SNAP CODES:
080501
080502
080503
080504

SOURCE ACTIVITY TITLE:
AIR TRAFFIC
Domestic airport traffic (LTO-cycles < 1000 m altitude)
International airport traffic (LTO-cycles < 1000 m altitude)
Domestic cruise traffic (> 1000 m altitude)
International cruise traffic (> 1000 m altitude)

NOSE CODES:
202.05.01
202.05.02
202.05.03
202.05.04

NFR CODE:
1 A 3 a i (i)
1 A 3 a i (ii)
1 A 3 a ii (i)
1 A 3 a ii (ii)

1 ACTIVITIES INCLUDED

This chapter presents common guidelines for estimation of emissions from air traffic. The guideline includes four activities (Table 1.1).

Table 1.1 Overview of the activities included in the present reporting guidelines

LTO is an abbreviation for the Landing and Take-Off cycle.

Domestic aviation is associated with the SNAP codes 080501 + 080503;
International aviation is associated with the SNAP codes 080502 + 080504;
LTO-cycle activities include SNAP codes 080501 + 080502;
Cruise activities include SNAP codes 080503 + 080504.

Emissions associated with domestic and international aviation are to be reported to the UNFCCC. According to the new reporting guidelines, only emissions from domestic aviation shall be reported to the UNFCCC as a part of national totals. However, all the items above shall be reported. Formerly, only emissions associated with the LTO-cycle were to be reported to the UNECE[1]. Activities include all use of aeroplanes consisting of scheduled and charter traffic of passengers and freight. This also includes taxiing, helicopter traffic and private aviation. Military aviation is included if it is possible to estimate.

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[1] However, UNECE wanted CO_2 emissions and other direct greenhouse gases estimated according to the UNFCCC definition.

2 CONTRIBUTION 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. 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 pollutants is illustrated in Table 2.1. The table reflects the current knowledge. It may be that the ranges actually are different from the figures given in the table. Emissions of H_2O are not covered in any reporting requirements, but can be estimated on the basis of the fuel consumption.

Table 2.1 Emissions from air traffic in Europe. Ranges of contribution to total emissions according to Corinair-94. Per cent of total excluding international cruise.

Category	LTO (%)	Domestic cruise (%)
SO_2	0-0.2	-
NO_x	0-3	0-2
NMVOC	0-0.6	-
CO	0-0.3	-
CO_2	0-2	0-1
CH_4	0	-
N_2O	0	-
PM_{10}[2]	0-0.3	0-2
$PM_{2.5}$	0-0.4	0-0.2

Typical contributions to total particulate emissions for Civil Aviation range between 0.1% and 0.2% (Table 2.2).

Table 2.2 Contribution to total particulate matter emissions from 2004 EMEP database (WEBDAB)

NFR Sector	Data	PM_{10}	$PM_{2.5}$	TSP
1 A 3 a ii (i) - Civil Aviation (Domestic, LTO)	No. of countries reporting	12	12	12
	Lowest Value	0.0%	0.0%	0.0%
	Typical Contribution	0.1%	0.1%	0.1%
	Highest Value	0.3%	0.4%	0.3%
1 A 3 a ii (ii) - Civil Aviation (Domestic, Cruise)	No. of countries reporting	11	10	9
	Lowest Value	0.0%	0.0%	0.0%
	Typical Contribution	0.2%	0.0%	0.0%
	Highest Value	2.1%	0.2%	0.0%

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[2] PM_{10} and $PM_{2.5}$ data are taken from Corinair-2004

3 GENERAL

3.1 Description

In principle the activities include all flights in a country. The traffic is often divided into four categories:

Category 1. Civil IFR (Instrumental Flight Rules) flights
Category 2. Civil VFR (Visual Flight Rules) flights, also called general aviation
Category 3. Civil Helicopters
Category 4. Operational Military flights

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

Data are mostly available for turbofans only, 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 3.1. 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 tuboprop aircraft may be significant in national aviation in some countries. More types and engines exist and engines can be seen in ICAO (1995) or at http://www.dera.gov.uk.

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.

3.2 Definitions

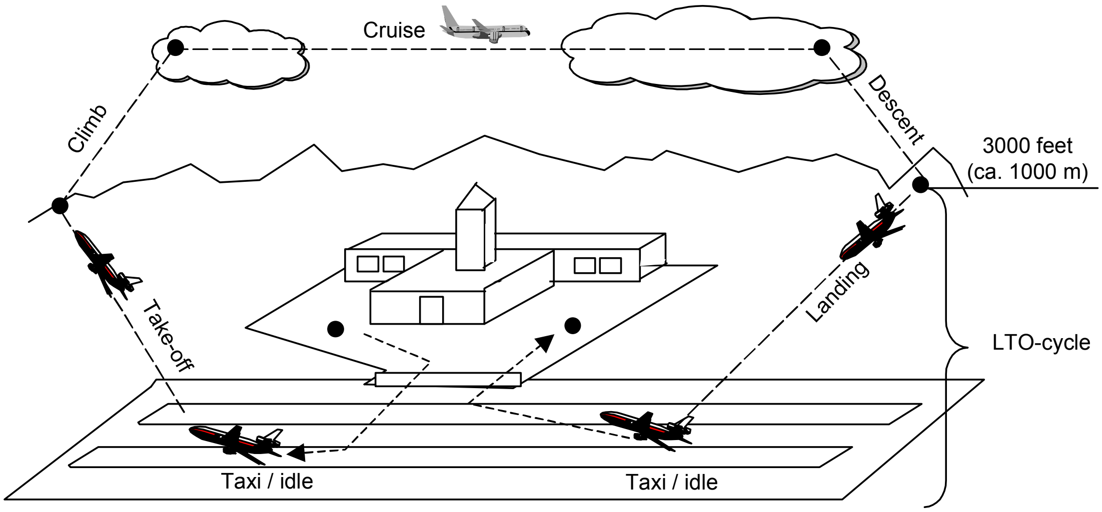
Abbreviations
AERONOX: EU-project “The impact of NO_x-emissions from aircraft upon the atmosphere at flight altitudes 8-15 km" (AERONOX, 1995)
ANCAT: Abatement of Nuisance Caused by Air Transport, a technical committee of the European Civil Aviation Conferences (ECAC)
ATC: Air Traffic Control
CAEP: Committee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

ICAO certification data prepared for the engines of an aircraft takes into account the population of engines fitted to that aircraft according to an aircraft registration database (ANCAT, 1998).

