the use of jet fuel (jet kerosene and jet gasoline) and aviation gasoline (used to fuel small piston engine aircraft only) that are used as fuel for the aircraft. Consequently, the principal pollutants are those common to other combustion activities, i.e. CO_2, CO, hydrocarbons and oxides of nitrogen, with SO_2 emissions being dependent of the level of sulphur in the fuel. Other important species, emitted at relatively low concentrations include PM, N_2O and CH_4.

2.4 Controls

ICAO's current environmental activities are largely undertaken through the Committee on Aviation Environmental Protection (CAEP), which was established by the Council in 1983. The species regulated are:

oxides of nitrogen (most recently updated in 2005);

carbon monoxide (most recently updated in 1997);

unburned hydrocarbon (most recently updated in 1984); and

engine smoke.

Compliance with the standards on the oxides of nitrogen is the most challenging task for the makers of aircraft engines.

The regulations published by ICAO, against which engines are certificated, are given in the form of the total quantity of pollutants (Dp) emitted in an LTO-cycle divided by the maximum sea level thrust (Foo) and plotted against engine pressure ratio at maximum sea level thrust. Table 2-2 shows engine power settings and times-in-mode for the LTO-cycle specified by ICAO (ICAO, 1993).

Table 2-2 Standard landing and take-off cycles in terms of thrust settings and time spent in the specific mode

Operating mode	Thrust setting (% of maximum sea level static thrust)	Time-In-Mode (min)
Take-off	100 % F_{oo}	0.7
Climb-out	85 % F_{oo}	2.2
Approach-landing	30 % F_{oo}	4.0
Taxi/ground idle	7 % F_{oo}	26.0

Source: ICAO, 1993

The limit values for NO_x are given by the formulae in Table 2-3 which includes CAEP/8 limits (39) although they are not yet integrated into the published editions of ICAO Annex 16 Part II.

Table 2-3 Current certification limits for NO_x for turbo jet and turbo fan engines

Applicability		**Limit value**
Manufacture Date	Engine Parameter	
≥ 1 January 1986 ≤ 31 December 1995[a)] ≤ 31 December 1999[b)]	-	$D_p / F_{oo} = 40 + 2 \cdot \pi_{00}$
CAEP/2 > 31 December 1995[a)] > 31 December 1999[b)]	-	$D_p / F_{oo} = 32 + 1.6 \cdot \pi_{00}$
CAEP/4 > 31 December 2003[a)]	**$\pi_{00} \leq 30$**	
	$F_{oo} \leq 89.0$ kN	$D_p / F_{oo} = 37.572 + 1.6 \cdot \pi_{00} - 0.2087 \cdot F_{oo}$
	$F_{oo} > 89.0$ kN	$D_p / F_{oo} = 19 + 1.6 \cdot \pi_{00}$
	$30 < \pi_{00} \leq 62.5$	
	$F_{oo} \leq 89.0$ kN	$D_p / F_{oo} = 42.71 + 1.4286 \cdot \pi_{00} - 0.4013 \cdot F_{oo} + 0.00642 \cdot \pi_{00} \cdot F_{00}$
	$F_{oo} > 89.0$ kN	$Dp / F_{oo} = 7 + 2.0 \cdot \pi_{00}$
	$\pi_{00} > 62.5$	$D_p / F_{oo} = 32 + 1.6 \cdot \pi_{00}$
CAEP/6 > 31 December 2007[a)]	**$\pi_{00} \leq 30$**	
	$F_{oo} \leq 89.0$ kN	$D_p / F_{oo} = 38.5486 + 1.6823 \cdot \pi_{00} - 0.2453 \cdot F_{oo} - 0.00308 \cdot \pi_{00} \cdot F_{00}$
	$F_{oo} > 89.0$ kN	$D_p / F_{oo} = 16.72 + 1.4080 \cdot \pi_{00}$
	$30 < \pi_{00} \leq 82.6$	
	$F_{oo} \leq 89.0$ kN	$D_p / F_{oo} = 46.1600 + 1.4286 \cdot \pi_{00} - 0.5303 \cdot F_{oo} + 0.00642 \cdot \pi_{00} \cdot F_{00}$
	$F_{oo} > 89.0$ kN	$Dp / F_{oo} = -1.04 + 2.0 \cdot \pi_{00}$
	$\pi_{00} > 82.6$	$D_p / F_{oo} = 32 + 1.6 \cdot \pi_{00}$
CAEP/8 > 31 December 2013[a)]	**$\pi_{00} \leq 30$**	
	$F_{oo} \leq 89.0$ kN	$D_p / F_{oo} = 40.052 + 1.5681 \cdot \pi_{00} - 0.3615 \cdot F_{oo} - 0.0018 \cdot \pi_{00} \cdot F_{00}$
	$F_{oo} > 89.0$ kN	$D_p / F_{oo} = 7.88 + 1.4080 \cdot \pi_{00}$
	$30 < \pi_{00} \leq 104.7$	
	$F_{oo} \leq 89.0$ kN	$D_p / F_{oo} = 41.9435 + 1.505 \cdot \pi_{00} - 0.5823 \cdot F_{oo} + 0.005562 \cdot \pi_{00} \cdot F_{00}$

	$F_{oo} > 89.0$ kN …………………… $\pi_{00} > 104.7$	$Dp / F_{oo} = -9.88 + 2.0 \cdot \pi_{00}$ …………………………………………………………………… $D_p / F_{oo} = 32 + 1.6 \cdot \pi_{00}$
* Generally $F_{oo} > 26.7$ kN a) model production b) individual production		
Source: International Standards and Recommended Practices, Environmental Protection, ICAO, Annex 16, Volume II, Part III, Paragraph 2.3.2, 2nd edition July 1993, plus amendments: Amendment 3 (20 March 1997) ,Amendment 4 (4 November 1999), Amendment 5 (24 November 2005) + CAEP/8		

where:

Dp = the sum of emissions in the LTO cycle in g;

Foo = thrust at sea level take-off (100 %);

πoo = pressure ratio at sea level take-off thrust point (100 %).

Further information on legislation can be obtained from the ICAO website www.icao.int/icao/en/env/aee.htm

The equivalent limits for HC and CO are Dp/Foo = 19.6 for HC and Dp/Foo = 118 for CO (ICAO, Annex 16, Vol. II, paragraph 2.2.2).

Smoke is limited to a regulatory smoke number = 83.6*(Foo) ^ (-0.274) or a value of 50, whichever is the lower.

The relevance of the data within this report is to indicate that whilst the certification limits for NO_x are getting lower, those for smoke, CO and HC remain unchanged.

Contribution of air traffic to total emissions:

The total contribution of aircraft emissions to total global anthropogenic CO_2 emissions is considered to be about 2 % (IPCC, 1999). This relatively small contribution to global emissions should be seen in relation to the fact that most aircraft emissions are injected almost directly into the upper free troposphere and lower stratosphere. The Intergovernmental Panel on Climate Change (IPCC) has estimated that the contribution to radiative forcing is about 3.5 %. The importance of this source is growing as the volume of air traffic is steadily increasing.

The importance of air traffic in Europe for various air pollutants is illustrated in Table 2-4.

Table 2-4 Range of contributions to reported air pollutant emissions from air traffic in 2007, illustrated for the EU-27 (% of reported national total to the LRTAP Convention).

Category	**Domestic and international LTO (%)**	**Domestic cruise (%)**	**International cruise (%)**
SO_2	0-0.6	0-0.4	0-3.4
NO_x	0-5.6	0-1.5	0-9.8
NMVOC	0-3.8	0-1.1	0-1.0
CO	0-6.1	0-0.6	0-2.0
PM_{10}	0-0.7	0-0.2	0-2.0
$PM_{2.5}$	0-0.9	0-1.8	0-3.9

Source: EEA Dataservice. European Community LRTAP Convention emission inventory dataset 1990-2007.

3 Methods

3.1 Choice of method

3.1.1 Overview

In Figure 3-1 a procedure is presented to select the methods for estimating the emissions from aviation. This decision tree is applicable to all nations. When estimating aviation emissions the following should be considered:

use as detailed information as is available;

if the source category is a key source, then a Tier 2 or Tier 3 method must be used for estimating the emissions.

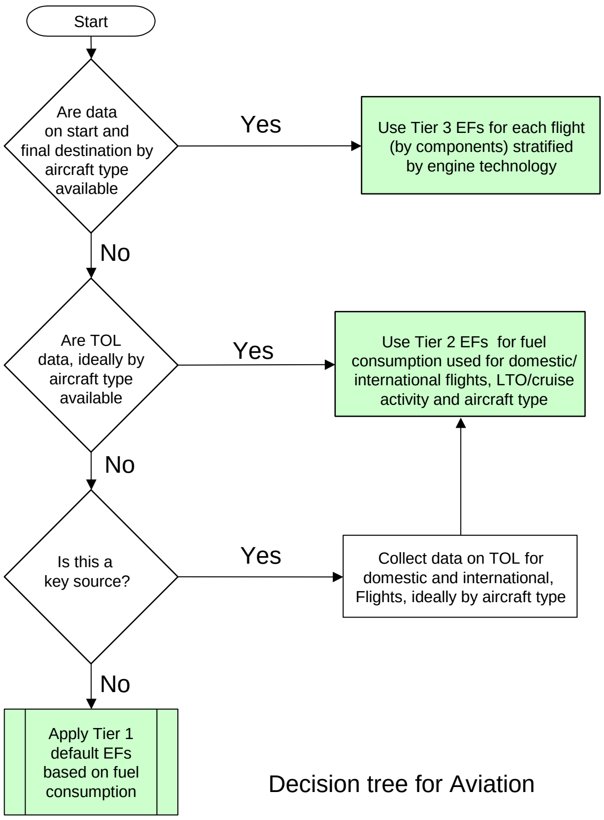

Figure 3-1 Decision tree for emissions from aviation

The three Tiers are harmonised with those specified in the IPCC 2006 Guidelines.

Table 3-1 summarises the data required to use the three Tiers in terms of activity measure and the degree of technology stratification required for the category 1 (IFR) flights. It will often be the case that the overall emissions for category 2 and 3 flights are sufficiently small and the statistics available so poor, that a Tier 1 approach for these portions of aviation is appropriate.

Table 3-1 Summary of input data required for the three Tiers of inventory methodology

	Activity	Technology stratification
Tier 1	Fuel sales sub-divided into domestic and international usage. Total LTO numbers for domestic and international.	Use average fleet mix (i.e. generic aircraft EFs) and average factors for LTO and cruise.
Tier 2	Fuel sales sub-divided into domestic and international use, as for Tier 1. LTO numbers for domestic and international, per aircraft type.	Use of aircraft specific LTO EFs and average EFs for cruise.
Tier 3	Data for each flight containing aircraft type and flight distance, sub-divided into domestic and international.	Use specific aircraft type data from the accompanying spreadsheet to this chapter, available from http://eea.europa.eu/emep-eea-guidebook

The Tier 1 and Tier 2 methodologies are both based on LTO data and the quantity of fuel sold or used as illustrated in Figure 3-2. It is assumed that fuel used equals fuel sold. From the total fuel sold for aircraft activities, allocations are made according to the requirements for IPCC and UNECE reporting. The emission estimation can be made following either the Tier 1 or Tier 2 methodology outlined below.

For estimating the total emissions of CO_2, SO_2 and heavy metals the Tier 1 methodology is sufficient, as the emissions of these pollutants are dependent on the fuel only and not on technology. The emissions of PM_{10} or $PM_{2.5}$ are aircraft and payload dependent. Therefore, when estimating the total emissions of these pollutants, it may be appropriate to consider the aircraft activity in more detail, using the Tier 2 methodology. The Tier 3 methodology may be used to get an independent estimate of fuel and CO_2 emissions from domestic air traffic.

