Emissions Estimation Technique Manual

for

Aggregated Emissions from Aircraft

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Disclaimer

The Manual was prepared in conjunction with Australian States and Territories according to the National Environment Protection (National Pollutant Inventory) Measure.

While reasonable efforts have been made to ensure the contents of this Manual are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this Manual.

Erratum for Aircraft AED Manual (Version 2.2 – 25 March 2003). Previous version (2.1) issued 14 May 2001

Page	Outline of alteration
Table 3 page 13	The general aviation: piston CO and NO_x factors were incorrect. The CO factors were in the NO_x column and vice versa
Table 9 Page 24	Corrected error in relation to ICAO page number and ensured the 'Fraction LTO' adds up to 1.0 by adjusting the largest factor for both aircraft companies.

Erratum for Aircraft AED Manual (Version 2.1 – 14 May 2001). Previous version (2.0) issued 19 Dec 2000

Removed various editorial comments and marked text

Page	Outline of alteration
11	Corrected Equation 5 so that it is now $E_{VOC}=E_{HC}$ x 1.0927 rather than $E_{VOC}=E_{HC}$ / 1.0927 as in previous version. Manual author checked original reference.

EMISSIONS ESTIMATION TECHNIQUE MANUAL:
AGGREGATED EMISSIONS FROM AIRCRAFT

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EMISSIONS ESTIMATION TECHNIQUE MANUAL: AGGREGATED EMISSIONS FROM AIRCRAFT

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1.0 Introduction

1.1 The NPI

The National Pollutant Inventory (NPI) was established under a National Environment Protection Measure (NEPM) made by the National Environment Protection Council (NEPC) under Commonwealth, State and Territory legislation on 27 February 1998. This Measure is to be implemented progressively through the laws and administrative arrangements of each of these participating jurisdictions (i.e. State and Territory Governments).

The NEPM and an associated Memorandum of Understanding for the NPI, which have been published as a single document by the NEPC, provide more details on the purpose and structure of the NPI, and the arrangements for implementation of the NEPM that have been agreed by the jurisdictions. Users of this Manual should read this publication if they are unfamiliar with the NEPM or the NPI.

1.2 Purpose and Scope of the Manual

The NPI will be developed as an internet database designed to provide information on the types and amounts of certain substances being emitted to air, land and water environments. If the NPI is to achieve its aim of communicating useful and reliable information to the community, industry and governments on pollutants present in our environment, the emissions estimation techniques (EETs) used to generate inputs to the NPI need to be consistent, and the process for developing these techniques needs to be transparent. This Manual has been developed, reviewed and finalised in this context.

The NEPM contains a list of substances for which emissions will be reported on an annual basis to the Commonwealth Government, which will then compile and publish the NPI. The aggregated emissions manuals, of which this is one, have been prepared to assist State and Territory Governments in preparing these submissions, and to facilitate consistent reporting between these jurisdictions.

State and Territory Governments will also be compiling and submitting emissions data based on annual inputs from reporting facilities. These facilities are primarily industrial enterprises which use (or handle, manufacture or process) more than specified amounts of certain polluting substances, burn more than specified amounts of fuel, or consume more than certain amounts of energy. These amounts or "thresholds" (which are clearly defined in the NEPM) govern whether an industrial facility is required to report and what substances it is required to report on, and industry handbooks are being developed to help industries to prepare the information for these reports.

The aggregated emissions manuals complement these handbooks, and are intended to enable Governments to estimate emissions from non-industrial activities (e.g. transportation, domestic and commercial activities) and emissions from industry which are not reported because the relevant thresholds are not exceeded.

Annual submissions are also to be prepared and submitted in conformance with the NPI Data Model and Data Transfer Protocol. For emissions to the air environment, this Protocol only requires jurisdictions to submit data on emissions into the particular airsheds that are listed in the Protocol, and not to the rest of each jurisdictional area. For example, in Victoria, emissions data are only required for the Port Phillip and Latrobe Valley Regions. In addition, emissions data are required to be submitted on a gridded basis, with each jurisdiction determining a grid domain and grid cell size appropriate to its needs and responsibilities (e.g. for air quality modelling purposes).

Therefore, in addition to recommending and providing details and examples of appropriate emissions estimation techniques (EETs) for the relevant NPI substances, this Manual provides guidance on the spatial allocation of emissions and the use of area-based surrogates for accurately distributing the activities or sources in question.

1.3 Application of the Manual

Each of the aggregated emissions manuals provides details of:

- the NPI substances that are expected to be emitted from the relevant aggregated source type;
- the origins or sources of the emissions, and the processes that may generate them;
- the impacts of any control equipment or procedures on those emissions;
- the broad approaches that may be employed in the estimation and spatial allocation of emissions;
- details of emission factors to be used in the estimation of emissions; and
- a series of illustrative sample calculations for each estimation technique.

Each of the manuals also contains a section on “Uncertainty Analysis”, which provides information and guidance to users on the reliability of the various estimation techniques, problems and issues associated with their development and application, and recommendations for their improvement. In preparing the aggregated emissions manuals it has been recognised that some jurisdictions already undertake detailed emissions inventories on a regular basis, based on relatively sophisticated methodologies. For these jurisdictions the manuals offer techniques which represent commonly available best practice for emissions estimation in Australia (i.e. techniques of high quality which can be employed by larger or more experienced jurisdictions with an acceptable expenditure of time and effort). The most recent developments in inventory methodology in Australia and overseas have been considered in selecting and documenting these techniques.

Where a more simplified methodology for emissions estimation of acceptable quality is available, it is recommended in the manual for the use of those jurisdictions which may, for the time being at least, lack the data, resources or expertise to employ a more sophisticated approach, or not see the need for highly reliable estimates in that particular part of the inventory.

2.0 Emissions Covered by the Manual

2.1 NPI Substances

Table 1 below lists the NPI substances that are typical emission from aircraft gas turbines (jet engines) and reciprocating engines (piston engines). The emission estimation techniques are described in this manual.

Table 1: NPI Substances Emitted from Aircraft

Acetaldehyde	Lead and compounds
Acetone	Nickel and compounds
Arsenic and compounds	Oxides of nitrogen
Benzene	Particulate matter ≤ 10 µm (PM10)
1,3-Butadiene	Phenol
Cadmium and compounds	Styrene
Carbon monoxide	Sulphur dioxide
Chromium (III) compounds	Toluene
Chromium (VI) compounds	Total volatile organic compounds (VOCs)
Ethylbenzene	Xylenes
Formaldehyde	

Notes:
1. Paragraph 2 (e) of Schedule A to the NEPM requires that, for the purposes of emissions estimation, a substance listed in Tables 1 and 2 of that Schedule as " (a metal) and a compound" refers only to the amount of metal that may be emitted. The EETs described in this manual have been prepared accordingly. Thus, the emission factors for metals and their compounds relate only to the amount of the metal itself that may be emitted as a part of these compounds.

2.2 Emission Sources and Related Processes

Aircraft engines are of two major types: gas turbine (jet) and reciprocating piston (internal combustion).

The gas turbine engine usually consists of a compressor, a combustion chamber and a turbine. Air entering the front of the engine is compressed and then heated by burning fuel in the combustion chamber. The major portion of the energy in the heated air stream is used for aircraft propulsion. The major portion of energy in the heated airstream as it expands through the high temperature turbine stages is used to drive both the front fan and compressor stages. Turbofan or turboprop engines use energy from the turbine for propulsion, and turbojet engines use only the expanding exhaust stream for propulsion.

In the piston engine, the basic component is the combustion chamber or cylinder in which mixtures of fuel and air are compressed by a reciprocating and burned, the energy from which is extracted mechanically by a piston and crank mechanism which drives a propeller.

Auxillary Power Units (APU) are used to supply power to the electrical components of the aircraft on the ground only while the aircraft are on the ground.

Although there are evaporative emissions from aircraft, no emission factors are available and hence techniques for estimating these emissions are not included in this manual.

Ground and maintenance operations emissions at airport facilities can be estimated from the industry handbook on airport operations.

Time in Mode (TIM)

A landing/takeoff (LTO) cycle incorporates all of the normal flight and ground operation modes including: descent/approach from a reference height above ground level (AGL), touchdown, landing run, taxi in, idle and shutdown, startup and idle, checkout, taxi out, takeoff and climbout to the reference height. TIM provides estimates of the time each aircraft spends in each operational mode at a given airport.

It should be noted that one LTO cycle consists of a landing and takeoff (i.e. the sum of all landing movements and takeoff movements, which is then divided by two).

All flight and ground operations in the LTO cycle have been grouped into the four standard modes for which emission rate data are readily available. These modes are:

- the *approach* mode, for which emissions are estimated from 1000 m AGL to ground level;

- the *taxi/idle* mode, which applies to both incoming and outgoing aircraft during taxiing and idling operations.

- the *takeoff* mode, which is defined as the period between commencement of acceleration on the tarmac and the aircraft reaching 200 m AGL, during which time the engine is operated at full throttle and fuel usage is at a maximum for any given engine; and

- the *climbout* mode, for which emissions are calculated for the period between 200 and 1000 m AGL.

Flight Types

The following descriptions of flight types were sourced from Avstats (1999).

International flights are based on airline movements between an Australian airport and an airport in another country.

Domestic aviation includes airline movements between two major airports within Australia. Domestic airlines provide scheduled Regular Public Transport services within Australia, and primarily operate high-capacity jet equipment between the principal cities (Adelaide, Brisbane, Cairns, Canberra, Coolangatta, Darwin, Hobart, Melbourne, Perth and Sydney). High capacity aircraft are currently defined as aircraft with more than 38 seats or with a payload of more than 4,200 kilograms.

Regional airlines provide scheduled Regular Public Transport services within Australia, generally linking smaller rural centres with principal cities. The strict definition is that their fleets contain exclusively low capacity aircraft, currently defined as aircraft with 38 seats or less or with a payload of 4,200 kilograms or less. However, a number of airlines which operate aircraft with 60 to 70 seats are still regarded as regional airlines.

The *general aviation* (GA) sector includes all non-scheduled flying activities in Australian-registered aircraft, other than those performed by the major domestic and international airlines. The major categories of this type of flying are private, business, training, aerial agriculture, charter and aerial work. In addition, the sport aviation segment of GA includes operations in ultralight aircraft, gliders, hang gliders and autogyros.

2.3 Emission Controls

The International Civil Aviation Organisation (ICAO) has standards to regulate hydrocarbons.

3.0 Emissions Estimation Techniques

3.1 Approaches Employed

The EETs in this manual allow aircraft emissions to be estimated by a best practice methodology and a default methodology, the former being more time consuming. Emissions estimation for military airports requires the best practice methodology to be used, as no default emission factors are available.

Best Practice Technique

Data that are required for estimating aircraft emissions in an airshed are as follows:

- the location of airports, runways, landing and approach flight paths, and associated ground movements, in the airshed;
- the number of landing/takeoff (LTO) cycles for each of the aircraft types operating at these airports;
- the prevalence of the different types of engines (and numbers of engines) and APUs used by each aircraft type;
- the time spent in each operating mode (approach, taxi/idle, takeoff and climbout) for the airport for estimating aircraft engine emissions;and
- the time spent operating the APU at the airport.

Airservices Australia can provide information on the locations, runways, flight paths and other details for the airports within an airshed for most of the airsheds except Darwin, Hobart and Canberra airsheds. Alternative sources of information such as the local airport environmental officer may have such information for Darwin, Hobart and Canberra airports.

The airports themselves may be willing to provide LTO data for the airlines by aircraft type. Alternatively, Airservices Australia can provide this data (a fee may be charged, particularly if consultants are receiving the information). The LTO data will include both passenger transport and cargo aircraft movements.