Operations of aircraft are divided into two parts:

- The *Landing/Take-off* (LTO) cycle which includes all activities near the airport that take place below the altitude of 3000 feet (1000 m). This therefore includes taxi-in and out, take-off, climb- out, and approach-landing. The LTO is defined in ICAO (1993).
- *Cruise* which here is defined as all activities that take place at altitudes above 3000 feet (1000 m). No upper limit of altitude is given. Cruise, in this report, includes climb from the end of climb-out in the LTO cycle to cruise altitude, cruise, and descent from cruise altitudes to the start of LTO operations of landing (figure 3.1).

Figure 3.1 Standard flying cycles



Some statistics count either a landing or a take-off as one operation. However it should be noted that *both* one landing and one take-off define a full LTO-cycle in this report.

The emission figures for national and international aviation have to be reported separately. The distinction between national and international aviation is as follows: *All traffic between two airports in one country is considered domestic* no matter the nationality of the carrier. The air traffic is considered international if it takes place between airports in two different countries. If an aircraft goes from one airport in one country to another in the same country and then leaves to a third airport in another country, the first trip is considered a domestic trip, while the second trip is considered an international trip. The only exceptions are technical refuelling stops, or domestic trips that only allow passenger or freight to board for an international trip or leave the aircraft after an international trip. These are not considered domestic but international. Further guidance on the allocation issue is given in the IPCC Good Practice Guidance for Inventory Preparation.

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

Table 3.1 Civil aircraft classification. Movements in Europe per aircraft type*, 1998.

	Movements per aircraft type %	% local (non- trans Atlantic) movements for this type	Number of engines	Type of engine	Most used engine
Boeing B 737, unspecified	14.8	99.6	2	TF	PW JT8D-17, CFMI CFM56-3
Airbus A 320	8.6	99.6	2	TF	CFMI CFM56-5A
McDonnell Douglas MD 80	8.1	100	2	TF	PW JT8D-217
ATR	5.2	100	2	TP	PWC PW120, PW124
BAe 146	4.6	100	4	TF	LY ALF 502R-5
Boeing B 757	3.4	95.3	2	TF	PW 2037
Boeing 737-100	3.3	99.7	2	TF	PW JT8D-17, CFMI CFM56-3
Fokker F-50	3.1	100	2	TP	PW125B
De Havilland DASH-8	2.8	100	2	TP	PW 121/123
Boeing B 767	2.7	46.8	2	TF	GE CF6-80A2, GECF6-80C2B6
Canadair Regional Jet	2.1	100	2	TF	LY ALF 502L-2C
McDonnell Douglas DC 9	1.8	99.8	2	TF	JT8D-15
Boeing B 727	1.7	99.6	3	TF	JT8D-7B
Fokker 100	1.6	100	2	TF	RR TAY 620-15
Boeing B 747 100-300	1.5	43.4	4	TF	PWJT9D-7A, PW4056
SAAB 2000	1.4	100	2	TP	AN GMA2100A
SAAB 340	1.4	100	2	TP	GE CT7-5A2
Airbus A 310	1.3	88.5	2	TF	GE CF6-80C2A5, PW JT9-7R4El
Airbus A 300	1.0	93.7	2	TF	GE CF6-80C2A5, PW JT9-7R4El

Data source: Eurocontrol - STATFOR, The Norwegian Civil Aviation Administration (personal comm.)
TJ - turbojet, TF - turbofan, TP - turboprop, R - reciprocating piston, O - opposed piston.
*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.

3.3 Techniques

In general there are two types of engines; *reciprocating piston* engines, and *gas turbines* (Olivier, 1990). In *piston engines*, energy is extracted from fuel burned in a combustion chamber by means of a piston and crank mechanism, which drives the propellers to give the aircraft momentum. In *gas turbines* air is first compressed and then heated by combustion with fuel in a combustion chamber and the major part of this is used for propulsion of the aircraft. A part of the energy contained in the hot air flow is used to drive the turbine, which in turn 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.

3.4 Emissions

Air traffic as a source of combustion emissions will depend on the:

- type of aircraft;
- type of engines and fuel used;
- emission characteristics of the engines (emissions per unit of fuel used depending on engine load);
- location (altitude) of operation;
- traffic volume (number of flights and distance travelled).

The effect of engine ageing on emissions is not taken into account. It is, however, generally assumed that this effect is of minor importance compared with the total emissions since aircraft engines are continuously maintained to tighter standards than the engines used in e.g. automotive applications.

Emissions come from use of kerosene and aviation gasoline that are used as fuel for the aircraft. Gasoline is used in small (piston engined) aircraft only.

Other emissions:
Which are related to aircraft, but which are not included under the present SNAP codes. Examples of these are:

- fuelling and fuel handling (SNAP 050402) in general;
- maintenance of aircraft engines (SNAP 060204);
- painting of aircraft (SNAP 060108);
- service vehicles for catering and other services (SNAP 0808);
- anti-icing and de-icing of aircraft (SNAP 060412). Much of the substances used flows off the wings during idle, taxi, and take-off and evaporates.