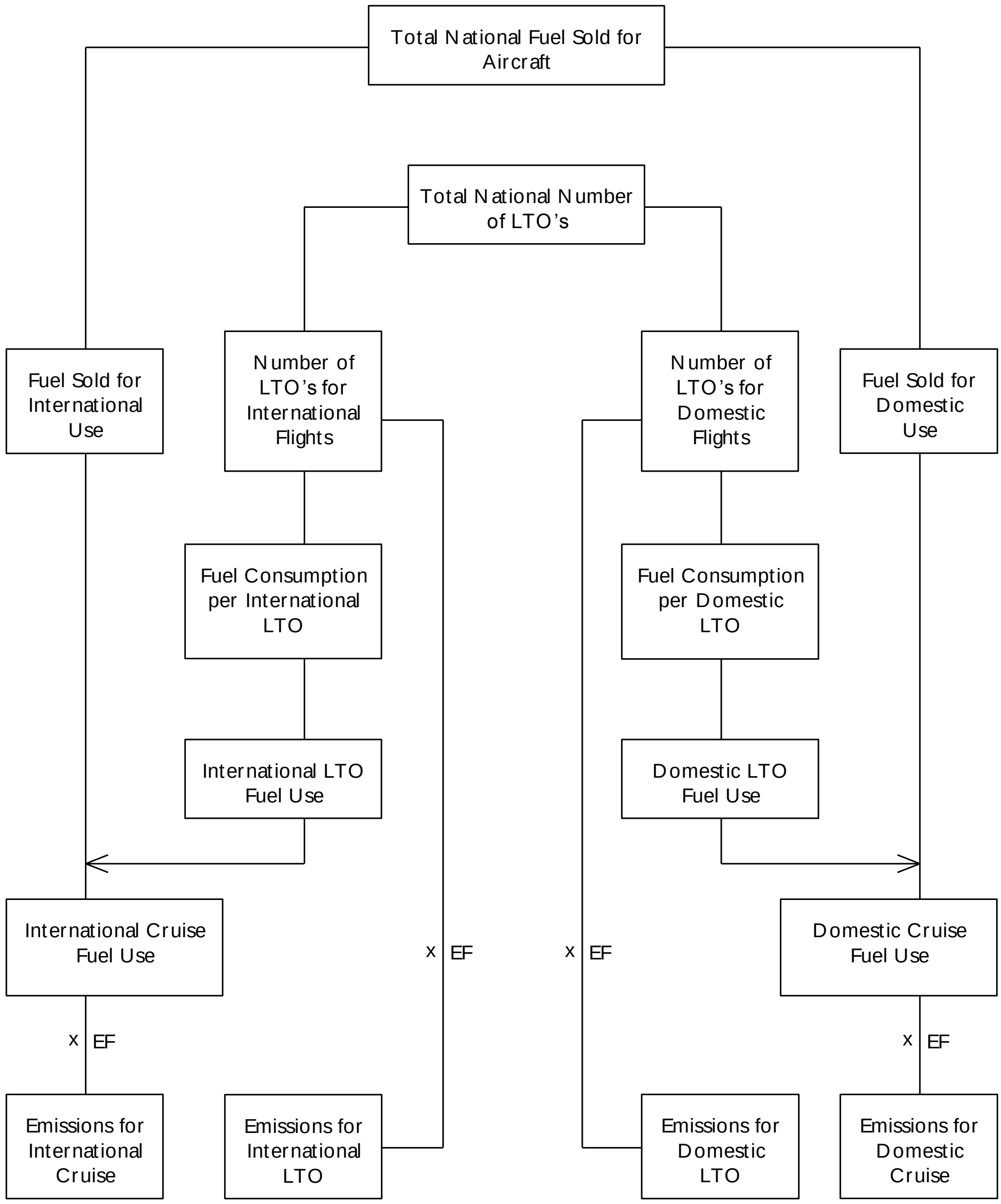

Figure 3-2 Estimation of aircraft emissions using the Tier 1 and Tier 2 methodologies

3.1.2 Choice of activity data

The way of deriving the activity statistics are critical to the difference between Tier 1 and 2. Since emissions from domestic aviation are reported separately from international aviation and for LTO and cruise, it is necessary to disaggregate activity data between these components. This section lays out options as to how this should be done —consistent also with the approach for estimating greenhouse gases. The basic starting point is national statistics on fuel consumption and for Tier 2 data on take-off and landings with more detailed aircraft type information.

Domestic and international split

To disaggregate the activity data between domestic and international, the following definitions should be applied irrespective of the nationality of the carrier (Table 3–2). For consistency, it is good practice to use similar definitions of domestic and international activities for aviation. In some cases, the national energy statistics may not provide data consistent with this definition. It is good practice that countries separate the activity data consistent with this definition. In any case, a country must clearly define the methodologies and assumptions used.

Table 3-2 Criteria for defining international or domestic aviation (applies to individual legs of journeys with more than one take-off and landing).

Journey type between two airports	**Domestic**	**International**
Departs and arrives in same country	Yes	No
Departs from one country and arrives in another	No	Yes

Note

Based on past experience compiling aviation emissions inventories, difficulties have been identified regarding the international/domestic split, in particular obtaining the information on passenger and freight drop-off and pick up at stops in the same country that was required by the *1996 IPCC Guidelines*/*GPG2000* (Summary report of ICAO/UNFCCC Expert Meeting April 2004). Most flight data are collected on the basis of individual flight segments (from one take-off to the next landing) and do not distinguish between different types of intermediate stops (as called for in *GPG2000*). Basing the distinction on flight segment data (origin/destination) is therefore simpler and is likely to reduce uncertainties. It is very unlikely that this change would make a significant change to the emission estimates ([3]).This does not change the way in which emissions from international flights are reported as a memo item and not included in national totals.

Improvements in technology and optimization of airline operating practices have significantly reduced the need for intermediate technical stops. An intermediate technical stop would also not change the definition of a flight as being domestic or international. For example if explicit data is available, countries may define international flight segments that depart one country with a destination in another country and make an intermediate technical stop. A technical stop is solely for the purpose of refuelling or solving a technical difficulty and not for the purpose of passenger or cargo exchange.

If national energy statistics do not already provide data consistent with this definition, countries should then estimate the split between domestic and international fuel consumption according to the definition, using the approaches set out below.

Top-down data can be obtained from taxation authorities in cases where fuel sold for domestic use is subject to taxation, but that for international use is not taxed. Airports or fuel suppliers may have data on delivery of aviation kerosene and aviation gasoline to domestic and to international flights. In most countries tax and custom dues are levied on fuels for domestic consumption, and fuels for international consumption (bunkers) are free of such dues. In the absence of more direct sources of data, information about domestic taxes may be used to distinguish between domestic and international fuel consumption.

Bottom-up data can be obtained from surveys of airline companies for fuel used on domestic and international flights, or estimates from aircraft movement data and standard tables of fuel

(3) It is good practice to clearly state the reasoning and justification if any country opts to use the *GPG2000* definitions.

consumed or both. Fuel consumption factors for aircraft (fuel used per LTO and per nautical mile cruised) can be used for estimates and may be obtained from the airline companies.

Examples of sources for bottom-up data, including aircraft movement, are:

statistical offices or transport ministries as a part of national statistics,

airport records,

ATC (Air Traffic Control) records, for example Eurocontrol statistics,

air carrier schedules published monthly by OAG which contains worldwide timetable passenger and freight aircraft movements as well as regular scheduled departures of charter operators. It does not contain ad-hoc charter aircraft movements.

Some of these sources do not cover all flights (e.g. charter flights may be excluded). On the other hand, airline timetable data may include duplicate flights due to code shares between airlines or duplicate flight numbers. Methods have been developed to detect and remove these duplicates. (Baughcum et al., 1996; Sutkus et al., 2001).

Large commercial aircraft

This includes aircraft that to a large extent reflect the 2004 operating fleet and some aircraft types for back compatibility, identified by minor models. To minimise table size, some aircraft minor models were grouped when LTO emissions factors were similar. The original data source for the Large Commercial Aircraft group LTO emissions factors is the ICAO Engine Exhaust Emissions Data Bank (ICAO, 2004a). The ICAO data is the basis for the further simulation of LTO and cruise emission factors made by MEET (1997) and ANCAT (1998) given in the from the accompanying spreadsheet to this chapter, which is available from the EMEP/EEA Guidebook website (www.eea.europa.eu/emep-eea-guidebook).

Turboprops

This group includes aircraft that are representative of the 2004 Turboprop fleet, which can be represented by three typical aircraft sizes based on engine shaft horsepower. The original data source for the Turboprop group LTO emissions factors is the Swedish Aeronautical Institute (FOI) LTO Emissions Database.

The equivalent data for regional jets, low-thrust jets (engines with thrust below 26.7 kN) and piston engine aircraft need to be obtained from other sources. The relationship between actual aircraft and representative aircraft types are provided in the Tables 3–7 and 3–8.

Aircraft fleet data may also be obtained from various sources. ICAO collects fleet data through two of its statistics sub-programmes: the fleet of commercial air carriers, reported by States for their commercial air carriers, and civil aircraft on register, reported by States for the civil aircraft on their register as of 31 December (ICAO 2004b).

Some ICAO States do not participate in this data collection, in part because of the difficulty surrounding splitting the fleet into commercial and non-commercial entities. Consequently, ICAO also makes use of other external sources. One of these sources is the International Register of Civil Aircraft, 2004, published by the Bureau Veritas (France), the CAA (UK) and ENAC (Italy) in cooperation with ICAO. This database contains the information from the civil aircraft registers of some 45 States (including the United States) covering over 450 000 aircraft.

In addition to the above, there are also commercial databases of which ICAO makes use. None cover the whole fleet as they have limitations in scope and aircraft size. Among these are the BACK Aviation Solutions Fleet Data (fixed-wing aircraft over 30 seats), AirClaims CASE database (fixed wing jet and turboprop commercial aircraft), BUCHAir, publishers of the JP Airline Fleet (covers both fixed- and rotary-wing aircraft). Other companies such as AvSoft may also have relevant information. Further information may be obtained from these companies' websites.

3.1.3 Military aircraft

Although military aviation is not reported here, it makes sense to include a basic description of the methodology in this chapter, appropriately cross-referenced from chapter for NFR code 1.A.5.

Military activity is defined here as those activities using fuel purchased by or supplied to the military authorities of the country. Emissions from aviation fuel use can be estimated using the Tier 1 algorithm and the same calculations approach recommended for civilian aviation. Some types of military transport aircraft and helicopters have fuel and emissions characteristics similar to civil types. Therefore, default emission factors for civil aircraft should be used for military aviation unless better data are available. Alternatively, fuel use may be estimated from the hours in operation. Default fuel consumption factors for military aircraft are given in Tables 3–9 and 3–10.

Military aircraft (transport planes, helicopters and fighters) may not have a civilian analogue, so a more detailed method of data analysis is encouraged where data are available. Inventory compilers should consult military experts to determine the most appropriate emission factors for the country's military aviation.

Due to confidentiality issues, many inventory compilers may have difficulty obtaining data for the quantity of fuel used by the military. Military activity is defined here as those activities using fuel purchased by or supplied to the military authorities in the country. Countries can apply the rules defining civilian, national and international aviation operations to military operations when the data necessary to apply those rules are comparable and available. In this case, the international military emissions may be reported under International Aviation (International Bunkers), but must then be shown separately. Data on military fuel use should be obtained from government military institutions or fuel suppliers. If data on fuel split is unavailable, all the fuel sold for military activities should be treated as domestic.

Emissions resulting from multilateral operations pursuant to the Charter of the United Nations (UN) should not be included in national totals; other emissions related to operations shall be included in the national emissions totals of one or more parties involved. The national calculations should take into account fuel delivered to the country's military, as well as fuel delivered within that country but used by the military of other countries. Other emissions related to operations (e.g. off-road ground support equipment) shall be included in the national emissions totals in the appropriate source category.