If the cost of acquiring a full year's worth of LTO data from Airservices Australia is prohibitive (e.g. for a smaller regional airport), an alternative is to purchase one month of data for that airport. These data can be analysed to estimate the proportions of LTO by airline and aircraft type for a single month. Avstats (1997) compiles annual LTO data, which can be obtained for the relevant inventory year. The Avstats annual LTO data can then be split into LTO by airline and aircraft type using the single month of data from Airservices Australia.

LTO for general aviation (non-airline aircraft) will be available from the individual airports. However, the airports will usually not be able to supply the

LTO by aircraft type. The airports may be able to supply the LTO data by broad aircraft descriptions (e.g. piston single/twin engine, or business jet).

The engine type and number of engines for each aircraft type and the number of arrivals and departures for an airline can be obtained from the airlines (including annual reports and web sites). Appendix A contains information on aircraft and engine type combinations for some Australian airlines. If emission factors for a particular engine type are not available, factors for another (similar) engine type will need to be used. Assumptions about the engine types for GA aircraft have to be made, since only broad aircraft descriptions are likely to obtained.

Time in mode (TIM) estimates can be obtained from individual airports. If these figures cannot be obtained, the default values in Table 2 can be used.

To calculate the annual emissions from aircraft engines at an airport for each of the four types of operating mode (see Section 2.2) aircraft movement and emission factor data is required. Aircraft movement data includes the number and distribution of aircraft operations (LTOs) by aircraft/engine type, and time spent in each mode by aircraft type, must be known or estimated for that airport.

Emission factor data for Jet Engines should be obtained from the ICAO data base in Appendix D as first preference, where two data sets are in the ICAO data base it is due to different combustor units fitted to the engine. If information about the combustor unit is not available the higher emission factor should be used. For other engines there maybe data available in the US Federal Aviation Authority (FAA) provided in Appendix E. For data not provided by these data sets use the default emission factors in Table 3.

Equation 1 is for calculating emissions by flight mode. This Equation combines the following calculation steps:

- estimating the emissions from each *engine type* in a particular mode by multiplying time-based emission factors (for CO, HC, NO_x, SO_2 and TSP) for that engine and mode, by the time spent in that mode for each LTO;

- calculating the emissions from each *aircraft type* in that mode by combining the above emissions estimates for each engine type with the number of engines used in that aircraft type and data on the LTOs for that aircraft/engine type combination; and

- summing the above emissions from each aircraft type in that mode to estimate *total aircraft emissions* in that mode.

Equation 1: Estimating modal emissions for the aircraft/engine types used at an airport

$$E_m = \sum_a \sum_e n_a * l_{a,e} * r_{e,m} * t_{m,a} / 60$$

where E_m	=	Annual emissions at an airport for mode m (i.e. approach, taxi/idle, takeoff or climbout), kg yr^{-1}
n_a	=	Number of engines of aircraft type a
$l_{a,e}$	=	Number of annual LTO cycles at an airport for aircraft type a with engine type e
$r_{e,m}$	=	Emission factor for engine type e and mode m, kg hr^{-1}
$t_{m,a}$	=	Time in mode m for aircraft type a, minutes

Subsequent steps in the best practice EET include:

- speciating the above estimates of total HC and TSP emissions in each mode into the *remaining NPI substances* (see Equations 2, 3 and 4 and Tables 4 and 5);
- spatially allocating the total emissions of *each NPI substance in each mode to grid cells* (Equation 6), and then summing the total emissions in each grid cell for each mode to calculate *total emissions in each cell*.

Table 2: Default Time in Mode Estimates (in Minutes) for Aircraft

Aircraft Type	Taxi / Idle	Takeoff	Climbout	Approach
Commercial Carrier				
Jumbo, long and medium range jet[1]	18	0.85	1.3	4.3
Turboprop[2]	26	0.5	2.5	4.5
Piston[2]	13	0.6	5	4.6
General Aviation[1]				
Business jet	13	0.4	0.5	1.6
Turboprop	26	0.5	2.5	4.5
Piston	16	0.3	5	6
Helicopter	35	1.4[c]	6.5	6.5
Military Aircraft[4]	15.9	0.4	1.2	5.1

Notes:
1. Melbourne Airport (1995), pers. comm.
2. Reference 7 (USEPA data (1985)) on typical duration for civil aircraft at large congested metropolitan airports.
3. Reference 4 (EPAV (1996)).
4. Reference 7 (USEPA data (1985)) on military aircraft (USAF general transport).

The relevant emission factors for this EET can be obtained in ICAO (1995). However, for most engine types, emission factors for TSP are not available. Emission factors from similar engine types may be used in these cases.

Alternatively, the default TSP emission factors (see Default Methodology section below) can be used for an aircraft (e.g. if the aircraft is used for international flights, the default international emission factor may be used).

To calculate annual emissions at an airport from APUs, data on the type of APU and the operational time is required. Equation 2 provides a formula for calculating emissions from APUs. not all engine types have all modes (load, maximum load, no load) listed in Appendix C and therefore the user is limited to the emission factor modes available for that given APU type.

Equation 2: Estimating emissions from APUs used at an airport

$$E_m = \sum_a \sum_e f_{e,m} * l_{a,e} * r_{e,m} * t_{m,a} / 60 / 1000$$

where

E_m = Annual emissions at an airport for mode m (i.e. load, no load, maximum load), kg yr^{-1}
$l_{a,e}$ = Number of annual cycles at an airport for aircraft type a with APU engine type e
$r_{e,m}$ = Emission factor for APU engine type e and mode m, kg hr^{-1}
$t_{m,a}$ = Time in mode m for aircraft type a, minutes
$f_{e,m}$ Fuel flow for an APU engine type e and mode m, kg hr^{-1}

Emissions of a number of organic compounds which are NPI substances may be estimated by speciating estimates of total VOC emissions (Equation 3), and emissions of PM10, metals and PAHs may be estimated by speciating TSP estimates (Equation 4). However, the estimates for hydrocarbons (HC) must first be converted to total VOCs using Equation 5 (USEPA 1992a).

Equation 3: Estimating emissions of a VOC species

Emissions of a VOC species can be calculated by multiplying total VOC emissions by the speciated weight fraction for that species

$$E_j = E_{voc} * w_i$$

where

E_j = Emissions of VOC species i, kg yr^{-1}
E_{voc} = VOC emissions, kg yr^{-1}
w_i = Weight fraction of VOC species i

Equation 4: Estimating emissions of a particulate species

Emissions of a particulate species can be calculated by multiplying TSP emissions by the speciated weight fraction for that species

$$E_j = E_{TSP} * w_i$$

where

E_j = Emissions of TSP species i, kg yr^{-1}
E_{TSP} = TSP emissions, kg yr^{-1}
w_i = Weight fraction of TSP species i

Equation 5: Converting hydrocarbon emissions to total VOCs

$$E_{VOC} = E_{HC} \times 1.0927$$

where

E_{VOC} = Emissions of total volatile organic compounds
E_{HC} = Emission of hydrocarbons

<u>Default Methodology</u>

The default EET may be used for estimating emissions from commercial aviation. This methodology can also be used for the general aviation sector, provided the aircraft types are piston-engined. The best practice methodology has to be used for military aircraft, and for general aviation aircraft which are not piston-engined.

The EET makes use of data from reports compiled by Avstats on the aviation sector, and the following data are required:

- annual aircraft movement data for a given airport, split into international, domestic and regional flights.

Avstats (1997) reports yearly LTO data, and all airports which have scheduled regular public transport (109 airports in 1996) traffic produce aircraft movement data. Annual movements for general aviation have to be obtained from individual airports.

The default EET provides emission factors for four aircraft fleet categories: international, domestic, regional and general aviation. Aircraft/engine types and TIM assumptions have been made to produce the emission factors used in this EET (in kilograms of pollutant per LTO cycle).

No default emission factors have been prepared for military aircraft, so the best practice methodology must be used. Royal Australian Air Force (RAAF) aircraft operate out of military airports, which must be contacted directly for the required data. There are 16 Royal Australian Air Force bases with airports in Australia, but five of these are located in remote areas.

To calculate emissions from an aircraft fleet type, the number of LTOs are multiplied by the emission factors for that fleet type (Equation 6). The default emission factors for this are presented in Table 3.

Equation 6: Estimating modal emissions from aircraft at an airport using default emission factors

$$E_m = \sum_o l_o * e_{m,o}$$

Where E_m = Annual emissions for mode m, kg yr^{-1}
l_o = Number of annual LTO cycles for aircraft fleet o (i.e. international, domestic or regional fleet)
$e_{m,o}$ = Emission factor for mode m and aircraft fleet o, kg hr^{-1}

The default EET requires the same steps as the best practice methodology for speciation and spatial allocation (see Equations 2, 3, 4 and 5).

There is no default EET for calculation of emissions from APUs. It is recommended that obtaining site specific data operational times for APUs be obtained.

3.2 Spatial Surrogates and Spatial Allocation

The estimates of total emissions for the various modes of operation must be spatially allocated to those grid cells within which the flight paths and associated ground movements at an airport occur. These paths must first be divided into approach, taxi/idle, takeoff and climbout modes. Then the total emissions for each mode need to be distributed between grid cells according to the proportions of each mode which occur in particular cells.

For example, the total emissions of aircraft in the approach mode may occur along a flight path which is in several grid cells. These emissions should be distributed to these grid cells according to the proportions (fractions by length) of the approach flight path in each cell. Even the taxiing/idling mode may occur in more than one cell. Some professional judgement may be required to spatially split paths into the four modes (e.g. to define the boundary between takeoff and climbout) and to divide the paths for each mode between cells (e.g. by taking into account the angles of approach and climbout at particular airports).

Equation 6 can be used to allocate emissions from each mode type to a grid cell. Of course, total aircraft emissions within an individual grid cell may include emissions from aircraft in one mode only (e.g. along the approach path) or a number modes (e.g. in the cell containing the airport itself).

Emissions from APU should be assigned to the grid cell which airport falls within.

Equation 6: Estimating modal emissions in a grid cell

Emissions in a grid cell can be estimated as follows

$$E_i = E_m \times L_i / \sum_i L_{i,}$$

where

E_i = Annual emissions for mode m in grid cell i, kg yr^{-1}
E_m = Total annual emissions for mode m, kg yr^{-1}
L_i = Length of flight path for mode m in grid cell i

3.3 Emissions and Speciation Factors

The emission and speciation factors to be used with the EETs in this manual are presented below.

Although TSP is not an NPI substance, it is required for estimating emissions of PM_{10} and a number of metals that are NPI substances.

The assumptions used to compile the default emission factors in Table 3 are presented in Appendix B.

Table 3: Aircraft Default Emission Factors Per LTO by Mode

	Emission Factor (kg LTO^{-1})				
	CO	**HC**	**NO_x**	**SO_2**	**TSP**
International					
Approach	0.989	0.210	5.40	0.552	0.194
Taxi / Idle	16.9	3.16	3.43	0.790	0.769
Takeoff	0.238	0.106	18.8	0.398	0.0651
Climbout	0.260	0.101	16.7	0.490	0.104
Domestic					
Approach	0.626	0.0387	1.27	0.157	0.0953
Taxi / Idle	7.66	0.891	0.973	0.250	0.116
Takeoff	0.0835	0.0134	2.14	0.106	0.0428
Climbout	0.107	0.0187	2.24	0.134	0.0465
Regional					
Approach	0.961	0.135	0.369	0.00227	0.0716
Taxi / Idle	6.36	3.80	0.317	0.00596	0.211
Takeoff	0.0790	0.0104	0.487	0.00049	0.0335
Climbout	0.254	0.0149	0.570	0.00218	0.0585
General Aviation: Piston					
Approach	2.89	0.0431	0.00391	0.00049	0.330
Taxi / Idle	1.29	0.0767	0.00107	0.00026	0.880
Takeoff	0.261	0.00269	0.00056	4.83E-05	0.0165
Climbout	2.97	0.0352	0.0123	0.00060	0.275

The VOC speciation data presented in Table 4 is from the US-EPA Speciate 3.1 program (reference 9) which is the most comprehensive VOC speciation data available. The data includes a range of NPI substances, not all of which are determined from other speciation work. As further data becomes available this data can be used to replace the data in Table 4. Regular checks will be made with the Australian Air Transport industry to check that these speciation factors have not been superseded by data produced by ICAO of other agencies. New data will be incorporated in the manual when it is available.

