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Comparative study of Swedish emission factors for aviation with the IPCC default emission factors

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Summary

The IPCC guidelines recommend that if national emission factors (EFs) are used to estimate emissions from aviation, they should be compared with the IPCC default EFs. This study has aimed at making such comparison. The estimates of emissions related aviation from the governmental airports in Sweden are based on information from the Swedish Civil Aviation Administration (SCAA) and the Swedish Defence Research Agency (FOI). They use two models – HARP and PIANO – to derive and calculate emissions. HARP is used to estimate national Times in Mode (TIM) and PIANO is used to calculate the actual emissions.

Results from this study elucidate that the PIANO model generates significantly lower fuel consumption and emissions compared to the IPCC defaults, due to the considerably shorter TIMs estimated by the HARP model. Comparisons on fuel consumption and aircraft basis show good agreement for CO_2 and SO_2, whereas CH_4, NMVOC and CO are about 20 % lower, and NO_X slightly higher for the PIANO model.

Sweden uses CORINAIR's default EFs for N_2O and its default ratio for separating HC into CH_4 and NMVOC. In order to be consistent with the IPCC guidelines we recommend that Sweden apply the IPCC standards instead when estimating these emissions.

Content

1 Introduction

Emissions from aviation contribute with about 2 % of the global anthropogenic emissions of CO_2 (EEA, 2001). The sector has had an increasing emission trend over the past decade and first half of this decade. In order to assess and determine the magnitude of the emissions from aviation, national submissions are handed in to the UNFCCC[1] by each Annex I country on yearly basis. To ensure comparability and transparency of estimated emissions, UNFCCC recommends each country to follow the IPCC[2] Guidelines[3], 1996 and the IPCC Guidance[4], 2000 when compiling the national data.

The IPCC Guidance state that emission factors (EFs), i.e. emissions per energy consumed, for different airplanes generally should vary little between countries, since emissions from airplanes are more related to the type of fuel used and engine characteristics more than in what part of the world the planes are operating. The IPCC Guidance also recommends that if national EFs are used for emission estimates, they should be compared with the IPCC Guidelines default EFs (hereinafter called IPCC default EFs), and if big differences occur, they should be explained and documented.

1.1 Aim

The aim of this project is to compare the Swedish emission factors for aviation, used for the yearly emission compilation to the UNFCCC, with the default emission factors provided by the IPCC. Furthermore, if big differences between the two sources are revealed, they will be investigated, explained and documented.

1.2 General overview of the methodology for Sweden's estimations of aviation emissions for international reporting

Emissions from aviation submitted by Sweden to the UNFCCC are calculated using national fuel sales statistics and information from the Swedish Civil Aviation Authority (SCAA) on fuel use and emissions estimates related to the governmental airports in Sweden. The estimations of fuel consumption and emissions published by the SCAA are in turn calculated by the Swedish Defence Research Agency (FOI). The FOI uses statistics on the number of flights between city pairs (domestic and international), type of aircraft, amount of fuel needed for different flights and emissions per fuel on specific flights, based on data on aircraft performance during different phases of the flight and the distance between destinations. This information is summed up into groups: domestic landing and take off (LTO), domestic cruise, international LTO and international cruise (Swedish EPA, 2005). This is in line with the IPCC guidelines. Data of good quality exists from 1995 and onwards. Sweden uses the Tier 1 method for CO_2 and Tier 2a for all other gases

Emissions of CO_2 are based on delivery statistics, national thermal values from Statistics Sweden and emission factors from the Swedish EPA. Division of CO_2 emissions on domestic and international, landing and take off (LTO), and cruise, are made based on information on CO_2 emissions from the SCAA regarding governmental airports.

[1] United Nations Framework Convention on Climate Change
[2] Intergovernmental Panel on Climate Change
[3] Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories
[4] IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

In the Swedish compilation, emissions of CO_2 from jet kerosene and aviation gasoline are separated using information on the delivery statistics and country-specific EFs. When it comes to the non-CO_2 gases, aviation gasoline has been assigned the same EFs as for jet kerosene. Since aviation gasoline only stands for about 0.5 % of the total delivered amounts, this assumption gives quite accurate results.

Emissions of all non-CO_2 emissions, except N_2O, are based on detailed information from the SCAA (4 groups) and corrected to be in line with the amounts of fuel delivered on national level:

$$National\ emission = \left(\frac{Delivered\ amount\ of\ \ fuel}{Fuel\ consumed\ (governmental\ airports)} \right) * Emission \begin{pmatrix} governmental\ airports, \\ per\ subs\tan ce \end{pmatrix}$$

Emissions of N_2O from the LTO phase are based on the number of LTO and EFs from CORINAIR (EEA, 2001), whereas emissions from the cruise phase are based on the estimated amounts of fuel used for cruise, corrected to be in line with the delivered amounts. Emissions of N_2O from LTO are not corrected to be in line with the delivered amounts.

Sweden is using CORINAIR default EFs for the very simple methodology when separating HC into CH_4 and NMVOC, giving a ratio of 1/6 CH_4 and 5/6 NMVOC respectively.

The fuel consumption for 1990-1994 is based on the information on the number of flights for domestic and international traffic together with assumptions on fuel consumption per flight. Division of emissions into LTO and cruise is made using the average ration for the years 1995-2001, which resulted in the quotas 25 % LTO and 75 % cruise for domestic traffic, and 10 % LTO and 90 % cruise for international traffic.