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

Auxiliary power operations:
Considerations might be given to allocating a SNAP code to the operation of APUs (Auxiliary Power Unit) (see section 3.4 below). APU is 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, currently no methodology has been developed. The use of APU is being severely restricted at some airports to maintain air quality, and therefore this source of fuel use and emissions may be declining.

Fuel dumping in emergencies:
From time to time aircraft will have to dump fuel before landing so that they do not to 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. 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 1000 m, these are currently not relevant for 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.

The use of energy, and therefore emissions, depends on the aircraft operations and the time spent at each stage. Table 3.2 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.

Table 3.2. 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%	0.7
Climb-out	85%	2.2
Approach-landing	30%	4.0
Taxi/ground idle	7%	26.0

Source: ICAO, 1993

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 1000 m. For CO it is about 50% and for VOC it is about 20-40% (Olivier, 1991).

3.5 Controls

The current status of regulations of NO_x is found in ICAO (1993), see Table 3.3. Standards are given for engines first produced before and after 1996. Further regulations will be put on engines manufactured after 31.12.2003 as specified by ICAO's latest regulations set in the CAEP (1998). Aircraft manufacturers are also helping with respect to reducing the fuel consumption by improvements in the aerodynamic properties of the aircraft.

The regulations published by ICAO against which engines are certificated are given in the form of the total quantity of pollutants (D_p) emitted in an LTO cycle divided by the maximum sea level thrust (F_{oo}) and plotted against engine pressure ratio at maximum sea level thrust. The limit values are given by the formulae in Table 3.3.

Table 3.3 Current and future regulations. Certification limits for NO_x for turbo jet and turbo fan engines.

	CURRENT REGULATIONS		**RECOMMENDATION**
	engines first produced before 31.12.1995 & for engines manufactured up to 31.12.1999	engines first produced after 31.12.1995 & for engines manufactured after 31.12.1999	recommended regulation (CAEP 4th meeting, 1998, CAEP-SG/2-Report pp B-2, B-3) for engines manufactured after 31.12.2003
Applies to engines >26.7 kN	$D_p/F_{oo} = 40 + 2\pi^{\circ}_{oo}$	$D_p/F_{oo} = 32 + 1.6\pi^{\circ}_{oo}$	
Engines of pressure ratio less than 30			
Thrust more than 89 kN			$D_p/F_{oo} = 19 + 1.6\pi^{\circ}_{oo}$
Thrust between 26.7 kN and not more than 89 kN			$D_p/F_{oo} = 37.572 + 1.6\pi^{\circ}_{oo} - 0.208 F_{oo}$
Engines of pressure ratio more than 30 and less than 62.5			
Thrust more than 89 kN			$D_p/F_{oo} = 7+2.0\pi^{\circ}_{oo}$
Thrust between 26.7 kN and not more than 89 kN			$D_p/F_{oo} = 42.71 +1.4286\pi^{\circ}_{oo} - 0.4013 F_{oo} +0.00642\pi^{\circ}_{oo} * F_{oo}$
Engines with pressure ratio 62.5 or more			$D_p/F_{oo} = 32+1.6\pi^{\circ}_{oo}$

Source: International Standards and Recommended Practices, Environmental Protection, ICAO Annex 16 Volume II Part III Paragraph 2.3.2, 2nd edition July 1993.

where:

D_p = the sum of emissions in the LTO cycle in g
F_{oo} = thrust at sea level take-off (100%)
π°_{oo} = pressure ratio at sea level take-off thrust point (100%)

The equivalent limits for HC and CO are $D_p/F_{oo} = 19.6$ for HC and $D_p/F_{oo} = 118$ for CO (ICAO Annex 16 Vol. II paragraph 2.2.2). Smoke is limited to a regulatory smoke number = $83\ (F_{oo})^{-0.274}$ or a value of 50, whichever is the lower.

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

The most recent regulatory changes (up to 2005) have continued this trend with certification limits for NO_x getting even lower, whilst those for smoke, CO and HC remain unchanged.

3.6 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 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 3.4. Note that these may be larger or smaller according to the rate at which the aircraft fleet is renewed (see below).

Table 3.4 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 ongoing 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 DTI (MEET, 1998) is shown in Table 3.5.

Table 3.5 World fleet age profile. 2010 and 2020, Per cent

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

* 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.

4 SIMPLE METHODOLOGIES

Within different countries, there may be large differences in the resources and data available as well as the relative importance of this emission source. Therefore, three methodologies, the Very Simple, the Simple and the Detailed Methodology, have been developed. The difference between the methodologies lies mainly in the aggregation level assumed for the aircraft.