Table 4: VOC Speciation for Exhaust Emissions from Aircraft[1]

NPI Substance	**Weight Fraction[a]**		
	Commercial	**General**	**Military**
Profile[2]	**1098**	**1099**	**1097**
Acetaldehyde	0.0465	0.0432	0.0483
Acetone	0.0245	0.0293	0.0241
Benzene	0.0194	0.0179	0.0202
1,3-Butadiene	0.018	0.0157	0.0189
Ethylbenzene	0.0017	0.0015	0.0018
Formaldehyde	0.1501	0.1414	0.1548
Polycyclic aromatic compounds[3]	0.0106	0.0095	0.0112
Phenol	0.0024	0.0022	0.0026
Styrene	0.0039	0.0037	0.0041
Toluene	0.0052	0.0049	0.0055
Xylenes[4]	0.0048	0.0044	0.0050

Notes:
1. From Reference 9 (USEPA 2000) – Speciate 3.1 database
2. Profile number from the Speciate 3.1 database
3. Sum of Napthelene and Methyl Napthelenes from Speciate 3.1 database
4. Sum of M & P Xylenes and O-Xylenes from Speciate 3.1 database

The particulate matter (TSP) speciation data presented in Table 5 is from the US CARB CEIDARS database (reference 3) which is the most comprehensive particulate matter speciation data available. Little work has been completed on the speciation of particulate matter from aircraft and the data presented here represents the most current data available. As further data becomes available this data can be used to replace the data in Table 5. Regular checks will be made with the Australian Air Transport industry to check that these speciation factors have not been superseded by data produced by ICAO of other agencies. New data will be incorporated in the manual when it is available.

Table 5: Particulate (TSP) Speciation of Exhaust Emissions from Aircraft

NPI Substance	Weight Fraction[a]	
	Piston	Jet
Arsenic and compounds	ND	0.0053
Cadmium and compounds	ND	0.0005
Chlorine	0.07	ND
Chromium (III) compounds[2]	0.00035	0.0037[b]
Chromium (VI) compounds[2]	0.00015	0.0016[b]
Cobalt and compounds	0.0005	ND
Copper and compounds	0.0005	ND
Lead and compounds	ND	0.0055
Manganese and compounds	0.0005	ND
Nickel and compounds	0.0005	0.0005
Zinc and compounds	0.0005	0.0055
Particulate matter ≤ 10 µm	0.90	0.976

Notes:
1. Reference 3 (CARB 1991) – California Emission Inventory Reporting System (CEIDARS) database.
2. Cr(III) and Cr(VI) emission factors are calculated from the CARB emission factor for total chromium assuming that the Cr(VI) contribution is 30%.
3. ND – No Data.

3.4 Sample Calculations

Example 1: Estimating carbon monoxide emissions from a single aircraft/engine type in the approach mode (best practice methodology)

Emissions of carbon monoxide from a Boeing 767 with engine type CF6-80A (ICAO data page C028)(two engines) and 4,000 annual LTO movements, and a time in approach mode of 4 minutes, can be estimated from Equation 1, using the ICAO CO emission factor for the engine type from Appendix D.

$$E_m = n_a * l_{a,e} * r_{e,m} * t_{m,a}/60$$
$$= 2 * 4000 * 6.86 * 4 / 60$$
$$= 3.66 * 10^3 \text{ kg yr}^{-1}$$

Example 2: Estimating oxides of nitrogen emissions from the domestic aviation sector at Perth Airport in climbout mode (using the default methodology)

Assuming an annual LTO at Perth airport of 16,000, and using Equation 5 with the appropriate default NO_x emission factor from Table 3, NO_x emissions in climbout mode from domestic aircraft can be estimated as

$$E_m = \sum_o l_o * e_{m,o}$$

$$= 16000 \times 2.24$$

$$= 3.58 * 10^4 \text{ kg yr}^{-1}$$

Example 3: Estimating annual benzene emissions from climbout mode at an airport

If total HC emissions for the climbout mode have been estimated at 12000 kg yr^{-1}, the weight fraction for benzene from Table 4 can be used with Equations 2 and 4 to estimate annual benzene emissions for this mode as

$$E_j = E_{HC} * 1.0927 * w_i$$

$$= 12000 * 1.0927 * 0.0194$$

$$= 254 \text{ kg yr}^{-1}$$

Example 4: Allocating annual emissions of benzene in climbout mode to grid cells

Assuming that the length of the climbout flight path is 1.1 km, and that 0.7 km of this flight path falls in a particular grid cell, Equation 6 can be applied to estimate the emissions of benzene in that cell as

$$E_i = E_m \times L_i / \sum_i L_{i,}$$

$$= 254 * 0.7 / 1.1$$

$$= 162 \text{ kg yr}^{-1}$$

4.0 Uncertainty Analysis

In the following discussion, reliability is classified into 3 levels of confidence: high (uncertainty of 20% or less), medium (uncertainty of between 20% and 80%) and low (uncertainty of greater than 80%).

4.1 Data Reliability

Airservices Australia and Avstats keep detailed records of LTO data and the levels of reliability of these data are high.

4.2 Reliability of Emission Factors

Emission factors for carbon monoxide, hydrocarbons, oxides of nitrogen, total suspended particles and sulphur dioxide are derived from test data by the manufactures of aircraft engines. The reliability of these emission factors is considered to be medium.

The default emission factors use broad assumptions about the aircraft fleet mix and TIM estimates. The reliability of these default emissions factors is therefore considered to be low.

The emissions of other substances are derived from the application of speciation profiles to estimates of volatile organic compounds and particulates, assuming that the same profile applies to each mode of operation. The reliability of these estimates is also considered to be low.

4.3 Recommendations for Further Work

Work should be undertaken to develop speciation profiles for different engine types under different modes of operation, and to rectify the serious lack of data on particulate emissions from aircraft engines. It should be noted that additional data from engine manufactures is not likely to be forthcoming as international focus is not directed to these trace emissions (focus is on greenhouse and NOx emissions).

5.0 Glossary of Terms and Abbreviations

AGL	Above ground level
APP	Approach mode
CARB	Californian Air Resources Board
CEIDARS	California Emission Inventory Reporting System
CLBO	Climbout mode
CO	Carbon monoxide
C/O	Climb Out
EET	Emissions estimation technique
EPAV	Environment Protection Authority of Victoria
FAA	Federal Aviation Authority
GA	General aviation
HC	Hydrocarbons
ICAO	International Civil Aviation Organisation
IDLE	Idle mode for aircraft
IDTX	Idle/taxi mode
LTO	Landing/takeoff cycle
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NO_x	Oxides of nitrogen
NPI	National Pollutant Inventory
PAHs	Polycyclic aromatic hydrocarbons
PM10	Particulate matter equal to or less than 10 μm
RAAF	Royal Australian Air Force
SO_2	Sulphur dioxide
TIM	Time in mode
T/O	Takeoff mode
TSP	Total suspended particles
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compound

6.0 References

1. Avstats (1997). *Air Transport Statistics: Airport Traffic Data 1985/86-1995/96*, Commonwealth Department of Transport and Regional Development, Canberra.
2. Avstats (1999). *Avstats web site, http://www.dot.gov.au/aviation/avstats.htm,* Commonwealth Department of Transport and Regional Development, Canberra.
3. CARB (1991). *Identification of Particulate Matter Species Profiles, ARB Speciation Manual*, 2nd ed, vol 2, California Air Resources Board, California, USA.
4. EPAV (1996). *Metropolitan Air Quality Study Air Emissions Inventory*, Environment Protection Authority of New South Wales, Sydney.
5. ICAO (1995). *ICAO Engine Exhaust Emissions Data Bank*, International Civil Aviation Organisation, Montreal, Canada. The updated version of this databank is incorporated in this manual and is available at: http://www.dera.gov.uk/html/te/combustion/t&e_aircraft_engine_exhaust_emissions_data_bank.htm
6. FAA (1991). *FAA Aircraft Engine Emission Database (FAEED),* FAA Technology Division, Office of Environment and Energy, Washington, USA.
7. USEPA (1985*). Compilation of Air Pollutant Emission Factors, Vol I1, Mobile Sources,* AP-42, 5th ed, United States Environmental Protection Agency, Research Triangle Park, North Carolina, USA.
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7.0 Appendices

APPENDIX A: AIRCRAFT/ENGINE TYPE COMBINATIONS FOR SELECTED AUSTRALIAN AIRLINES

APPENDIX B: ASSUMPTIONS USED TO COMPILE DEFAULT EMISSION FACTORS

APPENDIX C: EMISSION FACTORS FOR AUXILIARY POWER UNITS

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APPENDIX E: EMISSION FACTORS FOR NON-JET ENGINES – FAA DATA

APPENDIX A
AIRCRAFT/ENGINE TYPE COMBINATIONS FOR SELECTED AUSTRALIAN AIRLINES[a]

The table below indicates the aircraft and engine specifications for various Australian airlines. This is used in conjunction with emission factor data to determine the emissions from aircraft and APUs.

Table 6 Aircraft used by Australian Airlines

Airline	Aircraft	Engine Type	Number of Engines	ICAO/FAA page number	Type of Propulsion
Ansett					
	Boeing 767	CF6-80A	2	C-028 (ICAO)	Jet
	Airbus 320-200	CFM56-5-A1	2	C-015 (ICAO)	Jet
	Boeing 737-300	CFM56-3-B1	2	C-011 (ICAO)	Jet
	BAe 146	ALF 502 R-5	4	C-146 (ICAO)	Jet
	Fokker F28	Spey Mk 555-15P	2	C-139/140 (ICAO)	Jet
	Boeing 747-300	JT9D 7R4G2	4	C-092 (ICAO)	Jet
Qantas					
	Boeing 747-438	RB211-524D4G-T	4	C-132 (ICAO)	Jet
	Boeing 747-338	RB211-524D4	4	C-129 (ICAO)	Jet
	Boeing 747-238	RB211-524D4	4	C-129 (ICAO)	Jet
	Boeing 747SP-38	RB211-524D4	4	C-129 (ICAO)	Jet
	Boeing 767-338	CF6-80C2B6	2	C-47 (ICAO)	Jet
	Boeing 767-238	JT9 D-7R4E, JT9 D-7R4E1	2	C-90 (ICAO)	Jet
	Boeing 737-476	CFM56-3C-1	2	C-14 (ICAO)	Jet
	Boeing 737-376	CFM56-3B-2	2	C-12 (ICAO)	Jet
	BAe 146 – 100/200	ALF 502R-5	4	C-146 (ICAO)	Jet
	BAe146 – 300	LF507-1F,-1H	4	C-147 (ICAO)	
	BAe Jetstream 31	TPE331	2	FAA	Turboprop
	De Havilland Dash 8	PW120A	2	FAA	Turboprop
	Shorts SD 360	PT6A-67R	2	FAA	Turboprop
Kendell					
	Fairchild Metro 23	TPE331-12	2		Turboprop
	SAAB 340	GE CT7	2	FAA	Turboprop
Skywest					
	Fokker 50	PW 125B	2		Turboprop

[a] Sourced from the internet sites of the airlines.

APPENDIX B
ASSUMPTIONS USED TO COMPILE DEFAULT EMISSION FACTORS

International Aviation

The international aviation fleet was compiled by choosing seven airlines which comprise 58% of the total international LTO for Australia (Table 7). The assumption was made that the aircraft from these airlines were representative of the total international fleet.

Aircraft/engine types for these airlines were obtained from annual reports, in-flight magazines and the internet. The international aircraft type and numbers for the carriers are listed in Table 8.