These data should be used with care as national circumstances may vary from those assumed in this table. In particular, distances travelled and fuel consumption may be affected by national route structures, airport congestion and air-traffic control practices.

3.2 Tier 1 fuel-based methodology

3.2.1 Algorithm

The Tier 1 approach for aviation is based on quantity of fuel consumption data for aviation split by LTO and cruise for domestic and international flights separately. The method uses a simple approach to estimate the split of fuel use between cruise and LTO, as shown schematically in Figure 3–2. (This approach was labelled the 'very simple methodology' in the previous version of the Guidebook.

The Tier 1 approach for aviation emissions uses the general equation;

$$E_{pollutant} = AR_{fuel\ consumption} \times EF_{pollutant} \quad (1)$$

where:

$E_{pollutant}$	=	annual emission of pollutant for each of the LTO and cruise phases of domestic and international flights;
$AR_{fuel\ consumption}$	=	activity rate by fuel consumption for each of the flight phases and trip types;
$EF_{pollutant}$	=	emission factor of pollutant for the respective flight phase and trip type.

This equation is applied at the national level, using annual national total fuel use disaggregated by domestic and international flights. Information on fuel consumption for domestic and international flights should be available from national statistics as described above or is widely available from UN statistical yearbooks or national statistics. Aircraft emission estimates according to the Tier 1 approach can be obtained by following the steps detailed in subsection 3.2.3.

3.2.2 Default emission factors

Tier 1 emission factors ($EF_{Pollutant}$, Fuel type) assume an averaged technology for the fleet, and knowledge of the number of domestic and international LTO cycles for the nation. Default emission factors are presented in Table 3–3, but need statistics to be split into cruise and LTO as well as domestic and international.

Where statistics are available for fuel use and the number of LTOs by domestic and international flights, the assumptions on LTO fuel consumption below can be used to split these data by LTO and cruise using the following equation.

(AVIATION EQUATION 1)
Total fuel = LTO fuel +cruise fuel

Where:

(AVIATION EQUATION 2)
LTO fuel = number of LTOs x fuel consumption per LTO

(AVIATION EQUATION 3)
Cruise fuel = total fuel consumption — LTO fuel consumption

3.2.2.1 Jet kerosene

Using the relationships above and the data in Table 3–3, the emissions for the four different NFR codes can be calculated.

Table 3–3 Emission factors and fuel use for the *Tier 1* methodology using jet kerosene as fuel. Emission factors are given on a representative aircraft basis

Tier 1 emission factors									
Domestic	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NMVOC**	**CH_4**	**N_2O**	**$PM_{2.5}$**
LTO (kg/LTO) — average fleet (B737-400)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1	0.07
LTO (kg/LTO) — old fleet (B737-100)	920	0.9	2900	4.8	8.0	0.5	0.1	0.1	0.10
Cruise (kg/tonne) — average fleet (B737-400)	-	1.0	3150	2.0	10.3	0.1	0	0.1	0.20
Cruise (kg/tonne) — old fleet (B737-100)	-	1.0	3150	2.0	9.4	0.8	0	0.1	0.20
International	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NMVOC**	**CH_4**	**N_2O**	**$PM_{2.5}$**
LTO (kg/LTO) — average fleet (B767)	1617	1.6	5094	6.1	26.0	0.2	0.0	0.2	0.15
LTO (kg/LTO) — average fleet (short distance, B737-400)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1	0.07
LTO (kg/LTO) — average fleet (long distance, B747-400)	3400	3.4	10717	19.5	56.6	1.7	0.2	0.3	0.32
LTO (kg/LTO) — old fleet (DC10)	2400	2.4	7500	61.6	41.7	20.5	2.3	0.2	0.32
LTO (kg/LTO) — old fleet (short distance, B737-100)	920	0.9	2900	4.8	8.0	0.5	0.1	0.1	0.10
LTO (kg/LTO) — old fleet (long distance, B747-100)	3400	3.4	10754	78.2	55.9	33.6	3.7	0.3	0.47
Cruise (kg/tonne) — average fleet (B767)	-	1.0	3150	1.1	12.8	0.5	0.0	0.1	0.20
Cruise (kg/tonne) — old fleet (DC10)	-	1.0	3150	1.0	17.6	0.8	0.0	0.1	0.20

Notes:
1. Sulphur content of the fuel is assumed to be 0.05 % S (by mass) for both LTO and cruise activities.
2. Assuming a cruise distance of 500 nm for short distance flights and 3 000 nm for long distance flights.
Source: derived from ANCAT/EC2 1998, Falk 1999 and MEET 1999.
3. $PM_{2.5}$ data (= PM_{10} emissions).*Source: inferred from smoke data from ICAO database (ICAO 2006) using the methodology described in ICAO (2007)*
4. BC fractions of PM (f-BC) = 0.48. *Source: for further information see Appendix C*

3.2.2.2 Aviation gasoline

Aviation gasoline is assumed to only be used for domestic aviation. Table 3—4 provides the Tier 1 emission factors for NFR 1.A.3.a.ii.(i): Civil aviation (domestic, LTO) for gasoline fuelled aircraft. These emission factors are based on data for piston engine aircraft provided in Table 3—14. The 95 % confidence limits quoted are 50 % and 200 % of the mean values.

Table 3-4 Tier 1 emission factors for NFR 1.A.3.a.ii.(i): Civil aviation (domestic, LTO)

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	1.A.3.a.ii.(i)	Civil aviation (domestic, LTO)			
Fuel	Jet Gasoline and Aviation Gasoline				
Not estimated	SO_x, NH_3, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene				
Not applicable	Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB, HCB, PCP, SCCP				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	4	kg/tonne fuel	2	8	Calc from Tier 2
CO	1200	kg/tonne fuel	600	2400	Calc from Tier 2
NMVOC	19	kg/tonne fuel	9.5	38	Calc from Tier 2
TSP	0	kg/tonne fuel	0	0	Use Road Transport
PM_{10}	0	kg/tonne fuel	0	0	Use Road Transport
$PM_{2.5}$	0	kg/tonne fuel	0	0	Use Road Transport
(*) SO_2	1	kg/tonne fuel	0.5	2	Assuming 0.05% S by mass

Note:
If national PM emission factors are available, a BC fraction of PM (f-BC) = 0.15 is suggested.
Source: for further information see Appendix C

3.2.3 Calculation steps for Tier 1

The Tier 1 approach is based on the premise that data on the quantities of fuel sold for aviation use are available, most probably from nationally collected data. It also assumes that the annual quantity of fuel used is the same that sold.

Information on the country's total number of LTOs needs to be available, preferably also the destination (long and short distance) for international LTOs, together with a general knowledge about the aircraft types carrying out aviation activities.

Aircraft emission estimates according to the Tier 1 methodology can be obtained by following the steps below.

1. Obtain the *total* amount of *fuel* sold for all aviation (in ktonnes).
2. Obtain the amount of *fuel* used for *domestic* aviation only (in ktonnes).
3. Calculate the total amount of *fuel* used for *international* aviation by subtracting the domestic aviation (step 2) from the total fuel sold (step 1).
4. Obtain the total *number of LTOs* carried out for domestic aviation.
5. Calculate the *total fuel use for LTO* activities for domestic aviation by multiplying the number of domestic LTOs by the domestic fuel use factors for one representative aircraft (Table 3–3) (step 4 x fuel use for representative aircraft). Fuel use factors are suggested for an old and an average fleet.
6. Calculate the *fuel used for cruise* activities for domestic aviation by subtracting the fuel used for domestic LTO (step 5) from the total domestic fuel used (step 2).

7. Estimate the *emissions related to domestic LTO activities* by multiplying the emission factors (per LTO) for domestic traffic with the number of LTO for domestic traffic. Emission factors are suggested for an old and an average fleet by representative aircraft (Table 3–3).

8. Estimate the *emissions related to domestic cruise activities* by multiplying the respective emission factors (in emission/fuel used) in Table 3–3 with the domestic cruise fuel use. Emission factors are suggested for an old and an average fleet by representative aircraft.

9. Repeat step 4 to 8 substituting domestic activities with *international*. It is for international flights preferable to distinguish between short (< 1 000 nm ([4])) and long-distance flights (> 1000 nm). The latter is normally performed by large fuel consuming aircraft compared to the shorter distance flights (e.g. within Europe). If this distinction cannot be made the LTO emissions are expected to be largely overestimated in most countries.

3.3 Tier 2 method

3.3.1 Algorithms

The Tier 2 approach applies if it is possible to obtain information on LTOs per aircraft type but there is no information available on cruise distances. The level of detail necessary for this methodology is the aircraft types used for both domestic and international aviation, together with the number of LTOs carried out by the various aircraft types.

Apart from this level of further detail according to aircraft type, the algorithms are the same as for the Tier 1 approach:

$$E_{pollutant} = \sum_{Aircraft types} AR_{fuel\ consumption,\ aircraft type} \times EF_{pollutant,\ aircraft type} \quad (2)$$

where, analogous to before:

$E_{pollutant}$ = annual emission of pollutant for each of the LTO and cruise phases of domestic and international flights;

$AR_{fuel\ consumption,\ aircraft\ type}$ = activity rate by fuel consumption for each of the flight phases and trip types, for each aircraft type;

$EF_{pollutant,\ aircraft\ type}$ = emission factor of pollutant for the respective flight phase and trip type, for each aircraft type.

([4]) Where nm = nautical miles, 1 nm = 1 852 km.

3.3.2 Aircraft-type based emission factors

Table 3–5 lists LTO fuel consumption and emission factors for certain aircraft types. Note that the values provided for LTO are based on standard ICAO taxi times. These may differ significantly from average taxi times at European airports. Future work for this chapter includes plans to update the LTO values based on European average taxi times.

Table 3-5 Examples of aircraft types and emission factors for LTO cycles as well as fuel consumption per aircraft type, kg/LTO

Aircraft Icao	# of engines	CO_2_kg	NO_x_kg	CO_kg	HC_kg	H_2O_kg	Pm_{25}_kg	BurntFuel_kg
A306	2	5427.9	25.9	14.8	1.2	2119.5	0.1	1723.1
A310	2	4745.8	19.5	28.7	6.5	1853.1	0.1	1506.6
A319	2	2169.8	7.5	9.5	2.0	847.2	0.1	688.8
A320	2	2750.7	10.8	5.5	0.1	1074.1	0.1	873.3
A332	2	7029.3	35.6	16.2	1.3	2744.8	0.1	2231.5
A333	2	5934.6	27.6	13.0	1.0	2317.3	0.1	1884.0
A343	4	6362.6	34.8	25.2	3.9	2484.5	0.3	2019.9
A345	4	5867.3	28.3	26.2	4.2	2291.0	0.2	1862.6
A346	4	10624.8	64.7	15.0	0.2	4148.7	0.2	3373.0
A388	4	13048.6	67.3	29.6	0.4	5095.2	0.2	4142.4
B737	2	2454.5	9.1	8.0	0.9	958.4	0.1	779.2
B738	2	2775.5	12.3	7.1	0.7	1083.8	0.1	881.1
B742	4	9684.9	47.5	27.5	3.2	3781.7	0.2	3074.6
B743	4	10806.0	57.0	18.3	2.5	4219.5	0.2	3430.5
B744	4	10457.0	44.5	25.3	2.1	4083.2	0.2	3319.7
B752	2	4292.2	15.0	12.3	0.2	1676.0	0.1	1362.6
B753	2	4610.5	17.9	11.6	0.1	1800.3	0.1	1463.6
B762	2	4607.4	23.8	14.8	3.3	1799.1	0.1	1462.7
B763	2	5590.6	28.2	14.5	1.2	2183.0	0.1	1774.8
B772	2	7346.1	55.8	12.6	0.5	2868.5	0.1	2332.1
B773	2	7588.0	63.3	17.7	2.0	2962.9	0.1	2408.9
B77L	2	9736.1	69.8	47.5	5.1	3801.7	0.2	3090.8
B77W	2	9298.0	61.2	48.1	5.3	3630.7	0.2	2951.8
DC10	3	7263.7	35.7	20.6	2.4	2836.3	0.2	2305.9
DC85	4	4745.8	19.5	28.7	6.5	1853.1	0.1	1506.6
DC87	4	5339.9	15.6	26.3	1.5	2085.1	0.1	1695.2
F2TH	2	535.3	1.3	5.2	1.6	209.0	0.0	169.9
MD11	3	8277.9	38.2	18.3	1.4	3232.3	0.2	2627.9
T154	3	5939.9	12.0	82.9	13.2	2319.4	0.2	1885.7

Notes:
(a) For CH_4 and NMVOC it is assumed that emission factors for LTO cycles are 10 % and 90 % of total VOC (HC), respectively (Olivier, 1991). Studies indicate that during cruise no methane is emitted (Wiesen et al., 1994).
(b) Estimates based on IPCC Tier 1 default values.
(c) Sulphur content of the fuel is assumed to be 0.05% for both LTO and cruise activities**.**
(d) $PM_{2.5}$ data (= PM_{10} emissions).
Source: ICAO database (ICAO 2006) and ICAO 2007.