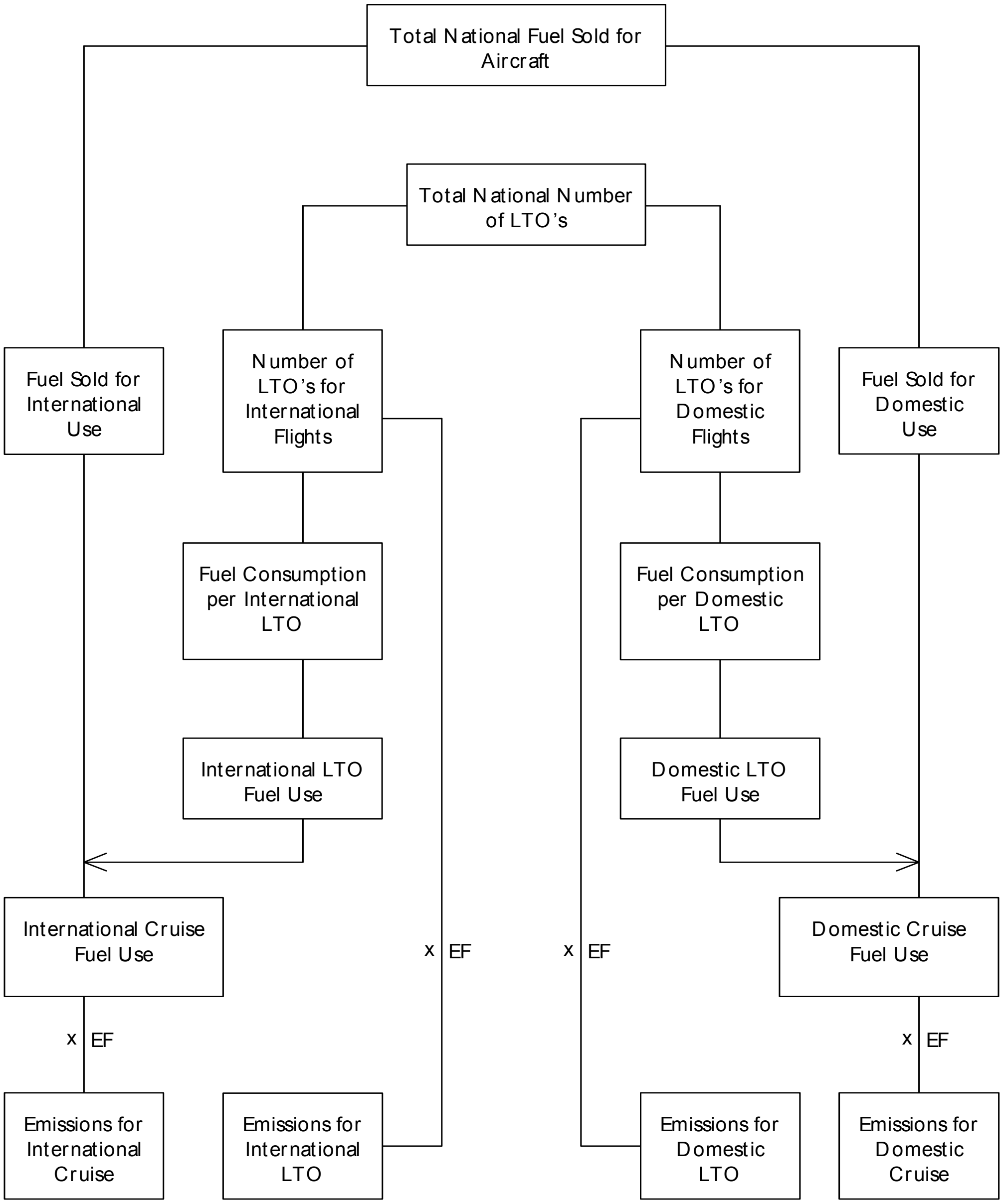
In the very simple methodology, estimations are made without considering the actual aircraft types used. In the simple methodology, it is assumed that information is available on the types of aircraft that operate in the country. Finally, the detailed methodology takes into account cruise emissions for different flight distances and possibly specific LTO times-in-modes. The third (detailed) methodology will be explained in section 5. The differences between the methodologies are shown in Table 4.1. See section 10 for a discussion of the advantages and disadvantages of the various methods.

All three methodologies are based on landing/take-off data. Of the aircraft categories described above (3.1), flight data will be fully available for Category 1, but only partly available or missing for Categories 2, 3 and 4. Thus, these methodologies outlined might only be applicable to Category 1. However this will represent the major part of the emissions. Emissions from the other categories may be roughly estimated from fuel data or hours of operation, if available. Such data may be available from the operating companies. The Detailed Methodology (section 5) will give some information in how to estimate emissions from these non-IFR flights.

Table 4.1 Basis for the methodologies.

		LTO	**Cruise and Climb**
Very Simple	*Activity*	LTO aggregated Time-in-mode (ICAO)	Fuel residual
	Emission factor	Generic aircraft	Generic aircraft
Simple	*Activity*	LTO per aircraft type (generic aircraft) Time-in-mode (ICAO)	Fuel residual
	Emission factor	Per aircraft type	One generic aircraft
Detailed	*Activity*	LTO per aircraft type (generic aircraft) (option also engine type) Time-in-mode: actual if available otherwise ICAO	Distances flown. Independent estimate of cruise fuel use.
	Emission factor	Per aircraft type (generic aircraft) (option also engine type)	Per aircraft type (generic aircraft) and distance flown

Figure 4.1 Estimation of aircraft emissions with the simple fuel based methodologies



The simple methodologies are both based on LTO data and the quantity of fuel sold or used as illustrated in Figure 4.1. 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 one of the two simple methodologies outlined below.

For estimating the total emissions of CO_2, SO_2 and heavy metals the Very Simple Methodology is sufficient, as the emissions of these pollutants are dependent of the fuel only and not 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 Simple Methodology. The Detailed Methodology may be used to get an independent estimate of fuel and CO_2 emissions from domestic air traffic.

See Table 4.2. for references to the recommended aircraft to be used for these calculations.

4.1 The Very Simple Methodology

Where the number of LTO cycles carried out on a per-aircraft type basis is not known, the Very Simple Methodology should be used. In this case 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 Very Simple 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 8.2) (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 8.2).
8. Estimate the *emissions related to domestic cruise activities* by multiplying the respective emission factors (in emission/fuel used) in Table 8.2 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 (< 1000 nm[3]) 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.