2 Methodology for comparing emission factors

The IPCC Guidelines and the IPCC Guidance were scrutinized, and data and information related to aviation were gathered. In order to make comprehensive assessment of data from various perspectives, the data was adjusted when necessary.

The SCAA and the FOI have been contacted to gather information on how the emissions from the governmental airports have been estimated, in order to understand possible differences in data compared to the IPCC defaults. Since FOI (experts Anette Näs and Anders Hasselrot) are doing the actual calculations, direct contact with them was taken. Data sets adjusted to fit comparisons with the IPCC defaults were produced. To understand the national circumstances and model assumptions, detailed background information was also collected. In addition, the FOI extracted data directly from the ICAO database in order to enable in-depth studies of emission factors.

Focus in this report will be on the greenhouse gases, but the indirect gases are also included.

3 Results

3.1 IPCC Guidance and IPCC Guidelines

The IPCC Guidance states that emissions from aviation varies depending on type of fuel used, location, the types and efficiency of the engines, and the length of the flight.

IPCC Guidelines describe two different tables displaying EFs for emission calculation of aviation emissions, Table 1-50 and 1-52. Table 1-52 displays EFs on fleet average basis and should be used when only agglomerated data is available. The default EFs are divided on both domestic and international aviation as well as on LTO and cruise. The figures for domestic traffic are derived from information on a number of typical aircraft, such as Airbus A320, Boeing 737-400 and McDonald Douglas DC9 and MD80, whereas international traffic is based on Airbus A300, Boeing B767, B747 and McDonald Douglas DC9.

Table 1-50 in the guidelines gives information about a number of typical aircraft and should be used when more statistics on aircraft basis are available.

Information on aircraft basis in the IPCC Guidelines is derived from the ICAO database, reference year 1995. Emissions of HC are separated into CH_4 and NMVOC using the ratio of 10% and 90% respectively.

IPCC Guidelines' LTO-cycle is based on a cycle time of 32.9 minutes, made up of four individual Times in Mode (TIM) – Taxi/ground idle, Approach, Climb-out and Take off - according to ICAO standards. It is said that depending on whether there is more or less congestion at the airport this time may be shorter or longer. In particular, taxi times may differ substantially between large metropolitan airports and small airports.

3.2 Description of PIANO and HARP models

The same flight simulation model, PIANO[5], has been used to calculate all emissions for all years 1995-2003. PIANO is a software tool used for parametric studies of airplane design (Pålsson, 1999). It contains information on aerodynamics, design and engines on about 200 airplanes where the most frequent types trafficking the Swedish airports are represented. Data on airplanes not included in the database can be simulated using information on airplane aerodynamics, geometry and engine characteristics. Emission data used in PIANO comes from ICAO Engine Exhaust Emissions Data Bank. Only jet engines are represented in ICAO, and information on other types of engines (for example piston engines) are collected from aircraft engine manufactures.

Emission parameters estimated in PIANO for both LTO and cruise are all more or less strongly linearly correlated to the expected distance, and also the fuel consumption (Pålsson, 1999). Emissions from the LTO-phase are estimated, divided into the four TIMs. Instead of using the standard ICAO times, national estimates have been calculated using the HARP model (Pålsson, 1999). Table V in Appendix 1 show how different motor types generate different output in time and fuel consumption for the ICAO and the HARP

[5] PIANO stands for Project Interactive ANalysis and Optimization

models. Input from on-site studies from the three largest airports in Sweden has been used to simulate more accurate estimates of the Swedish Taxi/ground idle times. Due to the fact that Sweden's airports are smaller than cosmopolitan airports in other countries, it has not only resulted in much shorter taxi times for domestic flights for the three largest airports (10 minutes compared to 26 minutes in ICAO) and even shorter times for the rest (approximately 8 minutes), but generally shorter times for both Climb-out and Takeoff as well. For international flights, ICAO standard taxi time has been used for the part of the LTO cycle occurring on the international airport (Näs, 2005).

ICAO standard throttle settings (percent of maximum rated output), i.e. 7%, 30%, 85% and 100%, have been used as input in the PIANO model, except for the first phase, Taxi/ground idle where 5% has been used (Hasselrot, 2005).

3.3 Comparisons of emission factors

The following chapter will present two different comparative studies, where the Swedish EFs are compared with the IPCC default EFs on average basis and on aircraft basis. Note that for the Swedish EFs for HC have been separated into CH_4 and NMVOC according to the CORINAIR quotas.

3.3.1 Pairwise comparisons with the IPCC default average emission factors

Tables 1-6 show pairwise comparisons of fuel consumption and EFs between the IPCC default values for an average fleet and the Swedish EFs. The Swedish EFs of kg/LTO and kg/kg of fuel are based on the years 1995-2003 and 1990-2003 respectively.

It is obvious that the Swedish fuel consumption and emissions per LTO for both domestic and international traffic (Tables 1 and 2) are considerably lower than the IPCC defaults. The exception is N_2O where Sweden uses the CORINAIR default value. As described in chapter 3.2 the Swedish estimates are based on significantly shorter TIM (especially taxi times) for the LTO-phases, hence less fuel is consumed and less pollution is emitted.

Swedish estimates for domestic and international cruise (Tables 3 and 4) generally show good agreement with the IPCC default values. Nevertheless, it is notable that while the IPCC default EFs for CO and NMVOC are lower for domestic cruise compared to international, the Swedish EFs show an opposite pattern. The reason behind this has not yet been clearly sorted out.