Source: Derived from ANCAT/EC2 1998, Falk (1999) and MEET 1999.
ICAO Aircraft Engine Emissions Databank - http://easa.europa.eu/environment/edb/aircraft-engine-emissions.php
(e) BC fractions of PM (f-BC) = 0.48. *Source: for further information see Appendix C*

For jets, Table 3–6 provides a way of mapping some of the most important actual aircraft to the smaller list representative aircraft types in Table 3–5.

Table 3–6 Correspondence between representative jet aircraft and other jet aircraft types

Generic aircraft type	ICAO	IATA	Generic aircraft type	ICAO	IATA	Generic aircraft type	ICAO	IATA
Airbus A310	A310	310	**Boeing 737-400**	B734	734	**Fokker 100**	F100	100
		312		B735	735	**Fokker F-28**	F28	F28
		313		B736	736			TU3
		A31		B737	737	**Boeing 737-100 * 2**	DC8	DC8
Airbus A320	A318	318			73A			D8F
	A319	319			73B			D8M
	A320	320			73F			D8S
	A321	321			73M			707
		32S			73S			70F
Airbus A330	A330	330			B86			IL6
		332			JET			B72
		333	**Boeing 747-100-300**	B741	741			VCX
Airbus A340	A340	340		B742	742	**McDonnell Douglas DC-9**	DC9	D92
		342		B743	743			D93
		343			747			D94
BAe 111	BA11	B11			74D			D95
		B15			74E			D98
		CRV			74F			D9S
		F23			A4F			DC9
		F24			74L			F21
		YK4			74M			YK2
BAe 146	BA46	141			74R	**McDonnell Douglas DC-10**	DC10	D10
		143			IL7			D11
		146			ILW			D1C
		14F			C51			D1F
Boeing 727	B721	721	**Boeing 747-400**	B744	744			L10
	B722	722	**Boeing 757**	B752	757			L11
	B727	727		B753	75F			L12
		72A			TR2			L15
		72F	**Boeing 767-300 ER**	B763	762			M11
		72M			763			M1F
		72S			767	**McDonnell Douglas M82**	MD81-88	717
		TU5			AB3		MD90	M80
		TRD			AB4			M81
Boeing 737-100	B731	731			AB6			M82
	B732	732			A3E			M83
	B733	733			ABF			M87
		DAM	**Boeing 777**	B772	777			M88
				B773	772			M90
					773			

Notes:

1. MD90 goes as MD81-88 and B737- 600 goes as B737- 400.
2. DC8 goes as double the B737- 100. F50, Dash8 — see separate table.

Turboprops may be classified by the number of seats they contain, and use this classification to provide representative aircraft types, see Table 3–7. Table 3–8 contains an overview of smaller aircraft types.

Table 3–7 Classification of turboprops

	Representative aircraft*
Up to 30 seats	Dornier 328
Up to 50 seats	Saab 2000
Up to 70 seats	ATR 72

* More representative aircraft are included in the accompanying spreadsheet to the chapter (available from the EMEP/EEA Guidebook website www.eea.europa.eu/emep-eea-guidebook), if the actual turboprop in use is known.

Table 3–8 Overview of smaller aircraft types

Aircraft type	Aircraft category/engine principle	Maximum take-off weight according to Frawley's	Rank in Danish inventory 1998
Can_CL604 (CL60)	L2J	18	19
Canadair RJ 100 (CARJ)	L2J	24	17
CitationI (C500)	L2J	5.2	10
Falcon2000 (F2TH)	L2J	16.2	-
Falcon900 (F900)	L3J	20.6	8
Avro_RJ85 (BA46)	L4J	42	1
C130 (C130)	L4T	70.3	1
P3B_Orion (L188)	L4T	52.7	2
AS50 (AS50)	H1T	2	2
S61 (S61)	H2T	8.6	1

Notes:

L = landplane, H= helicopter, J = jet engine, T = turboprop, 1, 2 or 4 equals the number of engines.

Source: Supplied by Danmarks Miljøundersøkelser.

3.3.3 Calculation steps for Tier 2

The Tier 2 methodology is predominantly a top down (fuel sold) methodology that uses statistics on aviation fuel consumption (split by domestic and international). To split the fuel use by LTO and cruise detailed LTO activity and knowledge of aircraft fleet composition are needed to provide a more accurate inventory as opposed to using only average emission factors per mass of fuel used (the Tier 1 approach). The Tier 2 methodology should include all types of aircraft frequently used for domestic and international aviation. The Tables 3–6 and 3–7 provides a way of mapping actual aircraft to representative aircraft types in the database.

The approach can best be described by the following steps.

1. Obtain the *total amount of fuel* sold for all aviation (in ktonnes).
2. obtain the total amount of *fuel* used for *domestic aviation* (in ktonnes);
3. calculate the amount of *fuel used for international aviation* by subtracting the domestic aviation (step 2) from the total fuel sold (step 1) (in ktonnes);

4. Obtain the total *number of LTOs* carried out *per aircraft type* for domestic aviation. Group the aircraft into the groups of generic aircraft given in the Tables 3–6 and 3–7. Use Table 3–8 for miscellaneous smaller aircraft.

5. Calculate the *fuel use for LTO activities* per aircraft type for domestic aviation. For each aircraft type, multiply the fuel use factor in the accompanying spreadsheet to this chapter (available from the EMEP/EEA Guidebook website www.eea.europa.eu/emep-eea-guidebook) corresponding to the specific aircraft type in the Tables 3–6 and 3–7 with the number of domestic LTOs carried out for the generic aircraft (fuel use factor in LTO for aircraft type * number of LTOs with the same aircraft type). The calculations are carried out for all types of generic aircraft. Calculate the total fuel use for LTO activities by summing all contributions found under step 5 for domestic aviation. If some types of national aircraft in use are not found in the table, use a similar type taking into account size and age. For LTOs for smaller aircraft and turboprops, see also section on non-IFR flights. Their emissions will have to be estimated separately, by a simpler method.

6. Calculate the total *fuel use for domestic cruise* by subtracting the total amount of fuel for LTO activities found in step 6 from the total in step 2 (estimated as in the Tier 1 methodology).

7. Estimate the *emissions from domestic LTO activities* per aircraft type. The number of LTOs for each aircraft type is multiplied by the emission factor related to the particular aircraft type and pollutant. This is done for all generic aircraft types. Relevant emission factors can again be found in the accompanying spreadsheet to this chapter (available from the EMEP/EEA Guidebook website www.eea.europa.eu/emep-eea-guidebook). If some types of national aircraft in use are not found in the latter database, use a similar type taking into account size and age. For LTOs for smaller aircraft, see also section on non-IFR flights. Their emissions will have to be estimated separately by a simpler method.

8. Estimate the emissions from domestic *cruise activities*. Use the domestic cruise fuel use and the corresponding emission factor for the most common aircraft type used for domestic cruise activities (the Tier 1 methodology or Tier 3 methodology). Relevant emission factors can be found in Table 3–3 or accompanying spreadsheet for the Tier 3 methodology (available from the EMEP/EEA Guidebook website www.eea.europa.eu/emep-eea-guidebook).

9. Calculate the *total emissions for LTO activities* for domestic aviation. Add up all contributions from the various aircraft types as found under step 7. The summations shall take place for each of the pollutants for which emissions are to be estimated (for CO_2, NO_x, SO_2, etc.).

10. Calculate the *total emissions for cruise activities* for domestic aviation. Add up all contributions from the various types of aircraft types as found under step 8). The summations shall take place for each of the pollutants for which emissions are to be estimated (for CO_2, NO_x, SO_2, etc.).

11. Repeat the calculation (step 4-10) for *international aviation*.

3.3.4 Abatement

Technology abatement approach not relevant for this methodology.

3.3.5 Military aircraft

The Tier 2, i.e. aircraft type-specific, methodology is also applicable to calculating the emissions from military aircraft. However, it should be noted that the reporting of emissions from military aircraft is under NFR code 1.A.5, not 1.A.3.a.

There are two potential activity indicators:

- total fuel used by military aircraft, or
- number of flight hours, per aircraft type, multiplied by average fuel consumption in kg/hr.

Tables 3–9 and 3–10 provide generic and aircraft specific fuel consumption data for military aircraft. The emission factors given in Table 3–3 (which are per unit of fuel combusted) can then be used with the fuel used data to calculate emissions.

Table 3-9 Fuel consumption factors for generic military aircraft

Group	Sub-group	Representative type	Fuel flow kg/hour
1. Combat	Fast jet — high thrust	F16	3283
	Fast jet — low thrust	Tiger F-5E	2100
2. Trainer	Jet trainers	Hawk	720
	Turboprop trainers	PC-7	120
3. Tanker/transport	Large tanker/transport	C-130	2225
	Small transport	ATP	499
4. Other	MPAs, maritime patrol	C-130	2225

Source: ANCAT, British Aerospace/Airbus.

Table 3-10 Fuel consumption per flight hour for specific military aircraft

Aircraft Type	Aircraft description	Fuel use (litres per hour)
A-10A	Twin engine light bomber.	2 331
B-1B	Four engine long-range strategic bomber. Used by USA only.	13 959
B-52H	Eight engine long-range strategic bomber. Used by USA only.	12 833
C-12J	Twin turboprop light transport. Beech King Air variant.	398
C-130E	Four turboprop transport. Used by many countries.	2 956
C-141B	Four engine long-range transport. Used by USA only.	7 849
C-5B	Four engine long-range heavy transport. Used by USA only.	13 473
C-9C	Twin engine transport. Military variant of DC-9.	3 745
E-4B	Four engine transport. Military variant of Boeing 747.	17 339
F-15D	Twin engine fighter.	5 825
F-15E	Twin engine fighter-bomber.	6 951
F-16C	Single engine fighter. Used by many countries.	3 252
KC-10A	Three engine tanker. Military variant of DC-10.	10 002
KC-135E	Four engine tanker. Military variant of Boeing 707.	7 134
KC-135R	Four engine tanker with newer engines. Boeing 707 variant.	6 064
T-37B	Twin engine jet trainer.	694
T-38A	Twin engine jet trainer. Similar to F-5.	262

3.4 Tier 3 flight- and aircraft-type methodology

The Tier 3 methodologies are based on actual flight movement data, either for Tier 3A origin and destination (OD) data or for Tier 3B full flight trajectory information. Hence these methodologies are bottom-up, flight-based, rather than top-down calculation-based on the fuel consumed. Further details are provided in Appendix D.