Aircraft within each carrier fleet were proportioned by the number of aircraft and multiplied by the fraction of LTO for that carrier to produce the LTO splitting factors.

The default time in mode for commercial carriers (jumbo, long and medium range jet) from Table 2 was used. The emission factors by mode were compiled using Equation 1.

Table 7: Number of LTO in 1995/96 by International Airline

Airline	Number of LTO[a]	Fraction of LTO
Air New Zealand	3,173	0.14
Ansett	1,131	0.05
Cathay Pacific	1,160	0.05
Japan Airlines	1,103	0.05
Qantas	10,783	0.49
Singapore Airlines	2,183	0.10
Trans-Tasman code share (Qantas/Air New Zealand)	2,353	0.11
Total	21,886	

[a] Data from K. Beard, Avstats (1998) pers. comm.

Table 8: LTO Splitting Factors Used for International Aviation

Airline	Aircraft	Number of Aircraft	Engine Type	ICAO page number	Fraction of LTO
Air New Zealand	747-400	2	RB211-524G	C-131/132 (ICAO)	0.02
	747-200	5	RB211-524D4	C-131/132 (ICAO)	0.06
	767-200ER	6	CF6-80A2	C-130 (ICAO)	0.07
	767-200ER	2	JT9D-7R4D	C-089 (ICAO)	0.02
	767-300ER	1	CF6-80C2	various	0.01
Cathay	747-400	21	RB211-524H	C-133 (ICAO)	0.03

Airline	Aircraft	Number of Aircraft	Engine Type	ICAO page number	Fraction of LTO
Pacific	747-300	6	RB-211-524C2	C-128 (ICAO)	0.01
	747-200	6	RB-211-524C2	C-128 (ICAO)	0.01
	747-200	5	RB211-524D4	C-129/130 (ICAO)	0.01
Ansett	747-300	2	JT9D 7R4G2	C-092 (ICAO)	0.01
	767-200	6	CF6-80A	C-028 (ICAO)	0.04
Singapore Airlines	747-400	42	PW4056	C-104/105 (ICAO)	0.08
	747-300	2	JT9D-7R4G2	C-92 (ICAO)	0.00
	B747-300	3	JT9D-7R4G2	C-62 (ICAO)	0.01
	A340-300E	8	CFM 56-5C4	ADD1/C4 (ICAO)	0.01
Qantas	747-438	18	RB211-5 24D4G	C-131/132 (ICAO)	0.19
	747-338	6	RB211-524D4U	C-131/132 (ICAO)	0.06
	747-238B	4	RB211-524D4U	C-131/132 (ICAO)	0.04
	767-338ER	18	CF6-80C2B6	C-047/017 (ICAO)	0.19
	767-238ER	7	JT9D-7R4E	C-090 (ICAO)	0.07
Japan Airlines	B747	48	JT9D-7A/7Q/7R4G2	C-084 (ICAO)	0.02
	B747-400	32	CF6-80C2B1F	C-041/042 (ICAO)	0.02
	B767	20	JT9D-2R4D and CF6-80C2B4F	C-089 (ICAO)	0.01

Domestic Aviation

The assumption was made that the total domestic aviation fleet could be characterised by the Qantas and Ansett domestic fleets.

The domestic aircraft types and numbers for both domestic carriers are listed in Table 9. The proportion of total LTO for the two airlines was obtained from Avstats (Table 10).

Aircraft within each carrier fleet were proportioned by the number of aircraft and multiplied by the fraction of LTO for that carrier to produce the LTO splitting factors.

The default time in mode for commercial carriers (jumbo, long and medium range jet) from Table 2 was used. The emission factors by mode were compiled using Equation 1.

Table 9: LTO Splitting Factors Used for Domestic Aviation

Airline	Aircraft Type	Number of Aircraft	Engine Type	ICAO page number	Fraction of LTO
Ansett	A320	12	CFM56-5-A1	C-015 (ICAO)	0.10
	737-300	21	CFM56-3-B1	C-011 (ICAO)	0.19
	727-200 LR	5	JT8D-15	C-072/073 (ICAO)	0.04
	BAe 146	12	ALF 502 R-5	C-146 (ICAO)	0.10
Qantas	737-476	22	CFM56-3C-1	C-014 (ICAO)	0.23
	737-376	16	CFM56-3B-2	C-012 (ICAO)	0.16
	A300-B4	4	CF6-50	Various	0.04
	BAe 146	14	ALF 502R-5	C-146 (ICAO)	0.14

Table 10: Number of LTO in 1995/96 by Domestic Airline

Airline	Number of LTO[a]	Fraction of LTO
Qantas	106,096	0.43
Ansett	140,639	0.57
Total	246,735	1.00

[a] Data from Ken Beard, Avstats, personal communication, 1998.

Regional Aviation

The regional aircraft fleets from the regional carriers were compiled into aircraft, engine type and number of aircraft. The regional carriers included in this analysis were Qantas (including all of the wholly-owned subsidiary airlines Airlink, Eastern Australian Airlines, Southern Australian Airlines and Sunstate Airlines), Ansett, Kendell and Skywest. The aircraft and engine types were obtained from the internet. The fraction of LTO by aircraft was obtained by weighting against the number of aircraft in the regional fleet, which implies the assumption that LTO is proportional to the number of aircraft.

Table 11: LTO Splitting Factors Used for Regional Aviation

Aircraft	Engine Type	Number of Aircraft	Fraction of LTO	Number of Engines	ICAO page number	Time in Mode[1]
Bae-146	ALF 502R-5	26	0.32	4	C-144 (ICAO)	Jumbo, long and medium range jet
De Havilland Canada Twin Otter	PT6A-27	5	0.06	2	NA	Turboprop
BA Jetstream 31	TPE331	4	0.05	2	NA	Turboprop
Shorts SD360	PT6A-67R	7	0.09	2	NA	Turboprop
Cessna C404 Titan	GTSIO-520-M	7	0.09	2	NA	Turboprop

Aircraft	Engine Type	Number of Aircraft	Fraction of LTO	Number of Engines	ICAO page number	Time in Mode[1]
F28	Mk 555-15P	8	0.10	2	Various	Jumbo, long and medium range jet
SAAB 340	GE CT7	16	0.20	2	NA	Turboprop
Fairchild Metro 23	TPE331-12	7	0.09	2	NA	Turboprop
Notes: 1. Time in mode for commercial carriers in Table 2. 2. NA – Not Applicable (The ICAO database only contains emission factors for jet engines).						

The emission factors by mode were compiled using Equation 1.

Domestic Aviation

It was assumed that general piston aviation emissions consist of 90% single engined and 10% twin engined aircraft. The other data required to estimate the default emission factors from Equation 1 are presented in Table 12.

Table 12: LTO Splitting Factors Used for General Piston Aviation

Aircraft	Engine Type	Fraction of LTO	Number of Engines	Data Source	Time in Mode[1]
Piston: single engine	O-320	0.9	1	FAA	General aviation: piston
Piston: twin engine	TSIO-360C	0.1	2	FAA	General aviation: piston
Notes 1. Time in mode for general aviation from Table 2.					

APPENDIX C

EMISSION FACTORS FOR AUXILIARY POWER UNITS

Table 13: Auxiliary Power Units and Commercial Aircraft Models[1]

Auxiliary Power Unit	Aircraft Model
Allied Signal Inc. GTP 30 Series [2]	Fairchild F-27 [3]
GTCP 30 Series [2]	Dassault-Bregue Falcon 20 Jet Commander [3]
GTCP 35-300 [2]	Airbus A-321 [4]
GTCP 36 Series [5] 59.66 kW (80 HP) 59.66 kW (80 HP)	Airbus A320 Airbus A-320-100 [6] Airbus A-320-200 [6] Airbus A-321 [6] Aerospatiale ATR-42 [3] Beechcraft Beech 18 [7] British Aerospace 111-400 [7] British Aerospace BAe 146 British Aerospace BAe 146-100 [6] British Aerospace BAe 146-200 [6] British Aerospace Jetstream 31 [7] British Aerospace Super 31 [7] Canadair CL600/CL601 [3] Cessna C-208 [7] Dessault-Bregue Falcon 50 [3] DeHavilland Dash 7 [7] DeHavilland DHC-6/300 [7] DeHavilland DHC-8 [7] DeHavilland DHC-8-100 [7] Embraer EMB-110 [6] Embraer EMB-120 [3] Embraer EMB-145 [6] Fokker F-27 Series [6] Fokker F-28 Fokker F-100 Fokker F-100-100 [6] NAMC YS-11 [3] Saab Fairchild 340 [3] Saab Fairchild 340A [6] Short Brothers SHT-360 [7] Swearingen SA227 [7]
GTC 85 [2]	Convair CV-580 [2]
GTCP 85 Series [8] 149.14 kW (200 HP)	Boeing B-707 Boeing B-707-300 [6] Boeing B-727 Boeing B-727-100 [6]

Table 13: Auxiliary Power Units and Commercial Aircraft Models[1] (cont.)

Auxiliary Power Unit	Aircraft Model
Allied Signal Inc. (cont'd)	Boeing B-727-200 [6] Boeing B-737 [9] Boeing B-737-100 [9] Boeing B-737-200 [9] Boeing B-737-300 [10] Boeing B-737-400 [10] Boeing B-737-500 [10] Lockheed L-100 [3] McDonnell Douglas DC-8 McDonnell Douglas DC-8-50F [6] McDonnell Douglas DC-8-60 [6] McDonnell Douglas DC-8-62 [6] McDonnell Douglas DC-8-63F [6] McDonnell Douglas DC-8-70 [6] McDonnell Douglas DC-8-71 [6] McDonnell Douglas DC-8-73 [6] McDonnell Douglas DC-9 McDonnell Douglas DC-9-15F [6] McDonnell Douglas DC-9-30 [6] McDonnell Douglas DC-9-40 [6] McDonnell Douglas DC-9-50 [6] McDonnell Douglas MD-80 [6]
GTCP 331 Series [11] 106.64 kW (143 HP)	Airbus A-300-600 Airbus A-310 Airbus A-310-200 [6] Airbus A-310-300 [6] Airbus A-330 [4] Airbus A-340 [4] Boeing B-757 [12] Boeing B-757-200 [12] Boeing B-767 [12] Boeing B-767-200 [12] Boeing B-767-200ER [12] Boeing B-767-300 [6, 12] Boeing B-767-300ER [6, 12] Boeing B-777 [4, 13] Boeing B-777-200 [6, 13]
GTCP 660 [14] 223.71 kW (300 HP)	Boeing B-747 Boeing B-747-100 [6] Boeing B-747-200 [6] Boeing B-747-300 [6]
TSCP 700 [15] 105.89 kW (142 HP)	Airbus A-300B [6] Airbus A-300-B2 Airbus A-300-B4 McDonnell Douglas DC-10 McDonnell Douglas DC-10-10 [6]

Table 13: Auxiliary Power Units and Commercial Aircraft Models[1] (cont.)