When comparing EFs for LTO based on kg emissions per kg of fuel (Table 5 and 6) the Swedish EFs generally show good agreement with the IPCC default EFs. However, it is notable that EFs for CH_4 and NMVOC for international LTO are 2-4 times lower in the Swedish estimates. For CH_4, the difference is actually even bigger considering the fact that Sweden uses CORINAIR methodology to separate emission of HC into CH_4 and NMVOC.

Table 1. Pairwise comparisons of fuel consumption and emission factors for *domestic LTO:s* between IPCC default for average fleet and Swedish estimates for 1995-2003. (kg/LTO)

Source	Fuel consumption	CO_2	CH_4	N_2O	NO_X	CO	NMVOC	SO_2
IPCC	850	2680	0.3	0.1	10.2	8.1	2.6	0.8
Swedish EFs 1995-2003	195-211	617-668	0.061-0.094	0.1	1.93-2.19	3.58-4.43	0.31-0.47	0.20-0.21

Table 2. Pairwise comparisons of fuel consumption and emission factors for *international LTO:s* between IPCC default for average fleet and Swedish estimates for 1995-2003. (kg/LTO)

Source	Fuel consumption	CO_2	CH_4	N_2O	NO_X	CO	NMVOC	SO_2
IPCC	2500	7900	1.5	0.2	41	50	15	2.5
Swedish EFs 1995-2003	384-457	1213-1443	0.09-0.23	0.3	4.53-5.39	3.32-5.31	0.47-1.15	0.38-0.46

Table 3. Pairwise comparisons of emission factors for *domestic cruise* between IPCC default for average fleet and Swedish estimates for 1990-2003. (kg/t of fuel)

Source	CO_2	CH_4	N_2O	NO_X	CO	NMVOC	SO_2
IPCC	3150	0	0.1	11	7	0.7	1
Swedish EFs 1990-2003	3140	0	0.1	13-14	10-13	1.7-2.3	1

Table 4. Pairwise comparisons of emission factors for *international cruise* between IPCC default for average fleet and Swedish estimates for 1990-2003. (kg/t of fuel)

Source	CO_2	CH_4	N_2O	NO_X	CO	NMVOC	SO_2
IPCC	3150	0	0.1	17	5	2.7	1
Swedish EFs 1990-2003	3140	0	0.1	13-15	5-9.7	0.65-1.8	1

Table 5. Pairwise comparisons of emission factors for *domestic LTO* between IPCC default for average fleet and Swedish estimates for 1990-2003. (kg/kg of fuel)

Source	CO_2	CH_4	N_2O	NO_X	CO	NMVOC	SO_2
IPCC	3.15	0.00035	0.1	0.012	0.0095	0.0031	0.001
Swedish EFs 1990-2003	3.14	0.00031-0.00047	0.1	0.01-0.011	0.018-0.022	0.0016-0.0024	0.001

Table 6. Pairwise comparisons of emission factors for *international LTO* between IPCC default for average fleet and Swedish estimates for 1990-2003. (kg/kg of fuel)

Source	CO_2	CH_4	N_2O	NO_X	CO	NMVOC	SO_2
IPCC	3.16	0.00060	0.2	0.016	0.0200	0.0060	0.001
Swedish EFs 1990-2003	3.14	0.00015-0.00033	0.3	0.011-0.012	0.0084-0.012	0.0013-0.0028	0.001

3.3.2 Comparisons with the IPCC default emission factors for LTO on airplane basis

Tables I and II in Appendix 1 present fuel consumption and EFs per LTO from the IPCC and PIANO respectively. There are major discrepancies between the two data sets for most parameters and aircraft, generally resulting in significantly lower emissions per LTO with the PIANO estimations. For example, the EFs for the aircraft A300 are at least 60% lower in the PIANO model. This, again, is derived from the fact that PIANO is based on the national HARP model simulating the different TIMs, see chapter 3.2.

Table III and IV in Appendix 1 show EFs for LTO per kg of fuel from the IPCC and PIANO respectively. When comparing the two data sets, it is obvious that for a majority of the aircraft, the EFs for CH_4, NMVOC and CO are considerably (> 20 %) lower for the PIANO model. For CO_2 and SO_2, the EFs show good agreement between the sets, whereas for NO_X, there are generally small discrepancies, with a few aircraft resulting in relatively higher values for the PIANO model.

In order to understand the reasons for such differences, more detailed information per aircraft was assessed.

PIANO divides each airplane type into 3 different distance groups, enabling more accurate estimations compared to the IPCC. However, since EFs for these groups differ just slightly, they do not contribute to any significant differences. The difference is of course more obvious in the cruise phase.

When comparing EFs on fuel consumption basis, differences in absolute time and fuel consumption are eliminated. However, the total emissions per LTO are dependent on the relative weight each TIM carries, i.e. 10% less time consumption for a TIM with high fuel consumption carries more weight than 10% less for a TIM with low fuel consumption. Table 7 elucidates how the fuel consumption per TIM and the relative distribution between them for the motor type CF6-80C2A3 differs in PIANO compared to ICAO. This motor type is used for example in the airplane Airbus A300 in the PIANO model. Note that the estimated amounts are not taking the difference in throttle setting into consideration. Despite that, it is obvious that PIANO estimates that relatively less fuel consumption occurs in the Taxi/ground idle mode compared to ICAO. Since Taxi/ground idle has the highest EF (g/kg fuel) for both HC and CO, PIANO generates lower emissions of HC and CO for the selected motor type.