Tier 3A takes into account cruise emissions for different flight distances. Hence details on the origin (departure) and destination (arrival) airports and aircraft type are needed to use this approach, for both domestic and international flights. In Tier 3A, inventories are modelled using average fuel consumption and emissions data for the LTO phase and various cruise phase lengths, for an array of representative aircraft categories.

The data used in Tier 3A methodology takes into account that the amount of emissions generated varies between phases of flight. The methodology also takes into account that fuel burn is related to flight distance, while recognising that fuel burn can be comparably higher on relatively short distances than on longer routes. This is because aircraft use a higher amount of fuel per distance for the LTO cycle compared to the cruise phase.

Tier 3B methodology is distinguished from Tier 3A by the calculation of fuel burnt and emissions throughout the full trajectory of each flight segment using aircraft- and engine-specific aerodynamic performance information. To use Tier 3B, sophisticated computer models are required to address all the equipment, performance and trajectory variables and calculations for all flights in a given year.

Models used for Tier 3B level can generally specify output in terms of aircraft, engine, airport, region, and global totals, as well as by latitude, longitude, altitude and time, for fuel burn and emissions of CO, hydrocarbons (HC), CO_2, H_2O, NO_x, and SO_x. To be used in preparing annual inventory submissions, Tier 3B model must calculate aircraft emissions from input data that take into account air-traffic changes, aircraft equipment changes, or any input-variable scenario.

The components of Tier 3B models ideally are incorporated so that they can be readily updated, so that the models are dynamic and can remain current with evolving data and methodologies. Examples of models include the system for assessing Aviation's Global Emissions (SAGE) by the United States Federal Aviation Administration (Kim, 2005 a and b; Malwitz, 2005) and AERO2k (Eyers, 2004) by the European Commission.

The Tier 3 methodology described in this chapter only relates to Tier 3A.

3.4.1 Algorithm

As for Tier 2 EFs for CO_2, SO_2, heavy metals are based on the fuel used, and PM are calculated from the $PM_{2.5}$ emissions. The emissions of NO_x, HC, CO and smoke, as well as the fuel used, are calculated on a flight by flight basis using EFs available from the accompanying spreadsheet to the chapter, which is available from the EMEP/EEA Guidebook website (www.eea.europa.eu/emep-eea-guidebook).

An illustrative data set for a Boeing 737-400 is given in Table 3–11. How this data may be used to calculate the emission from a flight is illustrated with the example in subsection 3.4.4 of the present chapter.

3.4.2 Tier 3 emission factors

3.4.2.1 IFR flights

The emission factors for the Tier 3 methodology are listed in the accompanying spreadsheet to the chapter, which is available from the EMEP/EEA Guidebook website (www.eea.europa.eu/emep-eea-guidebook). Note that the values provided for LTO are based on standard ICAO taxi times. These may differ significantly from average taxi times at European airports. Future work for this chapter includes plans to update the LTO values based on European average taxi times in which case LTO values in the table below may change significantly. Note that the updated values provided in Table 3-11 were calculated using optimum trajectory profiles with the AEM tool (see Appendix D), and are significantly different from the values obtained previously with the older 'PIANO' model.

Table 3–11 Illustrative dataset for Boeing 737-400.

Standard flight distances (nm) [1nm = 1.852 km]

B737-400		**125**	**250**	**500**	**750**	**1000**	**1500**	**2000**
Distance (km)	*Climb/Cruise/Descent*	*231.5*	*463*	*926*	*1389*	*1852*	*2778*	*3704*
Fuel (kg)	Flight Total	1921.9	2700.3	4120.1	5617.6	7099.2	10221.9	13208.2
	LTO	842.5	842.5	842.5	842.5	842.5	842.5	842.5
	a. Taxi out	271.3	271.3	271.3	271.3	271.3	271.3	271.3
	b. Take off	88.7	88.7	88.7	88.7	88.7	88.7	88.7
	c. Climb out	231.8	231.8	231.8	231.8	231.8	231.8	231.8
	d. Climb/cruise/descent	1079.4	1857.8	3277.6	4775.1	6256.7	9379.4	12365.8
	e. Approach landing	150.7	150.7	150.7	150.7	150.7	150.7	150.7
	f. Taxi in	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NO_x (kg)	Flight Total	26.5	36.1	52.2	68.9	85.5	120.8	154.5
	LTO	8.4	8.4	8.4	8.4	8.4	8.4	8.4
	a. Taxi out	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	b. Take off	1.7	1.7	1.7	1.7	1.7	1.7	1.7
	c. Climb out	3.9	3.9	3.9	3.9	3.9	3.9	3.9
	d. Climb/cruise/descent	18.1	27.6	43.8	60.5	77.0	112.4	146.1
	e. Approach landing	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	f. Taxi in	0.4	0.4	0.4	0.4	0.4	0.4	0.4
HC (g)	Flight Total	994.7	1075.9	1223.2	1331.7	1437.5	1647.0	1856.3
	LTO	674.8	674.8	674.8	674.8	674.8	674.8	674.8
	a. Taxi out	474.8	474.8	474.8	474.8	474.8	474.8	474.8
	b. Take off	3.2	3.2	3.2	3.2	3.2	3.2	3.2
	c. Climb out	10.9	10.9	10.9	10.9	10.9	10.9	10.9
	d. Climb/cruise/descent	319.9	401.1	548.4	656.8	762.7	972.1	1181.5
	e. Approach landing	11.0	11.0	11.0	11.0	11.0	11.0	11.0
	f. Taxi in	174.9	174.9	174.9	174.9	174.9	174.9	174.9
CO (g)	Flight Total	17689.6	19294.6	22290.4	24641.3	26937.8	31590.5	36039.8
	LTO	11976.4	11976.4	11976.4	11976.4	11976.4	11976.4	11976.4
	a. Taxi out	8166.7	8166.7	8166.7	8166.7	8166.7	8166.7	8166.7
	b. Take off	79.8	79.8	79.8	79.8	79.8	79.8	79.8
	c. Climb out	208.6	208.6	208.6	208.6	208.6	208.6	208.6
	d. Climb/cruise/descent	5713.2	7318.2	10314.0	12664.9	14961.4	19614.1	24063.4

e. Approach landing	512.4	512.4	512.4	512.4	512.4	512.4	512.4
f. Taxi in	3008.8	3008.8	3008.8	3008.8	3008.8	3008.8	3008.8

This provides details of NO_x, hydrocarbon, CO emissions and fuel usage for the different phases of flights of different distances. For other species the fuel based values given for the Tier 2 methodology, Table 3–4, should be used in conjunction with the fuel usage data.

3.4.2.2 Fuel consumption and emission factors for representative aircraft types

The emission factors for NO_x, hydrocarbons, CO and the fuel used for all the components of a flight (see Figure 2–2) are available from the accompanying spreadsheet to the chapter (available from the EMEP/EEA Guidebook website www.eea.europa.eu/emep-eea-guidebook) for the representative jet and turboprop (TP) aircraft types listed in Table 3–12.

Table 3–12 Representative aircraft types given in the accompanying spreadsheet to this chapter (available from the EMEP/EEA Guidebook website)

ICAO aircraft type	Description
A306	Airbus A300 – B4
A310	Airbus A310
A318	Airbus A318
A319	Airbus A319
A320	Airbus A320
A321	Airbus A321
A332	Airbus A330-200
A333	Airbus A330-300
A343	Airbus A340-200/300
A345	Airbus A340-500
A346	Airbus A340-600
A388	Airbus A380-800
AN26	Antonov 26
AT45	ATR 42 - 45
AT43	ATR 42 - 320
AT72	ATR 72 - 200
B721	Boeing 727-100
B722	Boeing 727-200
B731	Boeing 737 100
B732	Boeing 737-200
B733	Boeing 737-300
B734	Boeing 737-400
B735	Boeing 737-500
B736	Boeing 737-600
B737	Boeing 737-700
B738	Boeing 737-800
B741	Boeing 747-100/300/800
B742	Boeing 747-200
B744	Boeing 747-400
B752	Boeing 757-200
B753	Boeing 757-300
B762	Boeing 767 200

ICAO aircraft type	Description
B763	Boeing 767 300 ER
B772	Boeing 777-200 ER
B773	Boeing 777-200 LRF
B77L	Boeing 777-300
B77W	Boeing 777-300 ER
BA11	BAe 1-11
JS31	Bae Jetstream 31
JS41	Bae Jetstream 41
B190	Beech 1900C airline
BE20	Beech Super King Air 200B
B350	Beech Super King Air 350
C130	Lockheed C-130H Hercules
C550	Cessna Citation II
C208	Cessna 208 Caravan
CRJ1	Canadair Regional Jet CRJ-100
CRJ2	Canadair Regional Jet CRJ-200
CRJ9	Canadair Regional Jet CRJ-900
DH8A	Dash 8 A
DH8C	Dash 8 C
DH8D	Dash 8 D
DC10	McDonnell Douglas MD-11
DC85	McDonnell Douglas DC8-50
DC86	McDonnell Douglas DC8-60/70
DC91	McDonnell Douglas DC-9-10
DC92	McDonnell Douglas DC-9-20/30/40/50
D328	Dornier 328-110
E110	Embraer 110P2A Bandeirante
E120	Embraer EMB120 Brasillia
E145	Embraer ERJ145
E170	Embraer ERJ170-ERJ175
E190	Embraer ERJ190
F2TH	Falcon 2000
F100	Fokker F100
F27	Fokker F27
F28	Fokker F28
F50	Fokker F50
L410	Let L-410 Turbolet
MD11	McDonnell Douglas MD-11
MD82	McDonnell Douglas MD-82/87/88
MD83	McDonnell Douglas MD-83
B462	BAe146 -100/200/300
RJ85	Avro RJ85
SB20	Saab 2000
SF34	Saab 340B
SH36	Shorts 360-300
SW4	Swearingen Metro III
T204	Tupolev TU 204

3.4.2.3 Non-IFR flights

There is little information available on emission factors for non-IFR flights and it is at present not possible to recommend default emission factors. Generally, the NO_x emission factors will be lower and the CO and VOC factors substantially higher than for IFR flights.

Fuel consumption factors are given for two categories of aircraft (Cessna and others) to be used if other information of fuel used is not available (Table 3–13). Please note that the tables apply to single engine aircraft only. If the aircraft is fitted with two engines (e.g. Cessna 500), then double the fuel consumption. Ranges of emission factors are shown in MEET (1997). A summary is given in Table 3–14.

Some emission factors and fuel use factors for helicopters and military flights are given in Tables 3–15, 3–16 and 3–17. Also note that many types of military aircraft may have civil equivalents.

Table 3–13 Fuel consumption for piston-engined aircraft, litre/hour

Cessna C 152, C 172, C 182 (single engine)	0 feet altitude	2000 feet alt.	4000 feet alt
75 % power (=135 HP)	41	42	no data
70 % power (=126 HP)	37	38	39
65 % power (=117 HP)	33.5	34	34.5

Note:
For an average use 36 litre/hour.

Robin (French aircraft), various Piper types (single engine)	0 feet altitude	4000 feet alt.
70 % power	36.5	no data
64 % power	34	33.5
58 % power	31	31

Note:
For an average use 33 litre/hour.

Table 3–14 Examples of emission factors for piston-engined aircraft, g/kg fuel

	NO_x	HC	CO	SO_2
Netherlands FL 0-30	2.70	20.09	1,054	0.21
FL 30-180	4.00	12.50	1,080	0.17
Germany	3.14	18.867	798	0.42

Note:
Multiply FL by 100 to obtain the altitude in feet.
Source: MEET Deliverable No 18.