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[3] Where nm = nautical miles, 1nm = 1.852 km.

The estimated emissions are allocated to SNAP codes as follows:

- LTO, domestic aviation found in step 7 go under the SNAP code 080501;
- LTO, international aviation found in step 7 go under the SNAP code 080502;
- Cruise, domestic aviation found in step 8 go under SNAP code 080503;
- Cruise, international aviation found in step 8 go under SNAP code 080504.

4.2 The Simple Methodology

If it is possible to obtain information on LTOs per aircraft type but there is no information available on cruise distances, it is recommended to use the Simple Methodology. 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. The approach can best be described by following the 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 Table 4.2. Use table 4.3 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 Table 8.3 corresponding to the specific aircraft type in Table 4.2 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 Very Simple 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 Table 8.3. 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.
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 Very Simple Methodology or Detailed Methodology). Relevant

emission factors can be found in Table 8.2 or attached spreadsheets for Detailed Methodology (also available from the Task Force Secretariat & Website).

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*.

The estimated emissions are allocated to SNAP codes as follows:

- LTO, domestic activities found in step 9 go under the SNAP code 080501;
- LTO, international aviation found in step 9 go under the SNAP code 080502;
- Cruise, domestic aviation found in step 10 go under SNAP code 080503;
- Cruise, international aviation found in step 10 go under SNAP code 080504.

Table 4.2 Correspondence between aircraft type and representative aircraft

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			

* MD90 goes as MD81- 88 and B737- 600 goes as B737- 400.

** DC8 goes as double the B737- 100. F50, Dash8 - see separate table.

Table 4.3 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 full dataset (Grundstrøm 2000), if the actual turboprop in use is known.

Table 4.4 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

* L = Landplane, H= Helicopter, J = Jet engine, T = Turboprop, 1, 2 or 4 equals the number of engines
Source: Supplied by Danmarks Miljøundersøkelser

5 THE DETAILED METHODOLOGY

The data sources available for performing a Detailed Methodology may vary between countries. Also the scope of such a study may vary. We will present two detailed methodologies for aircraft here, one based on *aircraft movement data* recommend for *IFR flights* and one based on *fuel statistics or operational hours* recommended for *non-IFR flights*. In addition, both methodologies could be used to prepare an airport inventory e.g. for inclusion in an urban emission inventory.

The *Aircraft Movement Methodology* (based on aircraft movement data) is the preferred option for IFR flights when detailed aircraft movement data for LTO and cruise together with technical information on the aircraft are available. Basically, the use of the Detailed Methodology means that emissions are estimated for all the different types of aircraft which are in use and have been registered by LTO movements in the airports of the country. The Detailed Methodology may also include the actual times-in-mode at individual airports. The primary use of this method is to determine the fuel used and emissions from national and international aviation activities of a country, but it may also be used for other applications that may be required by research or monitoring. The methodology may be quite time consuming to perform.

The *Fuel Consumption Methodology* is particularly suited to use for aircraft categories where LTO data may be incomplete or not available at all, e.g. military aircraft, and miscellaneous uncertificated aircraft such as helicopters, taxi aircraft and pleasure aircraft.

5.1 The aircraft movement methodology 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, an ATC provider such as Eurocontrol 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 (Table 4.2). This is called the ‘representative aircraft’. Use Table 4.3 for turboprops and Table 4.4 for miscellaneous smaller aircraft. See also Section 5.2. on non-IFR flights. Their emissions will have to be estimated separately, by a simpler method.
2. Note the distance of the mission. See Section 6 “activity data” for a description of how this may be determined.
3. From the attached spreadsheets (also available from the Task Force Secretariat & Website) or Table 8.3, 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 3000 ft (1000 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 3000 ft (1000 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 3000 ft (1000 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 3000 ft (1000 m) (cruise emissions).
7. The total 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 Section 8.3 for an example on how to apply the method.

If a specific aircraft-engine combination is required, then the LTO data must be calculated from the data contained in the ICAO Engine Emissions Data Bank for which the standard method of calculation is included (ICAO, 1995). This may increase the accuracy in the LTO emission estimate, but the cruise estimate based on generic aircraft cannot be changed based on these individual ICAO data.

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 & 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.

5.2 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.

1. 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.
2. Select the appropriate emission factors and fuel use factors from Tables 8.6-8.10.
3. Multiply the fuel consumption data in tonnes by the fuel-based emission factors to obtain an annual emission estimate.

6 RELEVANT ACTIVITY STATISTICS

The activity statistics that are required will depend on the methodology. The available statistics may, however, to some extent determine the choice of methodology.

Fuel use statistics:
These should be split between national and international as defined above. Sources of these data include:

- The airline companies;
- The oil companies;
- Energy statistics;
- Estimations from LTOs and cruise distances (see also the Detailed Methodology);
- Estimation from time tables (see also the Detailed Methodology);
- Airport authorities.

The landing/take-off statistics:

These can be obtained directly from airports, from the official aviation authorities or from national reports providing aggregated information on the number of landings- and take-offs taking place for national and international aviation.

National time- in-mode LTO-data:
If data for individual aircraft at individual airports are to be used instead of standard ICAO values, these may be obtained from the airports or the operators of the aircraft.

Fuel use or numbers of hours in operation:
For particular aircraft types these may be obtained from the airline, taxi or helicopter companies (usually a limited number at national level). Also sales statistics of fuels and energy balances may give some information. Data on the quantity of fuel used in military aircraft may be obtained from fuel sales statistics and energy balances or directly from the defence authorities. These data may be classified information and therefore estimates might have to be made.