While EFs for HC and CO have the highest values for Taxi/ground idle and thereafter descending for each TIM, the EFs for NO_X show an opposite pattern with the highest values for Take off. Since PIANO estimates relatively higher fuel consumption in the Take off mode, the overall EF for NO_X for the selected motor type is higher (15.9 g/kg of fuel compared to ICAO’s 15.6 g/kg of fuel). This is in line with the rationale described above when comparing EFs (kg/kg of fuel) for LTO on aircraft basis.

Table 7. Estimated fuel consumption for motor type CF6-80C2A3 per TIM from ICAO and PIANO models

TIM	ICAO		PIANO	
Taxi/ground idle	315 kg	38 %	88 kg	27 %
Approch	156 kg	19 %	109 kg	33 %
Climout	264 kg	32 %	87 kg	26 %
Takeoff	103 kg	12 %	47 kg	14 %
Total LTO	**838 kg**	**100 %**	**330 kg**	**100 %**

Note that the IPCC does not state what kind of motor type is assigned to the respective aircraft. Hence, a detailed assessment of differences for each aircraft on motor type basis has not been possible to be carried out at present.

4 Discussion

4.1 Comparisons of emission factors

This chapter will mostly include analysis about the comparison of EFs on aircraft basis.

When comparing the Swedish EFs with the IPCC default EFs on a per LTO basis, it is obvious that the Swedish EFs are considerably lower for almost all aircraft and for all substances. That is generally related to how the national circumstances for the different TIMs in Sweden are simulated in the HARP model. The Swedish airports are considered to have significantly shorter LTO-times, hence lower fuel consumption and emissions, compared to the ICAO standards that the IPCC follows.

On the other hand, comparisons of the Swedish emission factors on a fuel consumption basis give better agreement with the IPCC defaults. For CO_2, the Swedish EFs are in line with the IPCC defaults. For N_2O, Sweden uses CORINAIR default EFs, which are the same as the IPCC values except for international cruise. We recommend that Sweden uses IPCC defaults for all stages to ensure consistency with the IPCC guidelines. For CH_4, there are discrepancies between the Swedish EFs and the IPCC defaults for LTO which to a large extent can be assigned to the significantly shorter Taxi-times estimated in the HARP model compared to the ICAO standards.

In addition, Sweden follows the CORINAIR very simple methodology to separate emission of HC into CH_4 and NMVOC. This leads to overestimation of CH_4 emissions of about 67 % compared to the IPCC recommendation. At the same time it leads to an underestimation of NMVOC-emission of about 8 %. We recommend that Sweden follows the IPCC methodology for dividing HC.

For the non-GHG EFs, the Swedish EFs for NO_X show relatively good agreement with the IPCC defaults, with a few exceptions where the Swedish EFs are higher. For NMVOC and CO, the Swedish EFs are generally lower, but a few aircraft show higher results in the PIANO model. As for CH_4, the differences found between the Swedish EFs for NO_X, NMVOC and CO and the IPCC are all depending on the how the HARP model generates different TIMs compared to ICAO standards. For SO_2, Sweden is using the standard quota for estimating the emissions, i.e. that 0.1 % of the fuel consumption is emitted as SO_2 emissions.

Generally, there can also be differences in compared EFs due to what kind of motor types are applied for the selected aircraft. However, to what extent this is true is hard to assess without further investigations to attain knowledge about the applied motor types in the IPCC default values.

4.2 Conclusion

This study has shown that Sweden generally has good agreement with the IPCC defaults factors on the greenhouse gas emission factors for aviation; and there are plausible explanations where differences occur. However, Sweden is recommended to apply the IPCC default values for N_2O estimations and the IPCC quota when separating HC emission into CH_4 and NMVOC, instead of the present CORINAIR defaults.

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Appendix 1. Aircraft-specific data from the IPCC and the FOI (the PIANO/HARP model)

Table I. Fuel consumption and emissions per LTO for common airplanes given by the IPCC Guidelines (Table 1-50).