Table 3–15 Examples of emission factors for helicopters and military flights [g/kg fuel]

	Nature of flights	NO_x	HC	CO	SO_2
Germany	LTO-cycle	8.3	10.9	39.3	1.1
	helicopter cruise	2.6	8.0	38.8	1.0
	combat jet	10.9	1.2	10.0	0.9
	cruise 0.46-3 km	10.7	1.6	12.4	0.9
	cruise > 3 km	8.5	1.1	8.2	0.9
Netherlands	Average	15.8	4.0	126	0.2
	F-16	15.3	3.36	102	0.2
Switzerland	LTO-Cycle	4.631	2.59	33.9	1.025
	cruise	5.034	0.67	14.95	0.999

Source: MEET Deliverable No 18.

Notes:

1. If national PM emission factors are available, a BC fraction of PM (f-BC) = 0.48 is suggested. *Source: for further information see Appendix C*

Table 3–16 Emission factors for helicopters of selected countries

g/kg	NO_x	HC	CO	SO_2
Germany: cruise	2.6	8.0	38.8	0.99
Netherlands: cruise	3.1	3.6	11.1	0.20
Switzerland	13.3	0.3	1.1	0.97

Source: MEET Deliverable No 18.

Table 3–17 Fuel consumption factors for military aircraft

Group	Sub-group	Representative type	Fuel flow kg/hour
1. Combat	Fast jet — high thrust	F16	3283
	Fast jet — low thrust	Tiger F-5E	2100
2. Trainer	Jet trainers	Hawk	720
	Turboprop trainers	PC-7	120
3. Tanker/transport	Large tanker/transport	C-130	2225
	Small transport	ATP	499
4. Other	MPAs, maritime patrol	C-130	2225

Source: ANCAT, British Aerospace/Airbus

3.4.3 Activity data

The Tier 3 methodology is based on actual flight movement data.

Emissions are calculated using the emission factors described in subection 3.4.2, and the flight movement data obtained nationally.

3.4.3.1 The aircraft movement methodology (Tier 3) for IFR flights

The total emissions from aircraft are given by the sum of emissions from various technologies of aircraft in a continuous set of flying modes. In this methodology we will simplify the calculations by classifying the aircraft into a representative set of generic aircraft types and into two classes of flying modes, that of LTO and that of cruise. However, the methodology allows adjustment for actual times-in-mode of LTO at individual airports. This method also permits the use of individual aircraft/engine combinations if the data are available.

The methodology involves the following steps.

1. Select the aircraft and flight details from National data, for example Civil Aviation records, airport records, the Eurocontrol Agency in Europe, or the OAG timetable. This will identify the aircraft that were used in the inventory period, the number of LTOs for each and the mission distance flown. For the aircraft actually flying, select the aircraft used to represent them from the table of equivalent aircraft (Tables 3–6 and 3–7). This is called the 'representative aircraft'. Use Table 3–8 for miscellaneous smaller aircraft. See also Subsection 3.4.3.2 on non-IFR flights. Their emissions will have to be estimated separately, by a simpler method.
2. Note the distance of the mission. See subsection 3.1.2 'activity data' for a description of how this may be determined.
3. From the attached spreadsheets (available from the EMEP/EEA guidebook website), select the data corresponding to the LTO phase for the representative aircraft, for both fuel used and all emissions. The fuel used and associated emissions from this table represent the fuel and emissions in the boundary layer below 3 000 ft (914 m). This gives an estimate of emissions and fuel used during the LTO phase of the mission.
4. From the table of representative aircraft types vs. mission distance (attached spreadsheets), select the aircraft, and select the missions which bracket the one which is actually being flown. The fuel used is determined as an interpolation between the two. This is an estimate of fuel used during operations above 3 000 ft (914 m) (cruise fuel use).
5. The total quantity of fuel used for the mission is the sum of the fuel used for LTO plus the fuel used in all operations above 3 000 ft (914 m).
6. Now apply step 4 to the table of pollutants (NO_x, CO and HC) emitted vs. mission distance and here again interpolate between the missions, which bracket the one being flown. This is an estimate of emissions during operations above 3 000 ft (914 m) (cruise emissions).
7. The total of pollutants emitted during the flight is the sum of the pollutants emitted in LTO plus the quantity emitted in the rest of the mission.

See subsection 3.4.4 for an example on how to apply the method.

The use of energy, and therefore emissions, depends on the aircraft operations and the time spent at each stage. Table 2–2 shows engine power settings and times-in-mode for the LTO-cycle specified by ICAO (ICAO, 1993). The actual operational time-in-mode might vary from airport to airport depending on the traffic, environmental considerations, aircraft types as well as topographical conditions. The proportion of fuel used in a mission which is attributed to LTO decreases as mission distance increases. Thus a substantial part of the fuel consumption takes place outside the LTO-cycle. Studies indicate that the major part of NO_x (60–80 %), SO_2 and CO_2 (80–90 %) is emitted at altitudes above 1 000 m. For CO it is about 50 % and for VOC it is about 20–40 % (Olivier, 1991).

Where *times-in-modes* are different from the assumptions made in this report, corrections may be made from basic data in the spreadsheets (also available from the Task Force Secretariat and website) or in the ICAO databank.

Please note: the total estimated fuel use for domestic aviation must be compared to sales statistics or direct reports from the airline companies. If the estimated fuel deviates from the direct observation, the main parameters used for estimating the fuel must be adjusted in proportion to ensure that the mass of fuel estimated is the same as the mass of fuel sold.

3.4.3.2 Non IFR-flights

For some types of military or pleasure aircraft the numbers of hours in flight is a better activity indicator for estimating the fuel used and the emissions produced than the number of LTOs. In some cases the quantity of fuel used may be directly available.

Compile information on fuel used by aircraft category. The fuel types, kerosene and aviation gasoline should be reported separately. If not directly available, estimate the fuel used from the hours of operation and fuel consumption factors.

Select the appropriate emission factors and fuel use factors from Tables 3–13 to 3–17.

Multiply the fuel consumption data in tonnes by the fuel-based emission factors to obtain an annual emission estimate.

3.4.4 An illustrative example

A B737-400 aircraft is travelling a mission distance of 1 723 nm. Based on the data given in Table 3.11, we want to estimate the fuel use:

the fuel use for LTO is taken directly from the table and is 842.5 kg (independent of mission distance);

for operation above 3 000 feet (cruise/climb/descent), the fuel used is 9 379.4 + ((12 365.8–9 379.4)*(1 723–1 500)/(2 000–1 500)) = 10 711.3 kg

The emissions of the various pollutants may be estimated in the same way:

the LTO NO_x may be read directly from the table = 8.4 kg;

for operation above 3 000 feet (flight less LTO), the NO_x is 112.4 + ((146.1–112.4)*(1 723–1 500)/(2 000–1 500)) = 127.4 kg

$EINO_x$ for the mission is therefore (8.3+127.4) kg / (842.5+10 711.3) kg = 11.7 g NO_x per kg fuel. This may be used as a check to ensure that no arithmetic error has been made in the calculations.

For pollutants not given in the Table 3–11 we recommend using the Tier 2 approach based on the estimate fuel use calculated using the Tier 3 approach.

3.5 Species profiles

Since very few experiments have been reported where the exhaust gas from aircraft turbines has been analysed in detail, it is not possible to give a specific species profile. In terms of NOx and VOC, the profiles vary with the thrust setting of the aircraft and therefore on the activity. In terms of aircraft cruise, it is not possible to obtain accurate estimates for emission factors.

In terms of the LTO activity, the situation is similar. Attempts have been made to estimate the composition of the VOC profile. USEPA (2009) reports a VOC profile for aircraft equipped with turbofan, turbojet, and turboprop engines. The composition is presented in Table 3–18.

Please note that the thrust setting during the landing and the take-off of the aircraft are different (see Table 2–2). Therefore, it is likely that the species profile will be different for the two situations.

Table 3–18 Speciated gas phase profile for aircraft equipped with turbofan, turbojet, and turboprop engines

Compound	CAS Registry No.[a]	Mass Fraction		Compound	CAS Registry No.[a]	Mass Fraction
1,2,3-trimethylbenzene	526-73-8	0.00106		glyoxal	107-22-2	0.01816
1,2,4-trimethylbenzene	95-63-6	0.00350		isobutene/1-butene	106-98-9	0.01754
1,3,5-trimethylbenzene	108-67-8	0.00054		isopropylbenzene [d]	98-82-8	0.00003
1,3-butadiene[d]	106-99-0	0.01687		isovaleraldehyde	590-86-3	0.00032
1-decene	872-05-9	0.00185		methacrolein	78-85-3	0.00429
1-heptene	25339-56-4	0.00438		methanol [d]	67-56-1	0.01805
1-hexene	592-41-6	0.00736		methylglyoxal	78-98-8	0.01503
1-methyl naphthalene	90-12-0	0.00247		m-ethyltoluene	620-14-4	0.00154
1-nonene	124-11-8	0.00246		m-tolualdehyde	620-23-5	0.00278
1-octene	25377-83-7	0.00276		m-xylene and p-xylene [d]	108-38-3 / 106-42-3	0.00282
1-pentene	109-67-1	0.00776		naphthalene [d]	91-20-3	0.00541
2-methyl-1-butene	563-46-2	0.00140		n-decane	124-18-5	0.00320
2-methyl-1-pentene	763-29-1	0.00034		n-dodecane	112-40-3	0.00462
2-methyl-2-butene	513-35-9	0.00185		n-heptadecane	629-78-7	0.00009
2-methyl-naphthalene [e]	91-57-6	0.00206		n-heptane	142-82-5	0.00064
2-methylpentane	107-83-5	0.00408		n-hexadecane	544-76-3	0.00049
3-methyl-1-butene	563-45-1	0.00112		n-nonane	111-84-2	0.00062
4-methyl-1-pentene	691-37-2	0.00069		n-octane	111-65-9	0.00062
acetaldehyde [d]	75-07-0	0.04272		n-pentadecane	629-62-9	0.00173
acetone	67-64-1	0.00369		n-pentane	109-66-0	0.00198
acetylene	74-86-2	0.03939		n-propylbenzene	103-65-1	0.00053
acrolein [d]	107-02-8	0.02449		n-tetradecane	629-59-4	0.00416
benzaldehyde [e]	100-52-7	0.00470		n-tridecane	629-50-5	0.00535
benzene [d]	71-43-2	0.01681		n-undecane	1120-21-4	0.00444
butyraldehyde	123-72-8	0.00119		o-ethyltoluene	611-14-3	0.00065
c14-alkane	No CAS	0.00186		o-tolualdehyde	529-20-4	0.00230
c15-alkane	No CAS	0.00177		o-xylene [d]	95-47-6	0.00166
c16-alkane	No CAS	0.00146		p-ethyltoluene	622-96-8	0.00064
c18-alkane	No CAS	0.00002		p-tolualdehyde	104-87-0	0.00048
c4-benzene + c3-aroald	No CAS	0.00656		phenol [d]	108-95-2	0.00726
c5-benzene + c4-aroald	No CAS	0.00324		propane	74-98-6	0.00078
cis-2-butene	590-18-1	0.00210		propionaldehyde [d]	123-38-6	0.00727
cis-2-pentene	627-20-3	0.00276		propylene	115-07-1	0.04534
crotonaldehyde	4170-30-3	0.01033		styrene [d]	100-42-5	0.00309
dimethylnapthalenes	28804-88-8	0.00090		toluene [d]	108-88-3	0.00642
ethane	74-84-0	0.00521		trans-2-hexene	4050-45-7	0.00030
ethylbenzene [d]	100-41-4	0.00174		trans-2-pentene	646-04-8	0.00359
ethylene[f]	74-85-1	0.15461		valeraldehyde	110-62-3	0.00245
formaldehyde [d,f]	50-00-0	0.12310		*unidentified* [b]	*NA*	*0.29213*
Sum of all compounds						1.00000

Source: EPA, 2009

4 Data quality

4.1 Completeness

Regardless of method, it is important to account for all fuel used for aviation in the country. The methods are based on total fuel use, and should completely cover CO_2 emissions. However, the allocation between LTO and cruise will not be complete for Tier 2 method if the LTO statistics are not complete. Also, Tier 2 method focuses on passenger and freight carrying scheduled and charter flights, and thus not all aviation. In addition, Tier 2 method does not automatically include non-scheduled flights and general aviation such as agricultural airplanes, private jets or helicopters, which should be added if the quantity of fuel is significant. Completeness may also be an issue where military data are confidential; in this situation it is good practice to aggregate military fuel use with another source category.