Distance tables:
Average cruise distances may be derived from timetables, national aircraft authorities or ATC providers. Note that distances given may be Great Circle and might not reflect the actual distances flown, for example deviations around restricted areas or stacking at busy airports. Total flight distance must be used and not only that part within the national territory.

7 POINT SOURCE CRITERIA

If an airport has more than 100.000 LTOs per year (national plus international), the airport should be considered as a point source.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The emission factors used for the three methodologies are based on different levels of detail of the aircraft used to represent the fleet in the calculations.

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 http://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 is in the process of being published as part of UK DfT’s Project for the Sustainable Development of Heathrow (UK-DfT 2006).

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 in Table 8.1 below.

Table 8.1 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

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.

There is not much 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.

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 POPs (Persistent Organic Pollutants) from aircraft engines. USEPA has derived a PAH-16/VOC fraction of $1.2*10^{-4}$ and a PAH-7/VOC fraction of $1.0*10^{-6}$ for commercial aviation (USEPA 1999). PAH-7 here includes the four UNECE PAHs and three additional species.

Emissions of *water* (H_2O) may be derived from the fuel consumption at the rate of 1.237 kg water/kg fuel.

8.1 Very Simple Methodology

The emission factors in Table 8.2 should be applied when using the Very Simple Methodology. The average international aircraft fleet is represented by a long distance aircraft (large aircraft). If the international trips from the inventory country are mostly short distance (smaller aircraft), it may be more accurate to use the information for domestic aircraft, or to make an appropriate split into short (< 1000 nm) and long (> 1000 nm) distance flights, see 4.1. The emission factors may also be averaged whenever appropriate. LTO emission estimates will in most countries be far too high using the average aircraft only. Such a distinction cannot be made for cruise emissions using the simple methodology. This is, however, a small error as the emissions are estimated from the fuel residual.

Table 8.2 Emission factors and fuel use for the *Very Simple* methodology. Emission factors are given on a representative aircraft basis.

Domestic	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NM-VOC**	**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**	**NM-VOC**	**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

*Sulphur content of the fuel is assumed to be 0.05% S (by mass) for both LTO and cruise activities.

** Assuming a cruise distance of 500 nm for short distance flights and 3000 nm for long distance flights.

Source: Derived from ANCAT/EC2 1998, Falk 1999 and MEET 1999.

$PM_{2.5}$ data (= PM_{10} emissions) Source: inferred from smoke data from ICAO database (ICAO 2006) using the methodology described in DfT PSDH (UK-DfT 2006).

The emission factors for the new fleet can well be higher than that for the fleet it replaces. The reason is that the newer fleet has engines which, in comparison with those of the older fleet, have higher pressure ratios and therefore operate more efficiently, but, at higher combustion temperatures, thus producing more emissions of NO_x. Other pollutants increase for other reasons. However, the increase in aircraft seating capacity of the newer fleet over the old one may lead to a reduction in emissions per passenger.

8.2 Simple Methodology

For the Simple Methodology emission factors in Table 8.3 should be used. For aircraft not contained here, the general factors (Table 8.2) may be used, or use correspondence tables for the Detailed Methodology.

Table 8.3 Examples of aircraft types and emission factors for LTO cycles as well as fuel consumption per aircraft type, kg/LTO

Aircraft type[a)]	CO_2	CH_4	N_2O[b)]	NO_x	CO	NMVOC	SO_2[c)]	$PM_{2.5}$[d)]	Fuel
A310	4853	0.5	0.2	23.2	25.8	5.0	1.5	0.14	1540.5
A320	2527	0.2	0.1	10.8	17.6	1.7	0.8	0.09	802.3
A330	7029	0.2	0.2	36.1	21.5	1.9	2.2	0.19	2231.5
A340	6363	1.9	0.2	35.4	50.6	16.9	2.0	0.21	2019.9
BAC1-11	2147	2.1	0.1	4.9	37.7	19.3	0.7	0.17	681.6
BAe146	1794	0.1	0.1	4.2	9.7	0.9	0.6	0.08	569.5
B727	4450	0.7	0.1	12.6	26.4	6.5	1.4	0.22	1412.8
B737 100	2897	0.1	0.1	8.0	4.8	0.5	0.9	0.10	919.7
B737 400	2600	0.1	0.1	8.3	11.8	0.6	0.8	0.07	825.4
B747 100-300	10754	3.7	0.3	55.9	78.2	33.6	3.4	0.47	3413.9
B747 400	10717	0.2	0.3	56.6	19.5	1.6	3.4	0.32	3402.2
B757	3947	0.1	0.1	19.7	12.5	1.1	1.3	0.13	1253.0
B767 300 ER	5094	0.1	0.2	26.0	6.1	0.8	1.6	0.15	1617.1
B777	8073	2.3	0.3	53.6	61.4	20.5	2.6	0.20	2562.8
DC9	2760	0.1	0.1	7.3	5.4	0.7	0.9	0.16	876.1
DC10	7501	2.3	0.2	41.7	61.6	20.5	2.4	0.32	2381.2
F28	2098	3.3	0.1	5.2	32.7	29.6	0.7	0.15	666.1
F100	2345	0.1	0.1	5.8	13.7	1.3	0.7	0.14	744.4
MD81-88	3160	0.2	0.1	12.3	6.5	1.4	1.0	0.12	1003.1

(a) For CH_4 and NMVOC it is assumed that the emission factors for LTO cycles be 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 DfT PSDH (UK-DfT 2006)

For the DC8 use double the fuel consumption of the B737-100 because it is fitted with four engines instead of two. MD90 goes as MD81-88 and B737-600 goes as B737-400.

Source: Derived from ANCAT/EC2 1998, Falk (1999) and MEET 1999.

The CO_2 emissions are based on the following factor: 3.15 kg CO_2 /kg fuel.