Auxiliary Power Unit	Aircraft Model
Allied Signal Inc. (cont'd)	McDonnell Douglas DC-10-40 [6] McDonnell Douglas MD-11 [6] McDonnell Douglas MD-11-11 [6]
Hamilton Standard	
ST-6 [16]	Lockheed L-1011 Lockheed L-1011-100 [6] Lockheed L-1011-50 [6] Lockheed L-1011-500 [6]
Pratt & Whitney	
PW 901A	Boeing B-747 Boeing B-747-400 [6] Boeing B-747-SP [6]

Notes:
1. Federal Express Aviation Services, Inc., January 1991. Federal Express Fleet Guide, unless otherwise noted.
2. No emission factor available
3. Garrett Turbine Engine Company. Reference Guide - Auxiliary Power Systems. Phoenix, AZ, USA.
4. New aircraft scheduled to enter production.
5. Emission factors for the GTCP36-300 series can be used for calculation purposes as representative of all series of the APU model.
6. APU for a particular aircraft model assumed to be the same as other aircraft in that series or for similar aircraft.
7. GTCP 36 series assumed to be representative for this aircraft.
8. Emission factors for the GTCP85-98ck series can be used for calculation purposes as representative of all series of the APU model, unless otherwise noted.
9. Emission factors for the GTCP85-129 series should be used for calculation purposes.
10. Emission factors for the GTCP85-129ck series should be used for calculation purposes.
11. Emission factors for the GTCP331-200/250 series can be used for calculation purposes as representative of all series of the APU model, unless otherwise noted.
12. Emission factors for the GTCP331-200ER series should be used for calculation purposes.
13. Emission factors for the GTCP331-500 series should be used for calculation purposes.
14. Emission factors for the GTCP660-4 series should be used for calculation purposes as representative of all series of the APU model.
15. Emission factors for the TSCP700-4B series can be used for calculation purposes as representative of all series of the APU model.
16. Emission factors for the ST-6 L-73 series can be used for calculation purposes as representative of all series of the APU model.

Table 14: Auxiliary Power Units Model Emission Factors[1]

Model -Series (shaft HP)	Mode	Fuel Flow (kg/hr)	Emission Factors (kg of pollutant/tonne of fuel consumed)			
			VOC	CO	NOx	SO_2
GTC85-72 149.15 kW (200)	Load	95.45	0.14	14.83	3.88	0.54
GTCP100-544 298.28 kW (400)	Load	187.64	0.17	5.89	5.95	0.54
GTCP30-300	Load	128.27	0.22		10.10	
GTCP331-200/250 106.64 kW (143)	Load	121.78	0.47		9.51	
GTCP331-200ER 106.64 kW (143)	Load	121.78	0.47	4.13	9.51	
GTCP331-500 106.64 kW (143)	Load	243.64	0.14	0.09	14.67	
GTCP36-300 59.66 kW (80)	Load	128.27	0.22	2.05	10.10	
GTCP660-4 223.71 kW (300)	Load	392.24	0.31	8.65	5.33	
GTCP85 149.14 kW (200)	Load	106.95	1.03		4.75	
GTCP85-129 149.14 kW (200)	Load	106.95	1.13	17.99	4.75	
GTCP85-129ck 149.14 kW (200)	Load	106.95	1.13	17.99	4.75	
GTCP85-98ck 149.14 kW (200)	Load	106.95	1.13	17.99	4.75	
GTCP95-2 223.71 kW (300)	Load	133.09	0.39	3.20	5.65	0.54
PWC 901A	No Load	231.82	2.19	20.50	1.80	
PWC 901A	Load	408.64	0.00	5.60	6.50	
PWC 901A	Load	392.24	1.64	16.78	3.15	
ST6/ST6 L-73	Load	200.00	0.02	0.05	8.90	
T-62T-47C1	Load	106.95	0.18	40.20	4.30	
TSCP 700 105.89 kW (142)	Load	147.13	0.28		8.55	
TSCP 700-4B 105.89 kW (142)	Load	147.13	0.28	1.48	8.55	
WR27-1 63.38 kW (85)	Load	63.55	0.23	5.66	4.63	0.54

Notes:

1. Energy and Environmental Analysis Inc. September 1995. Technical Data to Support FAA's Advisory Circular on Reducing Emissions from Commercial Aviation. Arlington, VA, USA.

APPENDIX D

EMISSION FACTORS FOR JET ENGINES – ICAO DATA

The ICAO data is that recommended for estimating the emissions from jet engines. Appendix D contains the current ICAO database, new engines or updated data can be attained from DERA (UK Defence Evaluation and Research Agency http://www.dera.gov.uk).

The list of engines in Table 6 in Appendix A relate to Australian airline companies and these engines are in bold in the ICAO emission factor data following. Some details of engines from aircraft of other airlines is in Appendix B, if the details are not in Appendix B the information has to be attained from other sources. There is some information about the engines used by other airlines in Appendix B.

Table 15: Jet Engine Emission Factors from the ICAO Data Base

ICAO Page Number	Combustor	Engine Identification	HC Emission Factor (kg/h)				CO Emission Factor (kg/h)				NO_x Emission Factor (kg/h)			
			T/O	C/O	App	Idle	T/O	C/O	App	Idle	T/O	C/O	App	Idle
		Allied Signal												
C001		TFE731-2-2B	0.08	0.080	1.028	1.731	1.03	1.26	5.40	5.1	11.3	8.1	1.4	0.2
C002		TFE731-3	0.05	0.048	0.365	0.846	0.92	1.08	4.03	4.5	15.5	10.7	1.8	0.3
		Allison Engine Company												
ADD2/C1		AE3007C	0.29	0.278	0.272	0.820	0.98	1.00	1.47	4.2	17.1	12.3	2.2	0.5
		AE3007A1 series	0.36	0.345	0.303	0.558	1.08	1.11	1.60	4.0	27.1	19.3	3.0	0.6
		AE3007A	0.34	0.329	0.270	0.443	1.02	1.04	1.38	3.1	27.9	19.8	3.3	0.7
		AO 'Aviadgatel'												
C003		D-30 (II series)	0.50	0.491	1.890	20.40	11.18	11.23	18.27	28.2	79.1	57.2	8.8	1.7
C004		D-30KP-2	4.21	4.090	4.763	10.05	13.23	14.31	27.17	47.2	99.2	69.0	11.1	2.5
C005		D-30KU	1.64	1.872	2.160	8.127	15.32	17.32	21.24	41.8	89.2	59.0	9.2	2.1
C006		D-30KU-154	2.04	1.980	2.873	9.464	15.34	14.26	27.52	57.9	74.1	45.9	7.7	2.2
C007		PS-90A	0.75	0.618	0.352	0.192	2.19	2.06	1.58	4.4	231.6	162.3	20.8	3.7
		BMW Roll-Royce				7								
ADD2/C2		BR700-710A1-10	0.00	0.064	0.032	0.634	1.32	1.40	3.36	8.4	43.4	29.5	6.5	1.3
		BR700-715A1-30	0.00	0.050	0.009	0.073	2.35	1.86	3.32	5.6	72.1	46.3	9.9	1.9
		BR700-715B1-30	0.00	0.027	0.000	0.060	2.54	2.03	3.15	5.5	88.7	54.4	10.6	2.0
		BR700-715C1-30	0.00	0.000	0.000	0.051	2.65	2.24	3.01	5.4	110.7	64.5	11.4	2.1
		BR700-715A1-30	0.15	0.148	0.017	0.040	1.97	1.56	3.50	7.1	62.7	40.6	7.6	1.4
		BR700-715B1-30	0.10	0.162	0.019	0.026	2.36	1.70	3.32	6.9	79.5	49.3	8.3	1.5
		BR700-715C1-30	0.04	0.174	0.020	0.023	2.83	1.85	3.16	6.7	98.9	58.1	9.0	1.6

ICAO Page Number	Combustor	Engine Identification	HC Emission Factor (kg/h)				CO Emission Factor (kg/h)				NO_x Emission Factor (kg/h)			
			T/O	**C/O**	**App**	**Idle**	**T/O**	**C/O**	**App**	**Idle**	**T/O**	**C/O**	**App**	**Idle**
		BR700-710A1-10	0.05	0.043	0.039	0.349	2.67	1.99	3.68	8.9	48.2	32.2	5.9	1.5
		BR700-710A2-20	0.05	0.043	0.039	0.359	2.67	1.99	3.71	9.0	48.1	32.2	5.9	1.5
		CFM International												
C008		CFM56-2A series	0.16	0.131	0.092	0.529	3.61	2.95	3.89	11.0	81.8	56.7	10.0	2.0
C009		CFM56-2B-1	0.14	0.147	0.090	0.843	3.19	2.65	4.70	14.1	65.6	47.2	9.2	1.8
C010		CFM56-2-C5	0.14	0.147	0.090	0.843	3.19	2.65	4.70	14.1	65.6	47.2	9.2	1.8
C011		**CFM56-3-B1**	0.14	0.143	0.084	0.936	3.07	2.71	3.97	14.1	60.3	44.2	8.7	1.6
C012		**CFM56-3B-2**	0.14	0.149	0.083	0.750	3.42	2.84	3.84	12.9	73.8	52.8	9.8	1.8
C013		CFM56-3C (Rerated)	0.16	0.132	0.079	1.143	2.83	2.64	4.13	15.2	52.1	38.7	7.9	1.5
C014		**CFM56-3C-1**	0.12	0.137	0.085	0.634	3.74	3.09	3.75	12.0	86.0	61.1	11.0	1.9
C015		**CFM56-5-A1**	0.87	0.714	0.419	0.510	3.41	2.79	2.62	6.4	93.1	60.8	8.4	1.5
C016		CFM56-5A3	0.81	0.666	0.332	0.489	3.66	3.00	2.65	6.1	107.5	70.3	9.2	1.5
		CFM56-5A4	0.74	0.613	0.470	0.599	3.55	2.93	2.91	6.9	73.1	50.9	8.0	1.4
		CFM56-5A5	0.80	0.662	0.447	0.540	3.85	3.16	2.78	6.5	86.7	57.5	8.9	1.5
ADD1/C1		CFM56-5B1	0.49	0.401	0.157	1.352	2.45	2.00	2.06	12.0	171.7	109.0	14.2	1.9
ADD1/C5	DAC	CFM56-5B1/2	0.48	0.397	12.09	0.789	2.91	9.94	51.01	15.8	134.4	59.3	9.3	2.2
ADD2/C3	DAC-II	CFM56-5B1/2P	0.48	0.385	4.928	1.253	3.80	7.32	30.77	15.8	110.7	63.2	9.7	1.8
ADD2/C6		CFM56-5B1/P	0.47	0.762	0.621	1.465	4.20	3.43	2.48	7.8	153.8	99.8	13.3	1.8
ADD1/C2		CFM56-5B2	0.51	0.417	0.162	1.302	2.57	2.08	1.90	11.7	194.1	118.8	14.9	2.0
ADD1/C6	DAC	CFM56-5B2/2	0.51	0.408	11.40	0.802	2.02	6.93	48.59	15.9	149.7	64.6	9.8	2.3
	DAC-II	CFM56-5B2/2P	0.50	0.400	4.633	1.264	3.50	6.39	30.05	16.6	147.1	69.9	10.7	2.0
ADD2/C7		CFM56-5B2/P	0.49	0.791	0.641	1.464	3.92	3.56	2.44	7.9	172.0	108.4	14.0	1.9
	DAC-II	CFM56-5B3/2P	0.53	0.414	4.176	1.170	3.18	5.38	28.66	16.1	169.3	77.0	11.2	2.0
ADD2/C8		CFM56-5B3/P	0.51	0.822	0.659	1.449	4.12	3.70	2.24	7.9	192.0	117.1	14.8	1.9
ADD1/C3		CFM56-5B4	0.42	0.346	0.153	1.491	2.10	1.73	2.73	12.3	120.5	80.6	11.7	1.7