Other aviation-related activities that generate emissions include fuelling and fuel handling in general, maintenance of aircraft engines and fuel jettisoning to avoid accidents. Also, in the wintertime, anti-ice and de-ice treatment of wings and aircraft is a source of emissions at airport complexes. Many of the materials used in these treatments flow off the wings when planes are idling, taxiing, and taking off, and then evaporate. These emissions are, however, very minor and specific methods to estimate them are not included.

There are additional challenges in distinguishing between domestic and international emissions. As each country's data sources are unique for this category, it is not possible to formulate a general rule regarding how to make an assignment in the absence of clear data. It is good practice to specify clearly the assumptions made so that the issue of completeness can be evaluated.

4.2 Double counting with other sectors

Emissions and fuel from over-flights are excluded from these calculations to avoid double counting of emissions.

4.3 Verification

The methodology presented here could be used with international flight statistics (for example ATC providers) to provide a crosscheck against estimates made by individual national experts on the basis of national fuel and flight statistics.

National estimates may be checked against central inventories like ANCAT (1998) and NASA (1996) for 1991/92 and 1992, respectively.

Estimated emissions and fuel use per available seat kilometres travelled may also be compared between countries and aircraft types to ensure the credibility of the data which have been collected.

4.4 Uncertainty assessment

The uncertainties of the estimated aircraft emissions are closely associated with the emission factors assigned to the estimations.

The emissions of CO_2 (and fuel use) are generally determined with a higher accuracy than the other pollutants.

4.4.1 Tier 1 approach

The accuracy of the distribution of fuel between domestic and international will depend on the national conditions.

The use of 'representative' emission factors may contribute significantly to the uncertainty. In terms of the factors relating to the LTO activities, the accuracy is better than for cruise (due to the origin of the factors from which the average values are derived from). It would be hard to calculate a quantitative uncertainty estimate. The uncertainty may however lie between 20–30 % for LTO factors and 20–45 % for the cruise factors.

4.4.2 Tier 2 approach

The accuracy of the distribution of fuel between domestic and international will depend on the national conditions. The uncertainties lie mainly in the origin of the emission factors. There is a high uncertainty associated with the cruise emission factors.

4.4.3 Tier 3 approach

Uncertainties lie in emission factors for the engines. ICAO (1995) estimates that the uncertainties of the different LTO factors are approximately 5–10 %. For cruise, the uncertainties are assumed to be 15–40 %.

4.5 Inventory quality assurance/quality control QA/QC

No specific issues.

4.6 Gridding

Airports and emissions should be associated with the appropriate territorial unit (e.g. country). The airports can be divided into territorial units in the following way:

- the fuel and emissions from specific airports can be identified, and then summed to show the emissions from region, which in turn can be summed for a country as a whole. Airports located in the various territorial areas should be identified;
- from the total national emission estimate emissions can be distributed to the territorial areas and airports using a key reflecting the aviation activity (e.g. the number of landings and take-off cycles) between territorial areas and airports.

4.7 Reporting and documentation

No specific issues.

4.8 Areas for improvements in current methodology

The list given below summarises causes for concern and areas where further work may be required.

LTO

It is a key priority to update the fuel consumption and emission factors with data from the ICAO Aircraft Engine Emissions Databank maintained by EASA. in order to better reflect the emission performance of today's aircraft in use.

Estimates of fuel used and emissions based on ICAO cycles (refer to ICAO Annex 16, Volume I) it may not reflect accurately the situation of aircraft and airport operations.

The relationship between the minor pollutants and the regulated pollutants (HC, CO, NO_x) may need to be investigated in more detail.

Emissions above 3 000 ft (914 m)

It is a key priority to update the fuel consumption and emission factors in order to better reflect the emission performance of today's aircraft in use. The proposed Eurocontrol fuel burn and emissions calculation tool (AEM) uses Eurocontrol's Base of Aircraft Data (BADA) for calculating fuel burnt and emissions above 3 000 ft. This data base contains altitude- and attitude-dependent performance and fuel burn data for many types of aircraft.

The emission factors and fuel use for short distances (125 and 250 nm) are difficult to model and the suggested values are highly uncertain.

The actual distance flown compared with great circle distances that are given in the OAG timetable may vary by up to 10–11 % in Europe (ANCAT/EC2 1998).

PM emissions, including $PM_{2.5}$

There is a fundamental inconsistency between PM emissions (TSP, PM_{10} and $PM_{2.5}$) reported by LRTAP Parties to the EMEP Centre for Emission Inventories and Projections (CEIP), evident by there being variable ratios in $PM_{2.5}$/TSP and $PM_{2.5}/PM_{10}$. The most common value reported is 1.00, i.e. it is assumed that all PM emissions from aircraft can be viewed as PM_{10}. This is the relationship assumed in this Guidebook.

5 Glossary and abbreviations

AERONOX	EU-project 'The impact of NO_x-emissions from aircraft upon the atmosphere at flight altitudes 8-15 km' (AERONOX, 1995)
ANCAT	Abatement of Nuisance Caused by Air Transport, a technical committee of the European Civil Aviation Conferences (ECAC)
ATC	Air Traffic Control
CAEP	Committee on Aviation Environmental Protection
ICAO	International Civil Aviation Organisation
IPCC	Intergovernmental Panel on Climate Change
LTO	Landing/Take-off

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7 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on Transport. Please refer to the TFEIP website (www.tfeip-secretariat.org/) for the contact details of the current expert panel leaders.

Appendix A Projections

Future aircraft emissions will be determined by the volume of air traffic, new aircraft technologies and the rate at which the aircraft fleet changes.

According to the IPCC (1999), total global passenger-km will grow by 5 % annually between 1990 and 2015 with a corresponding growth in fuel use of 3 % per year over the same period. The difference is explained by an anticipated improvement in aircraft fuel efficiency. The anticipated growth rates in individual countries will probably be described in the transport plans, which should be available from national Ministries of Transport.

Over the last 30 years, aircraft engines have improved in efficiency, and due to the high cost of fuel, this trend is expected to continue. As mentioned in subsection 3.7, it is expected that tightening the emission regulations will lead to a decrease in NO_x emission factors.

NO_x may be reduced by introducing engines fitted with double annular combustion chambers (MEET, 1998). This technology has been implemented in new aircraft e.g. B737-600. Proposed average changes in emission factors are shown in Table A1. Note that these may be larger or smaller according to the rate at which the aircraft fleet is renewed (see below).

Table A1 Changes in emission factors relative to current level (baseline scenario)

	NO_x	CO	HC
2010	-10 %	-6 %	-6 %
2020	-20 %	-27 %	-24 %

Research is being undertaken on engines to substantially reduce emissions of NO_x, CO and HC (MEET 1998). However, the time scale over which the results from this research will become commercially available is unclear, and therefore their use in baseline projections is not recommended.

Research is also on-going to improve the aircraft design to further improve fuel efficiency. Also using new materials may prove to be beneficial (MEET, 1998). In a baseline scenario an annual improvement of average fuel efficiency of 1.5–2.5 % is recommended.

The rate of change of the aircraft fleet depends very much on the country of operation. Although an aircraft is expected to have a long life, typically 25 to 35 years, it will often be sold to other operators, possibly in other countries, and possibly converted to other uses (for example for carrying freight). Noise regulations may also influence the rate of change of aircraft fleet. For a projection of national emissions, it is expected that the major airlines are in a position to provide the most accurate information on anticipated fleet changes as part of their long-term plans. An analysis of future aircraft fleet made by UK BERR (MEET, 1998) is shown in Table A2.

Table A2 World fleet age profile in 2010 and 2020 (%)

Age (years)	2010	2020
0–5	27.6	32.5
6–10	20.5	22.9
11–15	19.7	17.8
16–20	23.5	16.2
21–25	8.6	10.6

Note: Growth of fleet from 2010 to 2020 is 26 %.

The commercial use of alternative fuels in aircraft is still a long way off and should not be incorporated into any national baseline emission projection. Hydrogen is the most likely alternative to kerosene (MEET, 1998). This fuel will be more efficient and has lower emissions compared to kerosene (producing NO_x and water vapour, but no carbon compounds). However, the life-cycle emissions depend on how the hydrogen is produced. Hydrogen is very energy-demanding to produce, and introducing hydrogen as an alternative fuel will also require massive investments in ground infrastructure in addition to rebuilding aircraft.

Appendix B Additional comments on emission factors

ICAO (1995) (exhaust emission databank) provides basic aircraft engine emission data for certificated turbojet and turbofan engines covering the rate of fuel used, and the emission factors for HC, CO and NO_x at the different thrust settings used. Other relevant emission data are derived from other sources. The exhaust emission databank is now accessible via the internet, via URL www.caa.co.uk/default.aspx?categoryid=702&pagetype=90. In addition to HC, CO and NO_x this version also contains emission factors for smoke at the different thrust settings (columns BL to BO of the databank in reference ICAO 2006). PM emission factors can be derived from those for smoke, the methodology used for this conversion (the so-called First Order Approximation version 3 - FOA3) is published in ICAO (2007).

The heavy metal emissions are, in principle, determined from the metal content of kerosene or gasoline. Thus, general emission factors for stationary combustion of kerosene and combustion of gasoline in cars may be applied. The only exception is lead. Lead is added to aviation gasoline to increase the octane number. The lead content is higher than in leaded car gasoline, and the maximum permitted levels in UK are shown below. A value of 0.6 g lead per litre gasoline should be used as the default value if there is an absence of better information. Actual data may be obtained from the oil companies.

Lead content of aviation gasoline, UK

AVGAS designation	Maximum lead content (as Tetra ethyl lead)
AVGAS 80	0.14 g/l
AVGAS low lead 100	0.56 g/l
AVGAS 100	0.85 g/l

There is little information on particulate matter from aircraft. In Petzol et al. (1999) and Döpelheuer et al. (1998) data are published for various aircraft types. Petzol (1999) also describes the particle size. For newer aircraft the size distribution is dominated by particles with a diameter between 0.025 and 0.15 µm. For newer aircraft (certificated after 1976), e.g. A300, B737 and DC10 the emission factor is found to be about 0.01 g/kg fuel. Döpelheuer (1998) also gives data for different phases of the flight for A300. The factor is higher at take-off (0.05 g/kg) and lower at cruise (0.0067 g/kg), while the factor for climb and descent is about 0.01 g/kg. From combustion science principles it is anticipated that the $PM_{2.5}/PM_{10}$ ratio for aircraft engines will be similar to, or higher than, that for internal combustion engines. Given that the ratio for IC engines is found to be 94 %, it is reasonable to assume that for aircraft their PM emissions can be considered as $PM_{2.5}$. The $PM_{2.5}/PM_{10}$ ratio most commonly used when reporting values within EMEP is 1.0. This is the relationship assumed in this Guidebook.

Little information is currently available about possible exhaust emissions of Persistent Organic Pollutants (POPs) from aircraft engines. Emissions of water (H_2O) may be derived from the fuel consumption at the rate of 1 237 kg water/kg fuel.