We recommend that the Very Simple Methodology (emission factor for a generic aircraft) is used to estimate the cruise emissions also when using the Simple Methodology. Alternatively pick another aircraft from Table 8.4 or Table 8.5 that may be assumed to be more representative and assume an appropriate cruise distance. The reason is that the residual step of the Simple Methodology does not rely on any knowledge of the proportion of aircraft types in the cruise mode nor the cruise distances.

Using the emission factors, special emphasis should be put on the assumptions of the weight percent 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 percent used for example is 0.01% instead of 0.05%, the emission factor should be divided by 5 to show the true factor.

8.3 Detailed Methodology

8.3.1 IFR-flights

For the Detailed Methodology emission factors for the representative aircraft are given in Table 8.4. The correspondence between actual aircraft and representative aircraft is given in Table 4.2 and 4.3.

Table 8.4 Emission factors and fuel use factors for various aircraft per LTO and distance cruised.

Table is given in associated spreadsheets available in the internet version of this Guidebook. Extracts of the tables are displayed below.

B737 400		Standard flight distances (nm)			[1nm = 1.852 km]			
		125	**250**	**500**	**750**	**1000**	**1500**	**2000**
Distance (km)	Climb/cruise/descent	231.5	463	926	1389	1852	2778	3704
Fuel (kg)	Flight total	1603.1	2268.0	3612.8	4960.3	6302.6	9187.7	12167.6
	LTO	825.4	825.4	825.4	825.4	825.4	825.4	825.4
	Taxi out	183.5	183.5	183.5	183.5	183.5	183.5	183.5
	Take off	86.0	86.0	86.0	86.0	86.0	86.0	86.0
	Climb out	225.0	225.0	225.0	225.0	225.0	225.0	225.0
	Climb/cruise/descent	777.7	1442.6	2787.4	4134.9	5477.2	8362.3	11342.2
	Approach landing	147.3	147.3	147.3	147.3	147.3	147.3	147.3
	Taxi in	183.5	183.5	183.5	183.5	183.5	183.5	183.5
NO_x (kg)	Flight total	17.7	23.6	36.9	48.7	60.2	86.3	114.4
	LTO	8.3	8.3	8.3	8.3	8.3	8.3	8.3
	Taxi out	0.784	0.784	0.784	0.784	0.784	0.784	0.784
	Take off	1.591	1.591	1.591	1.591	1.591	1.591	1.591
	Climb out	3.855	3.855	3.855	3.855	3.855	3.855	3.855
	Climb/cruise/descent	9.462	15.392	28.635	40.425	51.952	78.047	106.169
	Approach landing	1.240	1.240	1.240	1.240	1.240	1.240	1.240
	Taxi in	0.784	0.784	0.784	0.784	0.784	0.784	0.784
$EINO_x$ (g/kg fuel)	Taxi out	4.27	4.27	4.27	4.27	4.27	4.27	4.27
	Take off	18.51	18.51	18.51	18.51	18.51	18.51	18.51
	Climb out	17.13	17.13	17.13	17.13	17.13	17.13	17.13
	Climb/cruise/descent	12.17	10.67	10.27	9.78	9.49	9.33	9.36
	Approach landing	8.42	8.42	8.42	8.42	8.42	8.42	8.42
	Taxi in	4.27	4.27	4.27	4.27	4.27	4.27	4.27
HC (g)	Flight total	817.6	912.9	995.8	1065.2	1118.1	1240.4	1374.1
	LTO	666.8	666.8	666.8	666.8	666.8	666.8	666.8
	Taxi out	321.18	321.18	321.18	321.18	321.18	321.18	321.18
	Take off	3.09	3.09	3.09	3.09	3.09	3.09	3.09
	Climb out	10.58	10.58	10.58	10.58	10.58	10.58	10.58
	Climb/cruise/descent	150.78	246.13	329.05	398.47	451.33	573.67	707.37
	Approach landing	10.74	10.74	10.74	10.74	10.74	10.74	10.74
	Taxi in	321.18	321.18	321.18	321.18	321.18	321.18	321.18
EIHC (g/kg fuel)	Taxi out	1.75	1.75	1.75	1.75	1.75	1.75	1.75
	Take off	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	Climb out	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Climb/cruise/descent	0.19	0.17	0.12	0.10	0.08	0.07	0.06
	Approach landing	0.07	0.07	0.07	0.07	0.07	0.07	0.07
	Taxi in	1.75	1.75	1.75	1.75	1.75	1.75	1.75
CO (g)	Flight total	14252.5	15836.0	17525.5	19060.6	20369.3	23298.2	26426.3
	LTO	11830.9	11830.9	11830.9	11830.9	11830.9	11830.9	11830.9
	Taxi out	5525.45	5525.45	5525.45	5525.45	5525.45	5525.45	5525.45
	Take off	77.19	77.19	77.19	77.19	77.19	77.19	77.19
	Climb out	202.29	202.29	202.29	202.29	202.29	202.29	202.29
	Climb/cruise/descent	2421.54	4005.06	5694.59	7229.65	8538.39	11467.26	14595.41
	Approach landing	500.54	500.54	500.54	500.54	500.54	500.54	500.54

B737 400		Standard flight distances (nm)		[1nm = 1.852 km]				
		125	**250**	**500**	**750**	**1000**	**1500**	**2000**
	Taxi in	5525.45	5525.45	5525.45	5525.45	5525.45	5525.45	5525.45
EICO (g/kg fuel)	Taxi out	30.11	30.11	30.11	30.11	30.11	30.11	30.11
	Take off	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	Climb out	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	Climb/cruise/descent	3.11	2.78	2.04	1.75	1.56	1.37	1.29
	Approach landing	3.40	3.40	3.40	3.40	3.40	3.40	3.40
	Taxi in	30.11	30.11	30.11	30.11	30.11	30.11	30.11