IPCC Aircraft	Fuel consumption (kg/LTO)	CO2 kg/LTO	CH4 kg/LTO	N2O kg/LTO	NOX kg/LTO	CO kg/LTO	NMVOC kg/LTO	SO2 kg/LTO
A300	1730	5470	1	0,2	27,21	34,4	9,3	1,7
A310	1550	4900	0,4	0,2	22,7	19,6	3,4	1,5
A320	810	2560	0,04	0,1	11	5,3	0,4	0,8
BAC1-11	680	2150	6,8	0,1	4,9	67,8	61,6	0,7
Bae-146	570	1800	0,16	0,1	4,2	11,2	1,2	0,6
B707*	1860	5880	9,8	0,2	10,8	92,4	87,8	1,9
B727	1410	4455	0,3	0,1	12,6	9,1	3	1,4
B727*	1260	3980	0,7	0,1	9,2	24,5	6,3	1,3
B737-200	920	2905	0,2	0,1	8	6,2	2	0,9
B737*	870	2750	0,5	0,1	6,7	16	4	0,9
B737-400	830	2625	0,08	0,1	8,2	12,2	0,6	0,8
B747-200	3380	10680	3,6	0,3	53,2	91	32	3,4
B747*	3210	10145	4,8	0,3	49,2	115	43,6	3,2
B747-400	3390	10710	1,2	0,3	56,5	45	10,8	3,4
B757	1300	4110	0,1	0,1	21,6	10,6	0,8	1,3
B767	1710	5405	0,4	0,2	26,7	20,3	3,2	1,7
Caravelle*	840	2655	0,5	0,1	3,2	16,3	4,1	0,8
DC8	1860	5890	5,8	0,2	14,8	65,2	52,2	1,9
DC9	880	2780	0,8	0,1	7,2	7,3	7,4	0,9
DC10	2360	7460	2,1	0,2	41	59,3	19,2	2,4
F28	670	2115	5,5	0,1	5,3	54,8	49,3	0,7
F100	740	2340	0,2	0,1	5,7	13	1,2	0,7
L1011*	2540	8025	7,3	0,3	29,7	112	65,4	2,5
SAAB 340	300(E)	945	1,4(E)	0,03(E)	0,3(E)	22,1(E)	12,7(E)	0,3(E)
Tupolev 154	2190	6920	8,3	0,2	14	116,81	75,9	2,2
Concorde	6420	20290	10,7	0,6	35,2	385	96	6,4
GAjet	680	2150	0,1	0,1	5,6	8,5	1,2	0,7

Table II. Fuel consumption and emissions per LTO for common airplanes given by the PIANO model.

PIANO Aircraft	Distance	Fuel kg/LTO	CO2 kg/LTO	CH4 kg/LTO	N2O kg/LTO	NOx kg/LTO	CO kg/LTO	NMVOC kg/LTO	SO2 kg/LTO
A300_600R	340 km	647	2 045	0.29	Missing	10.1	8.3	1.5	0.6
	1200 km	660	2 087	0.29	Missing	10.5	8.4	1.5	0.7
	2600 km	690	2 179	0.30	Missing	11.3	8.6	1.5	0.7
A310	1000 km	769	2 429	0.05	Missing	12.2	2.1	0.2	0.8
	4500 km	857	2 708	0.05	Missing	14.7	2.3	0.3	0.9
	7500 km	965	3 050	0.06	Missing	17.9	2.4	0.3	1.0
A320_200	340 km	377	1 191	0.04	Missing	4.5	2.3	0.2	0.4
	1200 km	384	1 214	0.04	Missing	4.7	2.3	0.2	0.4
	2600 km	403	1 274	0.04	Missing	5.0	2.4	0.2	0.4
BAC 1-11	200 km	578	1 826	0.11	Missing	6.1	5.7	0.5	0.6
	500 km	587	1 853	0.11	Missing	6.2	5.7	0.5	0.6
	1200 km	609	1 923	0.11	Missing	6.6	5.8	0.5	0.6
Avro RJ 85	200 km	326	1 030	0.09	Missing	2.6	4.4	0.4	0.3
	500 km	330	1 041	0.09	Missing	2.6	4.4	0.4	0.3
	1200 km	355	1 122	0.09	Missing	2.9	4.4	0.4	0.4
B707	1000 km	993	3 138	5.63	Missing	6.3	44.9	28.2	1.0
	4500 km	1 152	3 641	6.04	Missing	7.9	47.8	30.2	1.2
	8000 km	1 421	4 491	6.56	Missing	10.5	51.6	32.8	1.4
B727-200	340 km	1 028	3 247	0.25	Missing	12.9	5.4	1.3	1.0
	1200 km	1 068	3 376	0.26	Missing	13.8	5.5	1.3	1.1
	2600 km	1 162	3 673	0.27	Missing	15.8	5.6	1.3	1.2
B737-200	340 km	603	1 905	0.38	Missing	4.9	8.5	1.9	0.6
	1200 km	618	1 952	0.39	Missing	5.1	8.6	1.9	0.6
	2600 km	647	2 043	0.39	Missing	5.5	8.7	2.0	0.6
B737-400	340 km	437	1 380	0.04	Missing	4.5	4.5	0.2	0.4
	1200 km	448	1 416	0.04	Missing	4.6	4.5	0.2	0.4
	2600 km	469	1 483	0.04	Missing	5.0	4.6	0.2	0.5
B747-200B	1000 km	1 591	5 027	0.15	Missing	28.0	6.4	0.7	1.6
	4500 km	1 821	5 755	0.16	Missing	35.0	6.8	0.8	1.8
	9000 km	2 289	7 232	0.18	Missing	49.7	7.6	0.9	2.3
B747-400	1000 km	1 295	4 091	0.60	Missing	21.3	17.0	3.0	1.3
	4500 km	1 441	4 554	0.63	Missing	25.2	17.9	3.2	1.4
	9000 km	1 711	5 406	0.68	Missing	32.3	19.2	3.4	1.7
B757-200	340 km	594	1 877	0.03	Missing	11.1	3.3	0.2	0.6
	1200 km	605	1 912	0.03	Missing	11.6	3.4	0.2	0.6
	2600 km	633	1 999	0.03	Missing	12.6	3.4	0.2	0.6
B767-300ER	340 km	600	1 896	0.06	Missing	10.1	4.3	0.3	0.6
	1200 km	610	1 929	0.06	Missing	10.4	4.3	0.3	0.6
	2600 km	639	2 018	0.06	Missing	11.0	4.4	0.3	0.6
Caravelle*	Missing data								
DC8	Missing data								
DC-9-41	200 km	502	1 586	0.32	Missing	4.1	7.6	1.6	0.5
	500 km	509	1 609	0.33	Missing	4.2	7.6	1.6	0.5
	1200 km	525	1 659	0.33	Missing	4.5	7.7	1.6	0.5
DC 10-30	340 km	1 316	4 159	1.26	Missing	21.6	21.5	6.3	1.3
	1200 km	1 348	4 260	1.28	Missing	22.5	21.7	6.4	1.3
	2600 km	1 414	4 469	1.30	Missing	24.5	22.1	6.5	1.4
F-28	200 km	350	1 107	0.04	Missing	3.2	3.7	0.2	0.4
	500 km	355	1 121	0.04	Missing	3.3	3.7	0.2	0.4
	1200 km	368	1 163	0.04	Missing	3.5	3.7	0.2	0.4
F-100	200 km	437	1 382	0.10	Missing	3.7	5.7	0.5	0.4
	500 km	444	1 403	0.10	Missing	3.8	5.7	0.5	0.4
	1200 km	461	1 457	0.11	Missing	4.1	5.8	0.5	0.5
L-1011-200	1000 km	1 176	3 716	4.35	Missing	15.4	41.0	21.8	1.2
	3000 km	1 250	3 950	4.44	Missing	17.4	41.7	22.2	1.3
	6000 km	1 402	4 431	4.58	Missing	21.7	43.0	22.9	1.4
Saab 340B	340 km	81	256	0.04	Missing	0.5	0.0	0.2	0.1
	800 km	82	258	0.04	Missing	0.6	0.0	0.2	0.1
	1200 km	82	260	0.04	Missing	0.6	0.0	0.2	0.1
TU154	400 km	987	3 120	0.86	Missing	6.7	33.7	4.3	1.0
	1200 km	1 027	3 245	0.87	Missing	7.2	34.0	4.3	1.0
	2600 km	1 118	3 534	0.88	Missing	8.3	34.6	4.4	1.1
Concorde	Missing data								
GAjet	Missing data								