ICAO Page Number	Combustor	Engine Identification	HC Emission Factor (kg/h)				CO Emission Factor (kg/h)				NO_x Emission Factor (kg/h)			
			T/O	C/O	App	Idle	T/O	C/O	App	Idle	T/O	C/O	App	Idle
ADD1/C7	DAC	CFM56-5B4/2	0.42	0.351	13.75	0.958	6.80	17.20	52.82	16.2	70.6	44.2	7.4	2.0
ADD2/C4	DAC-II	CFM56-5B4/2P	0.41	0.684	6.487	1.555	5.75	12.31	35.62	17.3	75.5	46.5	8.0	1.7
ADD2/C9		CFM56-5B4/P	0.82	0.673	0.562	1.722	3.67	3.03	2.58	8.8	114.1	78.1	11.2	1.6
ADD2/C10		CFM56-5B5/P	0.64	0.534	0.655	2.098	2.89	2.67	3.18	10.2	70.2	49.4	8.1	1.3
ADD1/C8	DAC	CFM56-5B6/2	0.36	0.595	0.227	1.359	16.10	36.26	20.13	18.4	48.5	31.0	11.7	1.6
ADD2/C5	DAC-II	CFM56-5B6/2P	0.70	0.583	0.446	1.822	10.83	21.58	23.99	17.7	49.6	32.1	9.7	1.4
ADD2/C11		CFM56-5B6/P	0.69	0.575	0.594	1.921	3.11	2.88	2.87	9.7	81.6	56.4	9.1	1.4
C017		CFM56-5C2	0.04	0.031	0.105	2.403	4.38	3.10	2.24	14.4	153.5	99.9	12.8	1.8
C018		CFM56-5C3	0.04	0.033	0.099	2.317	4.84	3.34	2.09	14.1	171.5	110.3	13.9	1.8
ADD1/C4		CFM56-5C4	0.04	0.034	0.090	2.232	5.24	3.66	1.95	13.8	197.5	125.0	14.8	1.9
ADD2/C12		CFM56-7B18	0.31	0.257	0.094	1.222	1.84	1.03	3.37	9.9	59.0	42.7	8.5	1.5
ADD2/C13		CFM56-7B20	0.33	0.274	0.099	1.116	1.97	1.37	3.16	9.3	67.4	47.7	9.4	1.5
		CFM56-7B20/2	0.23	0.624	0.360	2.978	13.85	30.89	11.38	18.3	43.1	29.3	9.4	1.4
ADD2/C14		CFM56-7B22	0.37	0.304	0.107	0.945	1.84	1.82	2.68	8.6	84.9	57.7	10.7	1.7
		CFM56-7B22/2	0.22	0.301	6.610	2.744	7.91	19.83	33.67	17.1	54.7	36.6	6.9	1.5
ADD2/C15		CFM56-7B24	0.40	0.328	0.114	0.942	1.59	1.97	2.50	8.6	100.5	67.2	11.5	1.7
		CFM56-7B24/2	0.20	0.227	6.772	2.570	5.41	13.96	34.16	16.8	65.2	43.0	7.6	1.6
ADD2/C16		CFM56-7B26	0.44	0.360	0.122	0.773	0.88	2.16	1.95	7.6	126.6	80.9	13.1	1.9
		CFM56-7B26/2	0.13	0.214	5.687	2.392	3.33	8.94	31.35	16.2	83.2	52.6	8.7	1.7
ADD2/C17		CFM56-7B27	0.46	0.375	0.126	0.710	0.92	1.88	1.76	7.5	142.8	89.0	13.8	2.0
		CFM56-7B27/2	0.23	0.223	5.320	2.302	2.46	7.33	30.68	16.0	94.8	58.0	9.5	1.8
		General Electric												
C052	LEC II	CF34-3A	0.09	0.072	0.056	0.705	0.00	0.00	0.81	7.6	17.0	12.2	2.9	0.7
C053	LEC II	CF34-3A1	0.09	0.072	0.056	0.705	0.00	0.00	0.81	7.6	17.0	12.2	2.9	0.7
ADD2/C29	LEFN	CF6-45A	0.66	0.838	0.746	0.000	3.14	3.23	10.68	0.0	185.7	129.4	19.9	0.0
C023		CF6-45A2	5.19	4.324	2.309	18.72	3.70	3.09	15.74	47.5	229.7	161.9	17.6	2.4

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ADD2/C30	LEFN	CF6-45A2	0.66	0.838	0.746	0.000	3.14	3.23	10.68	0.0	185.7	129.4	19.9	0.0
ADD2/C31	LEFN	CF6-50A	1.17	0.901	0.698	0.000	3.36	3.15	9.79	0.0	212.1	149.7	21.9	0.0
C024		CF6-50C	5.14	4.826	2.315	17.55	4.28	3.45	12.04	47.5	299.8	199.9	21.8	2.7
ADD2/C32	LEFN	CF6-50C	1.15	0.945	0.669	0.000	3.61	3.11	9.21	0.0	230.2	164.0	23.3	0.0
ADD2/C35	LEFN	CF6-50C1	1.19	1.048	0.668	0.000	3.82	3.14	8.86	0.0	246.2	178.1	24.2	0.0
C025		CF6-50C1, -C2	5.37	4.977	2.376	16.87	4.48	3.56	10.22	47.8	325.0	211.2	22.6	2.8
ADD2/C36	LEFN	CF6-50C2	1.19	1.048	0.668	0.000	3.82	3.14	8.86	0.0	246.2	178.1	24.2	0.0
ADD2/C40	LEFN	CF6-50C2B	1.13	1.078	0.624	0.000	3.99	3.16	8.21	0.0	256.7	189.4	25.2	0.0
C026		CF6-50C2R	5.14	4.826	2.315	17.55	4.28	3.45	12.04	47.5	299.8	199.9	21.8	2.7
ADD2/C34	LEFN	CF6-50C2R	1.15	0.945	0.669	0.000	3.61	3.11	9.21	0.0	230.2	164.0	23.3	0.0
ADD2/C33	LEFN	CF6-50CA	1.15	0.945	0.669	0.000	3.61	3.11	9.21	0.0	230.2	164.0	23.3	0.0
ADD2/C37	LEFN	CF6-50E	1.19	1.048	0.668	0.000	3.82	3.14	8.86	0.0	246.2	178.1	24.2	0.0
ADD2/C38	LEFN	CF6-50E1	1.19	1.048	0.668	0.000	3.82	3.14	8.86	0.0	246.2	178.1	24.2	0.0
C027		CF6-50E2	5.37	4.977	2.376	16.87	4.48	3.56	10.22	47.8	325.0	211.2	22.6	2.8
ADD2/C39	LEFN	CF6-50E2	1.19	1.048	0.668	0.000	3.82	3.14	8.86	0.0	246.2	178.1	24.2	0.0
ADD2/C41	LEFN	CF6-50E2B	1.13	1.078	0.624	0.000	3.99	3.16	8.21	0.0	256.7	189.4	25.2	0.0
C019		CF6-6D	1.87	1.545	1.219	13.06	3.12	2.58	11.32	33.7	250.0	167.9	19.9	2.8
C020		CF6-6D1A	1.96	1.622	1.067	12.61	3.26	2.70	9.78	32.9	271.4	183.3	21.0	2.9
C021		CF6-6K	1.87	1.545	1.219	13.06	3.12	2.58	11.32	33.7	250.0	167.9	19.9	2.8
C022		CF6-6K2	1.96	1.622	1.067	12.61	3.26	2.70	9.78	32.9	271.4	183.3	21.0	2.9
C028		**CF6-80A**	2.24	1.874	1.041	3.397	7.72	7.11	6.86	15.2	230.1	165.4	22.8	1.8
C029		CF6-80A1	2.24	1.874	1.041	3.397	7.72	7.11	6.86	15.2	230.1	165.4	22.8	1.8
C030		CF6-80A2	2.43	2.511	1.038	3.391	8.11	7.46	6.46	15.2	240.2	180.5	24.9	1.8
C031		CF6-80A3	2.43	2.511	1.038	3.391	8.11	7.46	6.46	15.2	240.2	180.5	24.9	1.8
C032		CF6-80C2A1	0.69	0.633	0.458	6.584	4.84	3.80	5.01	30.3	278.4	174.7	22.3	2.9
ADD1/C9	1862M39	CF6-80C2A1	0.44	0.358	0.281	1.151	0.44	0.29	4.80	14.3	234.5	146.4	29.1	3.4

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C033		CF6-80C2A2	1.07	0.691	0.522	7.307	4.42	3.52	6.35	31.7	212.6	130.1	19.9	2.7
C034		CF6-80C2A2	0.61	0.628	0.480	7.131	4.34	3.46	6.14	31.3	212.9	130.0	19.7	2.7
ADD1/C10	1862M39	CF6-80C2A2	0.39	0.319	0.255	1.313	0.31	0.32	5.44	15.2	173.1	117.1	25.2	3.1
C035		CF6-80C2A3	0.71	0.721	0.491	6.698	5.22	4.11	5.02	30.7	304.6	183.5	23.4	2.9
C036		CF6-80C2A3	0.53	0.577	0.444	6.501	5.13	4.04	4.84	30.2	305.2	183.6	23.2	2.9
ADD1/C11	1862M39	CF6-80C2A3	0.36	0.367	0.262	1.125	0.54	0.29	4.72	14.1	250.7	154.7	29.7	3.4
C037		CF6-80C2A5	0.65	0.600	0.495	6.699	4.83	3.90	4.77	31.0	286.6	171.3	22.5	2.8
C038		CF6-80C2A5	0.65	0.600	0.495	6.699	4.83	3.90	4.77	31.0	319.4	171.3	22.5	2.8
ADD1/C12	1862M39	CF6-80C2A5	0.37	0.377	0.266	1.092	0.56	0.30	4.62	13.9	265.4	163.7	30.3	3.5
ADD2/C18	1862M39	CF6-80C2A5F	0.47	0.303	0.274	0.935	0.47	0.30	4.78	13.4	266.1	161.3	31.4	3.9
C039		CF6-80C2A8	0.72	0.633	0.472	6.790	4.69	3.66	4.83	31.2	302.3	154.7	21.2	2.7
ADD1/C13	1862M39	CF6-80C2A8	0.44	0.358	0.281	1.151	0.44	0.29	4.80	14.3	232.5	146.4	29.1	3.4
C040		CF6-80C2B1	0.66	0.607	0.466	6.675	4.77	3.71	5.26	30.5	231.2	143.4	19.6	2.6
ADD1/C14	1862M39	CF6-80C2B1	0.42	0.346	0.272	1.213	0.34	0.28	4.94	14.6	210.0	136.2	27.9	3.3
C041		CF6-80C2B1F	0.68	0.620	0.455	7.144	4.40	3.58	4.98	32.3	237.7	147.0	20.4	2.8
C042		CF6-80C2B1F	0.67	0.616	0.447	7.078	4.38	3.56	4.94	31.8	233.7	144.2	20.1	2.7
ADD1/C18	1862M39	CF6-80C2B1F	0.44	0.357	0.257	1.103	0.35	0.29	4.98	13.8	217.5	140.8	29.2	3.4
C043		CF6-80C2B2	0.61	0.634	0.457	7.721	4.37	3.49	5.50	33.2	183.3	118.2	18.2	2.6
ADD1/C15	1862M39	CF6-80C2B2	0.38	0.316	0.253	1.347	0.31	0.32	5.50	15.3	168.4	115.4	24.8	3.0
C044		CF6-80C2B2F	0.60	0.551	0.462	7.867	3.88	3.19	5.89	33.2	175.7	112.3	17.2	2.4
ADD1/C19	1862M39	CF6-80C2B2F	0.39	0.320	0.256	1.259	0.31	0.38	5.64	14.6	166.6	90.0	25.2	3.1
C045		CF6-80C2B4	0.70	0.642	0.491	6.978	4.90	3.85	5.45	31.5	255.4	90.0	20.8	2.6
ADD1/C16	1862M39	CF6-80C2B4	0.43	0.354	0.277	1.151	0.43	0.28	4.89	14.3	224.9	142.7	28.5	3.4
C046		CF6-80C2B4F	0.68	0.618	0.442	7.190	4.42	3.57	4.88	31.7	243.9	146.4	19.6	2.6
ADD1/C20	1862M39	CF6-80C2B4F	0.44	0.357	0.257	1.103	0.35	0.29	4.98	13.8	219.6	140.8	29.2	3.4
ADD2/C19	1862M39	CF6-80C2B5F	0.48	0.389	0.276	0.971	0.48	0.31	4.59	12.9	276.3	169.4	32.0	3.6