Using the emission factors, special emphasis should be put on the assumptions of the weight per cent of sulphur (assumed at 0.05 %). If the sulphur percent of the fuel used is different, this should be taken into account. If the sulphur per cent used for example is 0.01 % instead of 0.05 %, the emission factor should be divided by 5 to show the true factor.

Appendix C BC fractions of PM emissions from aviation

Table C1 presents an overview of the five studies which have been regarded relevant as sources for BC fractions of PM emissions (f-BC) from aviation. Apart from f-BC fractions, for each study the engine type and emission test modes are listed, as well as the PM emission sampling conditions, as far as information is available. Some of the following references also report figures for OC which can be input for the further assessment of OC fractions of PM (f-OC).

Petzold et al. (2009) carry out test rig measurements of the emissions from four engine operational conditions in the SAMPLE (Study on sampling and measurement of aircraft particulate emissions) project. The measurements of PM are adjusted to include the particulate emissions in form of water bound sulphate. BC and EC values are also measured. Petzold et al. (2009) find that BC equals EC. No trend in emission could be observed for variations in engine test modes.

Petzold et al. (2003) simulates in a test rig for cruise power settings the emission influence from low, medium and high fuel sulphur content used by old and new engine technologies, respectively. BC and TC (total carbon) emissions are measured. Subsequently, the TC emissions are adjusted with 30 % in upwards direction (c.f. Petzold et al. (2009)) in order to calculate the total mass of PM and determine the f-BC fraction. No trend in emission could be observed for variations in engine test modes.

Rogers et al. (2005) carried out ground based plume measurements of the emissions from a jet engine military fighter and a turbo shaft engine being used by military helicopters. Rogers et al. (2005) measures EC, OC and total PM mass emissions, and mention the measured EC factor as the “black factor”. Based on one test run they derive BC factors which can be related to the PM mass emission factors.

Kinsey et al (2010) reports ground based plume emission measurements for nine commercial aircraft engines in three field campaigns of the Aircraft Particles Emissions eXperiment (APEX) 1-3 study. In the supplementary material for Kinsey et al. (2010), EC emissions are interpreted as BC and further it is noted that volatile PM emissions consist of sulphur and organic PM. In Kinsey et al. (2010) for five aircraft engines, the total PM mass emissions are split into volatile (PMvol) and non volatile (PMnon vol) fractions. For the present note, the non volatile share of total PM is assumed to be equivalent to the f-BC fraction.

Agrawal et al. (2008) measured the emissions of e.g. PM, EC and OC from four commercial aircraft. No trend in emission could be observed for variations in engine test modes. For the present discussion note EC values are used for BC, following the assumptions made by e.g. Rogers et al. (2005) and Kinsey et al. (2010).

Winther et al. (2012) calculated the emissions of PM for aircraft engines in Copenhagen Airport based on actual flight operational data and aircraft/engine combinations. The FOA3 method (ICAO, 2008) was used to estimate the PM emissions, split into volatile PM coming from the sulphur in the fuel and exhaust VOC, and non volative PM from soot. Subsequently, a fuel weighted f-BC fraction (non volatile share of total PM) was derived taking into account the landing, take off and taxi engine power modes. The f-BC fraction for Copenhagen Airport was similar to the f-BC fraction calculated for LTO for Shiphol Airport in Amsterdam also using the FOA3 method (pers. comm. Andreas Petzold, DLR, 2012).

f-BC fractions derived from the above mentioned studies are listed in the following Table C1.

Table C1 BC fractions of PM emissions from relevant studies

Study	Aircraft/Engine types	Test conditions	f-BC
Petzold et al. (2003)	Old engine	Cruise, low sulphur	61
		Cruise, medium sulphur	44
		Cruise, high sulphur	50
	New engine	Cruise, low sulphur	75
		Cruise, medium sulphur	31
		Cruise, high sulphur	40
Agrawal et al. (2008)	CFM56-7B22	Mode 1 (4 & 7 %)	31
		Mode 2 (30 & 40 %)	8
		Mode 3 (65 %)	59
		Mode 4 (85 %)	59
	CFM56-3B1	Mode 1 (4 & 7 %)	48
		Mode 2 (30 & 40 %)	60
		Mode 3 (65 %)	26
		Mode 4 (85 %)	85
	CFM56-3B2	Mode 1 (4 & 7 %)	55
		Mode 2 (30 & 40 %)	69
		Mode 3 (65 %)	74
		Mode 4 (85 %)	79
	CFM56-7B22	Mode 1 (4 & 7 %)	47
		Mode 2 (30 & 40 %)	72
		Mode 3 (65 %)	86
		Mode 4 (85 %)	68
Rogers et al. (2005)	Military F404-GE-400, T700-GE-401	65%-80%, 67%-98%	56
Kinsey et al. (2010)	CFM56-2C1	Various power modes	38
	CFM56-3B1	Various power modes	21
	AE3007A1E	Various power modes	38
	P&W4158	Various power modes	46
	RB211-535E4B	Various power modes	59
Petzold et al. (2009)	Test rig	Condition1	66
		Condition2	33
		Condition3	54
		Condition4	36
Winther et al. (2012)	Copenhagen Airport fleet/engine	Landing	33
		Take off	54
		Taxi	30
Petzold et al. (2003)		Average	50
Agrawal et al. (2008)		Average	58
Rogers et al. (2005)		Average	56

Kinsey et al. (2010)	Average	40
Petzold et al. (2009)	Average	47
Winther et al. (2012)	Average	39
Average (All)	Average	48

Conclusion

The amount of available data is regarded as being too scarce to propose different f-BC fractions for different Tiers and explicitly for LTO and cruise in the guidebook chapter for aviation. Hence, the same average f-BC fraction (f-BC = 0.48) will be proposed for the simple LTO and cruise methodology in Tier 1, the aircraft type specific Tier 2 methodology, the aircraft type city-pair based Tier 3 methodology, and for military aircraft. For piston engined aircraft data from Winther and Nielsen (2011) will be used (f-BC = 0.15) based on information from Kupiainen and Klimont (2004).

Table C2 list the tables in the guidebook chapter for aviation which contain f-BC fraction information. These fractions must then be combined with the existing PM factors in GB in order to establish the final BC emission factor in each case.

Table C2 Guidebook tables which contain f-BC fraction data

Table no.	Tier	Detail	f-BC source
3-3	1	Old/average fleet; LTO and cruise emf.	Present note; f-BC = 0.48
3-5	2	LTO emf. per aircraft type	Present note; f-BC = 0.48
3-4	1	Piston engined aircraft	Winther et al. (2011) ; f-BC = 0.48
3-15	2	Military	Present note; f-BC = 0.48

Acknowledgment

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Appendix D Example of a Tier 3A / Tier 3B methodology, EUROCONTROL's Advanced Emissions Model (AEM)

This appendix describes the application of a Tier 3a/Tier 3b methodology using the Advanced Emission Model (AEM) from EUROCONTROL, which is one of the models approved by the ICAO/CAEP Modelling and Databases group.

The methodology proposed by EUROCONTROL concerns only aircraft movement information available within the EUROCONTROL zone of coverage; it also concerns only IFR flights (plus civil helicopters). No military flight are included, and non-IFR flights are also excluded.

Below 3,000 ft, the fuel burn calculation is based on the LTO cycle defined by the ICAO Engine Certification specifications. The ICAO Engine Exhaust Emissions Data Bank includes emission indices and fuel flow for a very large number of aircraft engines. The AEM links each aircraft appearing in the input traffic sample to one of the engines listed in the ICAO Engine Exhaust Emissions Data Bank. EUROCONTROL can provide a larger range of aircraft performance modelling and a larger list of equivalent aircraft types when the exact performance model is not available.

Because of the lack of accuracy of the fuel burn and emissions calculations when modelling that part of an aircraft's trajectory under 3000 ft, EUROCONTROL has implemented a methodology that lies somewhere between a Tier 3A and a Tier 3B methodology.

Fuel burn and emissions above 3000ft (climb/cruise/descent) are based on real 4D trajectories extracted from a CFMU database that contains all aircraft movements for which the trajectory is wholly within the EUROCONTROL zone of coverage. For those aircraft movements for which the trajectory is partly within the EUROCONTROL zone of coverage best fit trajectories are created (based on the experience gained in the project AERO2K) and used for calculating fuel burn and emissions.

Above 3,000 ft, the fuel burn calculation is based on EUROCONTROL's Base of Aircraft Data (BADA). This database provides altitude- and attitude-dependent performance and fuel burn data for more than 150 aircraft types.

For aircraft movements for which the trajectory is completely outside of the EUROCONTROL zone of coverage, trajectories are created from the Official Airline Guide (OAG) data on the same principles used in the previous case.

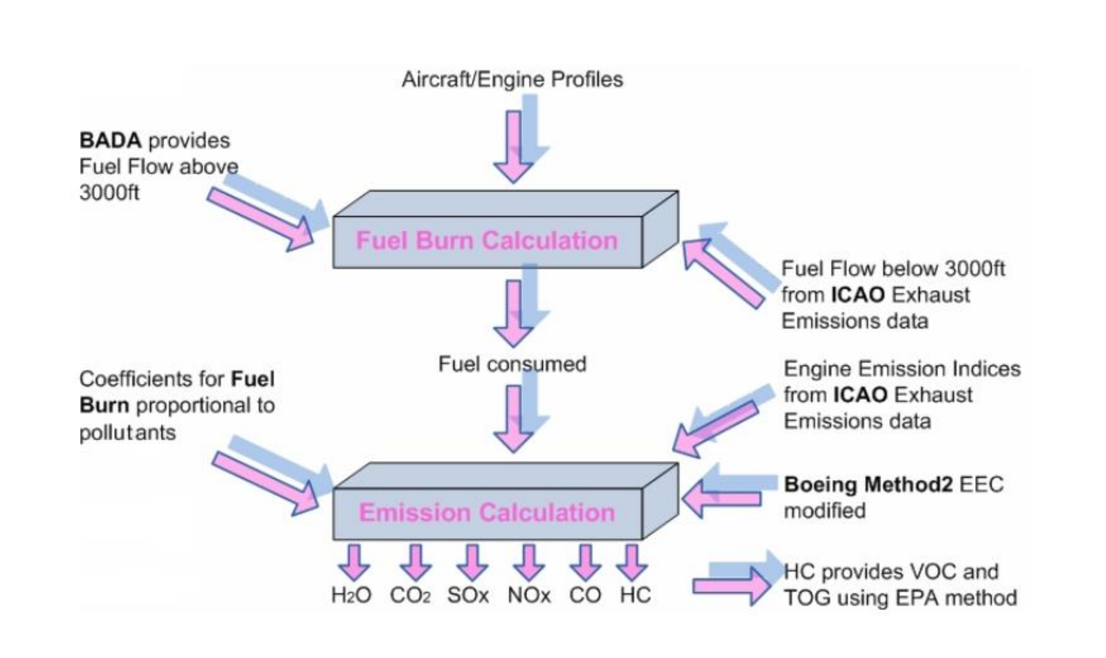

Figure D1.1 AEM fuel burnt and corresponding emissions calculation method.

About Taxi-times

EUROCONTROL's Central Office for Delay Analysis (CODA) provides statistics on aircraft delays in Europe in general and in particular statistics about taxi-in and taxi-out times per airport and per seasonal period; furthermore taxi-out times are provided per wake vortex categories. Taxi-in and taxi-out times are provided here: http://www.eurocontrol.int/articles/coda-publications (Tab: Taxi times at the bottom of the page).

These data could be used to improve the LTO calculation but as AEM does not currently take into account wake-vortex categories (turbulence formed after an aircraft, dependent on aircraft type and mass) or seasonal activities only average taxi times per airport can be used directly. Also, using different airport taxi-times would make historical comparisons and verification more difficult.