Table III. Emissions per kg of fuel for LTO for common airplanes, given by the IPCC Guidelines (Table 1-50).

IPCC Aircraft	CO2	CH4	N2O	NOX kg/kg Fuel	CO	NMVOC	SO2
A300_600R	3,16	0,00058	0,00012	0,016	0,020	0,0054	0,001
A310	3,16	0,00026	0,00013	0,015	0,013	0,0022	0,001
A320_200	3,16	0,00005	0,00012	0,014	0,007	0,0005	0,001
BAC 1-11	3,16	0,01000	0,00015	0,007	0,100	0,0906	0,001
Avro RJ 85	3,16	0,00028	0,00018	0,007	0,020	0,0021	0,001
B707	3,16	0,00527	0,00011	0,006	0,050	0,0472	0,001
B727-200	3,16	0,00021	0,00007	0,009	0,006	0,0021	0,001
B737-200	3,16	0,00022	0,00011	0,009	0,007	0,0022	0,001
B737-400	3,16	0,00010	0,00012	0,010	0,015	0,0007	0,001
B747-200B	3,16	0,00107	0,00009	0,016	0,027	0,0095	0,001
B747-400	3,16	0,00035	0,00009	0,017	0,013	0,0032	0,001
B757-200	3,16	0,00008	0,00008	0,017	0,008	0,0006	0,001
B767-300ER	3,16	0,00023	0,00012	0,016	0,012	0,0019	0,001
Caravelle*	3,16	0,00060	0,00012	0,004	0,019	0,0049	0,001
DC8	3,17	0,00312	0,00011	0,008	0,035	0,0281	0,001
DC-9-41	3,16	0,00091	0,00011	0,008	0,008	0,0084	0,001
DC 10-30	3,16	0,00089	0,00008	0,017	0,025	0,0081	0,001
F-28	3,16	0,00821	0,00015	0,008	0,082	0,0736	0,001
F-100	3,16	0,00027	0,00014	0,008	0,018	0,0016	0,001
L-1011-200	3,16	0,00287	0,00012	0,012	0,044	0,0257	0,001
Saab 340B	3,15	0,00467	0,00010	0,001	0,074	0,0423	0,001
TU154	3,16	0,00379	0,00009	0,006	0,053	0,0347	0,001
Concorde	3,16	0,00167	0,00009	0,005	0,060	0,0150	0,001
GAjet	3,16	0,00015	0,00015	0,008	0,013	0,0018	0,001

Table IV. Fuel consumption and emissions per kg fuel for LTO for common airplanes, given by the PIANO model.