Example:

A B737-400 aircraft is travelling a mission distance of 1723 nm. We want to estimate the fuel use:

> The fuel use for LTO is taken directly from the table and is 825 kg (independent of mission distance).
>
> For operation above 3000 feet (cruise/climb/descent), the fuel used is 8362 + ((11342-8362)*(1723-1500)/(2000-1500)) = 9691 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 = 8.3 kg.
>
> For operation above 3000 feet (flight less LTO), the NO_x is 78+ ((106-78)*(1723-1500)/(2000-1500)) = 90.5 kg
>
> EINOx for the mission is therefore (8.3+90.5)kg/(826+9691)kg = 8.9 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 8.3 we recommend using the Simple Methodologies based on the estimated fuel use in the Detailed Methodology.

Emissions from smaller IFR flight aircraft engines are not certificated, and emission data are less well known. Larger turboprops may be in use for domestic flights and short international flights. Though they do not contribute to emissions on a larger scale, they may be important when estimating domestic emissions. Default emission factors are given in Table 8.5.

Table 8.5 Fuel consumption and emission factors for turboprops.

Table is given in associated spreadsheets available in the internet version of this Guidebook (also available from the Task Force Secretariat & Website).

8.3.2 Non-IFR

There is little information available on emission factors for non-IFR flights. Generally, the NO_x emission factors will be lower and the CO and VOC factors substantially higher than for IFR flights.

It is at present not possible to recommend default emission factors.

Fuel consumption factors are given for two categories of aircraft (Cessna and others) to be used if other information of fuel used not is available (Table 8.6). 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 8.7.

Some emission factors and fuel use factors for helicopters and military flights are given in Tables 8.8, 8.9 and 8.10. Also note that many types of military aircraft may have civil equivalents. Helicopters are also included in Table 8.5.

Table 8.6 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

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

For an average use 33 litre/hour.

Table 8.7 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

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

Table 8.8 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.

Table 8.9 Emission factors for Helicopters of Germany

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 8.10 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

9 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 NO_x and VOC, the profiles vary, amongst other reasons, 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. Shareef et al., (1988) have estimated a VOC profile for a jet engine based on an average LTO cycle for commercial and general aviation. The composition is presented in Table 9.1.

PAH species profiles can be found in USEPA (1999), but not all species are available.

Table 9.1 The VOC profile for a jet engine based on an average LTO cycle for commercial and general aviation.

Compound in VOC profile	**Percentage of total VOC (weight)** **Commercial aircraft**	**General aviation**
Ethylene	17.4	15.5
Formaldehyde	15.0	14.1
$C_6H_{18}O_3Si_3$	9.1	11.8
Methane	9.6	11.0
Propene	5.2	4.6
Acetaldehyde	4.6	4.3
$C_8H_{24}O_4Si_4$	2.9	4.2
Ethyne	4.2	3.7
Acetone	2.4	2.9
Glyoxal	2.5	2.5
Acrolein	2.3	2.1
Butene	2.0	1.8
Benzene	1.9	1.8
1,3-butadiene	1.8	1.6
Methyl glyoxal	2.0	1.8
n-dodecane	1.1	1.2
Butyraldehyde	1.2	1.2
Others < 1%	14.8	13.9
Others	<1	<1
Total	100	100

Source: Shareef et al., 1988

Please note that the thrust setting during the landing and the take-off of the aircraft are different (see Table 3.1). Therefore, it is likely that the species profile will be different for the two situations. Again nothing is known on these aspects.

10 UNCERTAINTY ESTIMATES

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

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

10.1 Very Simple Methodology

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.

10.2 Simple Methodology

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.

10.3 Detailed Methodology

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

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

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

LTO

- Estimates of fuel used and emissions based on ICAO cycles (refer to ICAP 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 3000 ft (3000 m)

- 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 to 11 % in Europe (ANCAT/EC2 1998).
- The actual altitude flown will vary according to air traffic management constraints compared with ideal altitudes flown by the PIANO computer model used by the UK DTI. Altitude will influence fuel consumed (lower cruise altitudes equal higher fuel consumption rate and hence also the emissions) and also the rate of production of NO_x.

PM emissions, including $PM_{2.5}$

There is a fundamental inconsistency in the reporting of PM emissions (TSP, PM_{10} and $PM_{2.5}$) within the EMEP database 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.

Table 8.4 contains a small extract of data from the internet version of the Emissions Inventory Guidebook. It contains no $PM_{2.5}$ data. As an extension to this work a series of rows for $PM_{2.5}$ for each aircraft type could be added.

The internet version of the guidebook, from which the data in Tables 8.6, 8.7, 8.8 and 8.9 are extracted could be updated to include PM and $PM_{2.5}$

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

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

1. 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

2. 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.

13 TEMPORAL DISAGGREGATION CRITERIA

The temporal data may be obtained from flight timetables. There may be diurnal variations as well as variations over months and weekdays.

14 ADDITIONAL COMMENTS

The methodologies and data described in this chapter reflect the current state of the art knowledge. Obviously, the methods and data may be improved in the future.

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

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.

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Austria

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UK Department of Trade and Industry
UK

Morten Winther
National Environmental Research Institute
Denmark

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AEA Technology
UK
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20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Morten Winther

The National Environmental Research Institute
Frederiksborgvej 399
PO Box 358
DK-4000 Roskilde
Denmark

Tel: +45 46 301297
Fax: +45 46 301212
Email: mwi@dmu.dk