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C047		**CF6-80C2B6**	0.65	0.599	0.494	6.699	4.83	3.90	4.77	31.0	286.1	171.9	22.5	2.8
ADD1/C17	1862M39	CF6-80C2B6	0.37	0.377	0.266	1.092	0.56	0.30	4.62	13.9	265.4	163.7	30.3	3.5
C048		CF6-80C2B6F	0.64	0.582	0.440	6.883	4.75	3.78	4.44	31.0	294.1	167.9	21.0	2.7
ADD1/C21	1862M39	CF6-80C2B6F	0.47	0.379	0.270	1.045	0.47	0.30	4.74	13.5	255.7	159.4	31.0	3.5
ADD1/C27		CF6-80C2B7F	0.64	0.582	0.440	6.883	4.75	3.78	4.44	31.0	294.1	167.9	21.0	2.7
ADD1/C28	1862M39	CF6-80C2B7F	0.47	0.379	0.270	1.045	0.47	0.30	4.74	13.5	255.7	159.4	31.0	3.5
ADD2/C20	1862M39	CF6-80C2B8FA	0.47	0.381	0.272	1.041	0.47	0.30	4.88	13.5	252.3	158.9	31.3	3.6
C049		CF6-80C2D1F	0.65	0.595	0.473	6.372	4.86	3.87	4.59	29.5	305.1	178.6	21.7	2.7
ADD1/C22	1862M39	CF6-80C2D1F	0.38	0.383	0.272	1.018	0.47	0.31	4.71	13.3	266.1	163.0	31.4	3.6
C050		CF6-80E1A1	0.49	0.554	0.360	7.876	3.70	2.69	4.37	35.2	368.4	214.6	25.3	3.6
ADD1/C23	1862M39	CF6-80E1A1	0.49	0.317	0.283	1.058	0.49	0.32	4.94	14.4	268.4	169.7	32.4	4.0
C051		CF6-80E1A2	0.50	0.566	0.365	7.691	3.79	2.75	4.20	35.0	391.4	226.5	25.8	3.7
ADD1/C24	1862M39	CF6-80E1A2	0.40	0.323	0.287	1.026	0.50	0.32	4.82	14.3	286.1	177.9	33.0	4.0
ADD1/C25	DAC I	GE90-76B	0.71	0.503	1.881	3.694	0.92	1.09	16.29	43.6	457.0	296.9	35.6	6.4
ADD2/C24	DAC II	GE90-76B	0.41	0.333	0.197	0.575	1.52	1.41	3.71	15.5	407.8	262.8	43.7	5.5
ADD2/C21	DAC I	GE90-77B	0.71	0.501	2.229	4.067	0.92	1.09	17.81	46.0	465.0	298.1	34.7	6.1
ADD2/C25	DAC II	GE90-77B	0.41	0.336	0.198	0.566	1.53	1.43	3.68	15.4	414.4	267.7	44.3	5.5
ADD1/C26	DAC I	GE90-85B	0.92	0.655	4.651	3.294	0.92	1.12	77.57	40.9	597.3	376.9	31.5	6.5
ADD2/C26	DAC II	GE90-85B	0.46	0.372	0.215	0.473	1.71	1.49	3.37	14.4	539.4	332.0	51.3	6.0
ADD2/C22	DAC I	GE90-90B	0.98	0.695	4.264	3.121	0.98	1.09	74.72	40.3	705.8	435.8	33.8	6.9
ADD2/C27	DAC II	GE90-90B	0.49	0.399	0.227	0.421	1.84	1.50	3.17	13.7	654.0	390.5	56.5	6.3
ADD2/C23	DAC I	GE90-92B	1.14	0.713	3.799	3.003	0.96	1.05	71.02	39.5	755.4	462.6	35.4	7.0
ADD2/C28	DAC II	GE90-92B	0.51	0.410	0.231	0.405	1.90	1.54	3.10	13.5	707.4	414.8	58.6	6.5
	Standard	CF6-80E1A4	0.63	0.589	0.482	8.458	3.55	2.52	3.56	31.1	451.1	254.9	27.1	3.8
	Low emissions	CF6-80E1A4	0.42	0.337	0.241	0.752	0.42	0.17	3.86	12.3	327.0	198.0	33.9	3.9

ICAO Page Number	Combustor	Engine Identification	HC Emission Factor (kg/h)				CO Emission Factor (kg/h)				NO_x Emission Factor (kg/h)			
			T/O	C/O	App	Idle	T/O	C/O	App	Idle	T/O	C/O	App	Idle
		International Aero Engines												
C054		V2500-A1	0.40	0.366	0.180	0.098	2.20	1.83	0.93	3.5	148.8	102.5	16.2	2.6
ADD2/C42		V2522-A5	0.14	0.121	0.069	0.044	1.99	1.97	2.91	5.7	85.6	61.2	9.7	1.9
ADD2/C43		V2524-A5	0.16	0.131	0.072	0.044	2.03	1.97	2.80	5.6	98.3	68.7	10.6	2.1
C055		V2525-D5	0.16	0.130	0.070	0.048	2.01	1.96	2.80	5.7	100.5	70.6	10.2	2.2
C056		V2527-A5	0.16	0.130	0.070	0.048	2.01	1.96	2.80	5.7	100.5	70.6	10.2	2.2
C057		V2528-D5	0.19	0.147	0.074	0.049	2.05	2.01	2.58	5.6	132.7	90.0	12.2	2.4
C058		V2530-A5	0.22	0.159	0.076	0.050	2.16	2.02	2.46	5.4	162.0	105.1	13.7	2.5
ADD2/C44		V2533-A5	0.24	0.177	0.073	0.049	2.38	2.12	2.32	4.6	187.3	118.1	15.2	2.6
		KKBM												
C059		NK-8-2U	2.84	2.317	10.44	89.68	34.65	25.27	43.85	100.2	87.6	54.3	11.3	2.3
C060		NK-8-2U	12.60	9.576	5.148	25.34	31.50	28.73	25.74	50.7	0.0	0.0	0.0	0.0
C061		NK-86	4.32	3.456	2.506	39.31	33.70	24.19	19.42	41.1	110.6	69.7	10.6	2.0
C062		NK-86A	1.48	1.224	4.752	12.94	13.28	13.46	16.85	32.1	115.9	75.9	12.5	2.6
C063		NK-86MA	1.18	0.796	0.648	3.892	11.44	11.63	12.74	25.2	95.9	57.5	8.4	1.9
		Pratt & Whitney Aircraft Group												
C098		JT15D-1 series	0.01	0.004	0.813	4.181	1.41	1.56	7.44	10.9	4.0	3.0	0.6	0.1
C099		JT15D-4 series	0.05	0.098	1.094	3.758	1.28	1.64	6.80	9.1	5.6	4.4	1.1	0.2
C100		JT15D-5, -5A, -5B	0.00	0.808	2.780	12.69	0.00	0.71	9.17	12.7	8.2	6.3	1.2	0.2
C101		JT15D-5C	0.00	0.435	3.905	9.605	1.95	2.71	12.02	12.4	7.7	6.4	1.3	0.1
C064		JT3D-3B	16.91	6.710	4.982	54.43	6.34	9.39	30.52	47.6	51.1	33.2	6.0	1.2
C065		JT3D-7 series	2.26	1.486	2.941	56.68	4.02	7.06	27.31	64.0	57.3	35.6	7.4	1.0
C066	Smoke fix	JT3D-7 series	0.00	0.000	0.000	0.000	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0
C071		JT8D-11	1.61	1.480	1.683	5.238	4.84	6.25	11.30	18.3	76.3	48.0	7.0	1.4
C072	Smoke fix	JT8D-15	1.06	0.851	2.021	5.849	2.97	3.40	11.76	18.7	81.0	51.0	7.2	1.6

ICAO Page Number	Combustor	Engine Identification	HC Emission Factor (kg/h)				CO Emission Factor (kg/h)				NO_x Emission Factor (kg/h)			
			T/O	C/O	App	Idle	T/O	C/O	App	Idle	T/O	C/O	App	Idle
C073	Red. emiss	JT8D-15	1.02	0.953	0.674	0.776	4.37	3.91	3.39	5.8	82.3	51.4	8.5	1.7
C074		JT8D-15A	1.00	1.064	0.730	0.919	4.34	3.87	3.26	6.4	72.7	44.8	7.4	1.5
C075	Smoke fix	JT8D-17	3.09	2.835	2.498	5.398	3.32	3.59	10.88	16.4	86.1	54.7	7.8	1.7
C076	Red. emiss	JT8D-17	0.99	0.969	0.663	0.663	4.26	3.95	3.40	5.6	92.3	56.4	10.2	1.7
C077		JT8D-17A	1.06	1.009	0.761	3.329	4.52	3.90	3.43	6.3	80.7	48.1	8.0	1.6
C078		JT8D-17AR	1.03	1.018	0.708	0.707	4.57	4.07	3.45	5.7	120.4	60.3	10.3	1.7
C079		JT8D-17R	1.07	1.072	0.716	0.530	4.85	4.09	3.43	5.3	129.1	69.9	11.4	1.8
C080		JT8D-209	1.50	1.769	2.185	1.890	4.42	4.95	5.65	6.6	97.8	67.2	11.4	1.6
	E-Kit	JT8D-217	0.00	0.000	0.000	0.000	2.00	1.82	4.88	7.6	83.4	52.5	10.6	2.3
C081		JT8D-217 series	1.33	1.669	2.208	1.645	3.80	4.77	5.75	6.1	122.1	79.9	12.6	1.8
	E-Kit	JT8D-217A	0.00	0.000	0.000	0.000	2.00	1.82	4.88	7.6	83.4	52.5	10.6	2.3
	E-Kit	JT8D-217C	0.00	0.000	0.000	0.000	1.94	1.84	4.95	8.8	76.1	49.0	10.0	2.0
C082		JT8D-219	1.32	1.641	2.185	1.684	3.56	4.69	5.59	6.1	131.6	81.2	12.5	1.7
	E-Kit	JT8D-219	0.00	0.000	0.000	0.000	2.05	1.80	4.91	8.3	91.2	53.6	10.5	2.0
C067	Smoke fix	JT8D-7 series	1.42	1.460	1.648	4.926	5.34	5.84	10.81	16.5	60.9	39.4	5.7	1.3
C068	Red. emiss	JT8D-7 series	0.89	0.730	0.412	1.766	3.21	3.21	2.27	6.6	61.3	40.9	6.5	1.5
C069	Smoke fix	JT8D-9 series	1.76	1.431	1.856	4.752	4.64	5.06	10.12	16.4	67.1	43.3	6.1	1.4
C070	Red. emiss	JT8D-9 series	0.56	0.548	0.643	1.486	3.89	3.38	2.29	6.7	72.3	44.1	6.4	1.4
C094		JT9D-20	0.76	0.644	2.897	27.42	0.00	0.00	16.94	63.5	292.4	183.6	16.9	2.4
C095		JT9D-20J	0.00	0.000	1.222	20.99	7.50	6.16	13.44	57.1	374.2	239.0	23.0	2.8
C096		JT9D-59A	1.76	1.440	0.735	10.24	1.76	1.44	4.16	45.2	277.8	184.3	19.1	2.6
C083		JT9D-7	0.75	0.635	2.850	27.59	0.00	0.00	17.10	63.6	284.2	175.9	16.7	2.3
C097		JT9D-70A	1.76	1.440	0.735	10.24	1.76	1.44	4.16	45.2	277.8	184.3	19.1	2.6
C084		JT9D-7A	0.76	0.644	2.897	27.42	0.00	0.00	16.94	63.5	292.4	183.6	16.9	2.4
C085	Mod V	JT9D-7F	2.34	1.905	1.123	20.50	3.12	2.54	6.51	42.6	358.9	218.5	17.5	2.4
C086	Mod VI	JT9D-7F	0.00	0.000	1.348	21.63	7.00	5.76	13.03	57.3	324.4	201.7	20.4	2.7