PIANO Aircraft	Distance	CO2	CH4	N2O	NOX	CO	NMVOC	SO2
		kg/kg Fuel						
A300_600R	340 km	3.16	0.00027	Missing data	0.016	0.013	0.0024	0.001
	1200 km	3.16	0.00027	Missing data	0.016	0.013	0.0024	0.001
	2600 km	3.16	0.00026	Missing data	0.016	0.012	0.0024	0.001
A310	1000 km	3.16	0.00004	Missing data	0.016	0.003	0.0003	0.001
	4500 km	3.16	0.00004	Missing data	0.017	0.003	0.0003	0.001
	7500 km	3.16	0.00004	Missing data	0.019	0.003	0.0003	0.001
A320_200	340 km	3.16	0.00006	Missing data	0.012	0.006	0.0006	0.001
	1200 km	3.16	0.00006	Missing data	0.012	0.006	0.0005	0.001
	2600 km	3.16	0.00006	Missing data	0.013	0.006	0.0005	0.001
BAC 1-11	200 km	3.16	0.00011	Missing data	0.011	0.010	0.0010	0.001
	500 km	3.16	0.00011	Missing data	0.011	0.010	0.0010	0.001
	1200 km	3.16	0.00011	Missing data	0.011	0.009	0.0010	0.001
Avro RJ 85	200 km	3.16	0.00016	Missing data	0.008	0.013	0.0014	0.001
	500 km	3.16	0.00016	Missing data	0.008	0.013	0.0014	0.001
	1200 km	3.16	0.00015	Missing data	0.008	0.012	0.0013	0.001
B707	1000 km	3.16	0.00340	Missing data	0.006	0.045	0.0306	0.001
	4500 km	3.16	0.00314	Missing data	0.007	0.041	0.0283	0.001
	8000 km	3.16	0.00277	Missing data	0.007	0.036	0.0249	0.001
B727-200	340 km	3.16	0.00015	Missing data	0.013	0.005	0.0013	0.001
	1200 km	3.16	0.00015	Missing data	0.013	0.005	0.0013	0.001
	2600 km	3.16	0.00014	Missing data	0.014	0.005	0.0012	0.001
B737-200	340 km	3.16	0.00038	Missing data	0.008	0.014	0.0034	0.001
	1200 km	3.16	0.00037	Missing data	0.008	0.014	0.0034	0.001
	2600 km	3.16	0.00036	Missing data	0.009	0.013	0.0033	0.001
B737-400	340 km	3.16	0.00005	Missing data	0.010	0.010	0.0005	0.001
	1200 km	3.16	0.00005	Missing data	0.010	0.010	0.0005	0.001
	2600 km	3.16	0.00005	Missing data	0.011	0.010	0.0005	0.001
B747-200B	1000 km	3.16	0.00006	Missing data	0.018	0.004	0.0005	0.001
	4500 km	3.16	0.00005	Missing data	0.019	0.004	0.0005	0.001
	9000 km	3.16	0.00005	Missing data	0.022	0.003	0.0004	0.001
B747-400	1000 km	3.16	0.00028	Missing data	0.016	0.013	0.0025	0.001
	4500 km	3.16	0.00026	Missing data	0.017	0.012	0.0024	0.001
	9000 km	3.16	0.00024	Missing data	0.019	0.011	0.0021	0.001
B757-200	340 km	3.16	0.00003	Missing data	0.019	0.006	0.0003	0.001
	1200 km	3.16	0.00003	Missing data	0.019	0.006	0.0003	0.001
	2600 km	3.16	0.00003	Missing data	0.020	0.005	0.0003	0.001
B767-300ER	340 km	3.16	0.00006	Missing data	0.017	0.007	0.0005	0.001
	1200 km	3.16	0.00006	Missing data	0.017	0.007	0.0005	0.001
	2600 km	3.16	0.00006	Missing data	0.017	0.007	0.0005	0.001
Caravelle*	Missing data							
DC8	Missing data							
DC-9-41	200 km	3.16	0.00039	Missing data	0.008	0.015	0.0035	0.001
	500 km	3.16	0.00038	Missing data	0.008	0.015	0.0035	0.001
	1200 km	3.16	0.00038	Missing data	0.009	0.015	0.0034	0.001
DC 10-30	340 km	3.16	0.00058	Missing data	0.016	0.016	0.0052	0.001
	1200 km	3.16	0.00057	Missing data	0.017	0.016	0.0051	0.001
	2600 km	3.16	0.00055	Missing data	0.017	0.016	0.0050	0.001
F-28	200 km	3.16	0.00007	Missing data	0.009	0.010	0.0007	0.001
	500 km	3.16	0.00007	Missing data	0.009	0.010	0.0007	0.001
	1200 km	3.16	0.00007	Missing data	0.010	0.010	0.0006	0.001
F-100	200 km	3.16	0.00014	Missing data	0.008	0.013	0.0013	0.001
	500 km	3.16	0.00014	Missing data	0.008	0.013	0.0013	0.001
	1200 km	3.16	0.00014	Missing data	0.009	0.013	0.0012	0.001
L-1011-200	1000 km	3.16	0.00222	Missing data	0.013	0.035	0.0200	0.001
	3000 km	3.16	0.00213	Missing data	0.014	0.033	0.0192	0.001
	6000 km	3.16	0.00196	Missing data	0.015	0.031	0.0177	0.001
Saab 340B	340 km	3.16	0.00029	Missing data	0.007	0.000	0.0026	0.001
	800 km	3.16	0.00029	Missing data	0.007	0.000	0.0026	0.001
	1200 km	3.16	0.00029	Missing data	0.007	0.000	0.0026	0.001
TU154	400 km	3.16	0.00052	Missing data	0.007	0.034	0.0047	0.001
	1200 km	3.16	0.00051	Missing data	0.007	0.033	0.0046	0.001
	2600 km	3.16	0.00047	Missing data	0.007	0.031	0.0043	0.001
Concorde	Missing data							
GAjet	Missing data							

Table V. Time and fuel consumption, throttle setting and EFs for ICAO and HARP models for the four LTO Times in Mode (TIM) and a number of common motor types.

		ICAO						HARP					
Motor type	TIM	Time (min)	Throttle setting (%)	Fuel [kg/s]	Nox (g/kg)	HC (g/kg)	CO (g/kg)	Time (min)	Throttle setting (%)	Fuel (kg/s)	Nox (g/kg)	HC (g/kg)	CO (g/kg)
CF6-80C2A3	Taxing	26	7	0.2	4.0	9.2	42.2	10.0	5	0.1	4.0	9.2	42.2
	Approach	4	30	0.6	10.0	0.2	2.2	5.1	30	0.4	10.0	0.2	2.2
	Climbout	2.2	85	2.0	25.5	0.1	0.6	0.9	85	1.7	25.5	0.1	0.6
	Takeoff	0.7	100	2.5	34.4	0.1	0.6	0.3	100	2.5	34.4	0.1	0.6
CFM56-5A1	Taxing	26	7	0.1	4.0	1.4	17.6	10.0	5	0.1	4.0	1.4	17.6
	Approach	4	30	0.3	8.0	0.4	2.5	5.1	30	0.2	8.0	0.4	2.5
	Climbout	2.2	85	0.9	19.6	0.2	0.9	1.5	85	0.6	19.6	0.2	0.9
	Takeoff	0.7	100	1.1	24.6	0.2	0.9	0.4	100	1.1	24.6	0.2	0.9
PW JT3D	Taxing	26	7	0.1	2.2	123.0	139.0	10.0	5	0.1	2.2	123.0	139.0
	Approach	4	30	0.4	5.3	2.1	19.5	5.1	30	0.3	5.3	2.1	19.5
	Climbout	2.2	85	1.0	9.6	0.4	1.9	1.5	85	0.9	9.6	0.4	1.9
	Takeoff	0.7	100	1.3	12.7	0.5	0.9	0.5	100	1.3	12.7	0.5	0.9
PW JT8D-15	Taxing	26	7	0.1	3.0	11.0	35.2	10.0	5	0.1	3.0	11.0	35.2
	Approach	4	30	0.3	5.9	1.7	9.6	5.2	30	0.3	5.9	1.7	9.6
	Climbout	2.2	85	0.9	15.0	0.3	1.0	1.1	85	0.8	15.0	0.3	1.0
	Takeoff	0.7	100	1.2	19.1	0.3	0.7	0.4	100	1.2	19.1	0.3	0.7
PW JT9D-7R4G2	Taxing	26	7	0.2	3.8	1.6	11.8	10.0	5	0.2	3.8	1.6	11.8
	Approach	4	30	0.7	8.8	0.2	1.4	4.7	30	0.4	8.8	0.2	1.4
	Climbout	2.2	85	1.9	29.5	0.1	0.6	1.4	85	1.7	29.5	0.1	0.6
	Takeoff	0.7	100	2.4	41.3	0.2	0.7	0.5	100	2.4	41.3	0.2	0.7
PW4060	Taxing	26	7	0.2	4.9	1.7	20.3	10.0	5	0.2	4.9	1.7	20.3
	Approach	4	30	0.7	12.0	0.1	1.8	4.8	30	0.3	12.0	0.1	1.8
	Climbout	2.2	85	2.1	24.7	0.0	0.5	0.8	85	1.9	24.7	0.0	0.5
	Takeoff	0.7	100	2.6	32.8	0.1	0.4	0.3	100	2.6	32.8	0.1	0.4
PW JT8D-11	Taxing	26	7	0.1	2.8	10.0	35.0	10.0	5	0.1	2.8	10.0	35.0
	Approach	4	30	0.3	5.8	1.4	9.4	5.4	30	0.3	5.8	1.4	9.4
	Climbout	2.2	85	0.9	14.6	0.5	1.9	1.3	85	0.8	14.6	0.5	1.9
	Takeoff	0.7	100	1.1	18.9	0.4	1.2	0.4	100	1.1	18.9	0.4	1.2
SPEY Mk555	Taxing	26	7	0.1	3.7	1.9	29.3	10.0	5	0.1	3.7	1.9	29.3
	Approach	4	30	0.2	6.8	0.3	3.7	5.5	30	0.2	6.8	0.3	3.7
	Climbout	2.2	85	0.6	16.5	0.2	0.7	1.2	85	0.5	16.5	0.2	0.7
	Takeoff	0.7	100	0.7	21.9	0.3	0.3	0.3	100	0.7	21.9	0.3	0.3
RB211-22B	Taxing	26	7	0.2	2.9	67.8	89.0	10.0	5	0.2	2.9	67.8	89.0
	Approach	4	30	0.6	8.2	6.0	20.7	4.8	30	0.6	8.2	6.0	20.7
	Climbout	2.2	85	1.5	26.9	0.3	1.7	1.3	85	1.2	26.9	0.3	1.7
	Takeoff	0.7	100	1.9	37.3	0.2	0.8	0.4	100	1.9	37.3	0.2	0.8
D-30KU-154	Taxing	26	7	0.2	2.9	12.7	77.7	10.0	5	0.2	2.9	12.7	77.7
	Approach	4	30	0.4	5.1	1.9	18.2	5.1	30	0.3	5.1	1.9	18.2
	Climbout	2.2	85	1.1	11.6	0.5	3.6	2.4	85	0.6	11.6	0.5	3.6
	Takeoff	0.7	100	1.4	14.5	0.4	3.0	0.4	100	1.4	14.5	0.4	3.0