ICAO Page Number	Combustor	Engine Identification	HC Emission Factor (kg/h)				CO Emission Factor (kg/h)				NO_x Emission Factor (kg/h)			
			T/O	C/O	App	Idle	T/O	C/O	App	Idle	T/O	C/O	App	Idle
C087		JT9D-7J	0.00	0.000	1.222	20.99	7.50	6.16	13.44	57.1	374.2	239.0	23.0	2.8
C088		JT9D-7Q	1.76	1.440	0.735	10.24	1.76	1.44	4.16	45.2	277.8	184.3	19.1	2.6
C089		JT9D-7R4D, -7R4D1	1.11	0.725	0.355	0.924	3.77	2.90	3.72	6.5	284.8	181.2	26.8	3.0
C090		**JT9D-7R4E, -7R4E1**	1.22	0.807	0.306	0.883	4.35	3.29	2.89	6.6	317.2	212.3	24.4	3.3
C091		JT9D-7R4E4, -E1(H)	1.20	0.856	0.507	2.659	5.35	4.41	3.36	12.7	294.6	195.6	19.6	2.8
C092		**JT9D-7R4G2**	1.31	0.948	0.427	1.249	6.47	4.26	3.32	9.5	361.1	199.7	20.9	3.1
C093		JT9D-7R4H1	1.36	1.007	0.468	1.307	6.69	4.53	3.62	10.3	408.8	215.9	23.2	3.4
C102		PW2037	0.28	0.273	0.302	1.147	2.21	1.87	3.30	11.7	172.2	113.0	14.8	2.2
		PW2037	0.11	0.094	0.181	1.051	1.87	1.60	3.22	12.2	166.3	112.7	16.1	2.2
C103		PW2040	0.16	0.182	0.319	1.256	2.54	2.09	3.55	14.0	217.4	142.3	18.8	2.3
		PW2040	0.06	0.104	0.179	0.944	2.02	2.13	2.54	11.4	221.0	138.5	18.7	2.5
C104		PW4056	0.97	1.212	0.582	0.447	0.71	1.00	2.10	7.9	286.5	175.4	27.0	3.4
C105	Red. smoke	PW4056	0.51	0.069	0.308	1.438	3.71	3.96	4.74	16.4	236.9	159.1	27.5	3.6
C106	Red. smoke	PW4060	0.95	0.225	0.354	1.273	3.53	3.83	4.50	15.6	312.6	185.4	30.4	3.8
ADD1/C29		PW4074	1.04	0.852	0.572	2.627	1.04	0.85	1.14	17.2	397.6	268.5	31.5	3.4
ADD2/C45		PW4074D	0.32	0.435	0.233	4.362	2.44	2.17	1.87	29.5	449.6	299.9	34.6	3.3
ADD1/C30		PW4077	1.09	0.883	0.588	2.506	1.09	0.88	1.18	16.9	432.6	286.9	33.2	3.5
ADD2/C46		PW4077D	0.33	0.361	0.210	4.093	2.44	2.26	1.80	28.7	496.4	323.3	36.4	3.4
ADD1/C31		PW4084	1.23	0.968	0.630	2.352	1.23	0.97	1.26	16.3	552.6	343.7	37.8	3.8
ADD2/C47		PW4084D	0.38	0.299	0.196	3.056	2.28	2.39	1.57	23.9	670.2	393.7	41.5	3.8
ADD2/C48		PW4090	0.42	0.322	0.207	2.219	2.67	2.46	1.52	19.9	856.0	458.7	45.4	4.1
C107		PW4152	1.02	1.028	0.320	0.472	0.94	1.09	2.33	8.1	210.8	145.9	23.7	3.1
C108	Red. smoke	PW4152	0.23	0.064	0.287	1.637	3.83	3.98	5.05	17.3	193.9	135.4	24.5	3.5
C109		PW4156	0.97	1.212	0.582	0.447	0.71	1.00	2.10	7.9	286.5	175.4	27.0	3.4
C110	Red. smoke	PW4156	0.51	0.069	0.308	1.438	3.71	3.96	4.74	16.4	236.9	159.1	27.5	3.6
C111	Red. smoke	PW4158	0.80	0.144	0.344	1.352	3.57	3.90	4.62	15.9	269.7	171.0	29.0	3.6

ICAO Page Number	Combustor	Engine Identification	HC Emission Factor (kg/h)				CO Emission Factor (kg/h)				NO_x Emission Factor (kg/h)			
			T/O	**C/O**	**App**	**Idle**	**T/O**	**C/O**	**App**	**Idle**	**T/O**	**C/O**	**App**	**Idle**
C112	Floatwall	PW4164	0.28	0.314	0.434	3.372	6.52	6.20	5.05	20.2	364.6	248.4	38.3	3.0
C113	Floatwall	PW4168	0.31	0.335	0.431	2.618	7.35	6.20	5.03	18.7	432.8	284.1	42.1	3.3
	Floatwall	PW4168A	0.31	0.335	0.431	2.618	7.35	6.20	5.03	18.7	432.8	284.1	42.1	3.3
C114		PW4256	0.97	1.212	0.582	0.447	0.71	1.00	2.10	7.9	286.5	175.4	27.0	3.4
C115	Red. smoke	PW4460	0.95	0.225	0.354	1.273	3.53	3.83	4.50	15.6	312.6	185.4	30.4	3.8
C116	Phase 3	PW4x50	0.66	0.606	0.396	4.725	3.87	3.76	4.86	25.6	187.5	131.9	23.2	2.6
C117	Phase 3	PW4x52	0.61	0.633	0.367	4.291	3.98	3.80	4.64	24.6	206.9	142.6	24.6	2.7
C118	Phase 3	PW4x56	0.68	0.619	0.370	3.557	4.06	3.85	4.37	22.4	257.6	166.8	27.7	2.9
C119	Phase 3	PW4x58	0.71	0.646	0.359	3.290	3.93	3.80	4.36	21.5	290.5	180.9	29.3	3.1
	Talon II	PW4X58	0.00	0.000	0.000	1.297	1.80	2.16	9.07	18.5	202.2	129.5	26.5	3.3
C120	Phase 3	PW4x60	0.76	0.598	0.370	2.927	3.78	3.88	4.30	20.3	329.5	196.8	30.9	3.2
C121	Red. smoke	PW4x62	1.03	0.467	0.365	1.195	3.60	3.81	4.41	15.2	373.5	199.9	31.8	3.8
C122	Phase 3	PW4x62	0.80	0.624	0.382	2.617	3.79	3.98	4.28	19.2	375.0	214.8	32.6	3.3
		Rolls-Royce Ltd												
C123		M54H-01	1.34	1.108	3.889	11.35	11.12	11.83	26.81	34.0	20.6	13.9	1.9	0.3
C124		RB211-22B	2.42	2.165	15.39	65.19	16.66	22.98	52.52	92.9	230.5	142.3	16.0	2.7
C125		RB211-22B	1.01	1.391	12.14	54.88	5.27	9.35	42.08	72.1	252.2	149.7	16.7	2.3
C126	Package 1	RB211-524B series	4.46	2.792	12.43	49.55	15.70	19.68	49.90	80.5	403.2	230.4	24.3	3.5
C127	Phase 2	RB211-524B series	3.10	1.675	1.588	1.685	5.57	2.13	3.54	10.7	416.1	246.2	22.2	3.6
C128		RB211-524C2	0.00	1.600	11.78	58.54	5.89	11.85	50.35	87.5	374.1	234.9	27.7	3.6
C129	Package 1	**RB211-524D4**	0.00	3.039	12.79	50.18	4.61	8.54	45.02	79.7	514.1	296.7	25.7	4.4
C130	Phase 2	RB211-524D4	4.97	1.788	1.638	1.320	10.45	2.34	3.65	8.7	500.0	295.7	24.9	4.1
C131		RB211-524G	21.50	10.93	2.873	3.070	5.56	3.22	2.55	12.9	553.8	303.6	24.1	4.3
C132		**RB211-524G**	3.68	2.022	0.932	0.833	5.56	3.22	2.55	12.9	553.8	303.6	24.1	4.3
		RB211-524G-T	0.00	0.227	0.000	3.697	1.51	1.06	3.12	27.0	268.2	164.8	25.8	3.7
C133		RB211-524H	3.34	2.578	0.920	0.693	8.55	2.97	2.53	11.0	647.1	361.8	26.2	4.5

ICAO Page Number	Combustor	Engine Identification	HC Emission Factor (kg/h)				CO Emission Factor (kg/h)				NO_x Emission Factor (kg/h)			
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		RB211-524H-T	0.00	0.160	0.000	3.098	1.82	1.12	2.91	24.5	315.5	185.3	27.5	3.9
C134		RB211-535C	1.62	0.741	0.855	1.037	4.54	1.43	0.93	13.5	218.4	131.7	12.4	2.5
C135		RB211-535E4	4.62	5.110	2.729	1.949	6.76	6.69	3.51	10.6	352.9	196.8	15.4	2.9
C136		RB211-535E4	0.27	0.054	0.082	0.684	6.76	6.69	3.51	10.6	352.9	196.8	15.4	2.9
ADD2/C49		RB211-535E4	0.00	0.054	0.075	0.240	5.16	2.72	2.13	8.6	300.5	174.3	12.7	2.2
	Phase 5	RB211-535E4	0.20	0.000	0.075	0.175	1.73	1.57	5.09	13.2	148.6	94.8	15.7	2.9
ADD2/C55		RB211-535E4B	0.07	0.000	0.059	0.192	7.04	3.56	2.08	8.0	407.8	218.7	14.6	2.4
	Phase 5	RB211-535E4B	0.52	0.000	0.099	0.096	2.46	1.54	4.81	12.5	192.9	113.9	17.1	3.1
	Transply IIF	Spey 555	0.40	0.470	0.263	1.183	4.07	4.44	4.60	10.8	45.9	27.9	4.0	0.8
C137		SPEY Mk511	3.14	3.450	7.262	24.30	5.79	5.38	20.39	42.0	74.5	50.1	8.0	0.6
C138	Transply IIH	SPEY Mk511	0.29	0.314	0.180	1.687	0.38	1.65	2.65	14.5	72.8	45.2	7.2	1.6
C139		**SPEY Mk555**	2.28	3.393	5.570	38.39	1.14	0.00	17.76	36.5	49.0	31.0	4.7	0.8
C140	**Transply IIF**	**SPEY Mk555**	0.77	0.320	0.231	0.643	0.79	1.49	2.94	10.1	57.9	35.2	5.4	1.3
ADD2/C52	Pedhead	TAY 650	0.34	0.562	0.099	0.531	2.14	1.23	1.58	9.7	50.9	33.1	4.7	1.1
ADD2/C53	Pedhead	TAY 651	0.28	0.492	0.112	0.570	2.35	1.32	1.54	10.0	55.0	35.7	5.1	1.1
ADD2/C54	Transply	TAY 651	1.75	0.959	0.796	1.339	5.26	5.00	5.72	14.1	63.6	44.4	4.5	0.7
C141		TAY Mk611-8	2.19	0.680	0.745	1.346	1.92	1.81	3.23	9.5	57.7	38.1	4.7	1.0
C142		TAY Mk620-15	2.19	0.680	0.745	1.346	1.92	1.81	3.23	9.5	57.7	38.1	4.7	1.0
C143		TAY Mk650-15	1.16	1.055	0.805	1.409	5.47	5.17	5.98	14.5	62.3	42.4	4.2	0.7
ADD1/C32		Trent 768	2.65	3.311	2.419	1.011	1.91	1.13	2.48	9.8	413.9	261.4	29.8	5.2
ADD2/C50	ITC	Trent 768	0.00	0.087	0.029	1.837	1.92	1.31	2.97	19.7	334.1	215.7	29.2	4.4
ADD1/C33		Trent 772	3.74	3.251	2.449	0.943	2.04	1.39	2.36	9.1	494.4	303.3	32.3	5.6
ADD2/C51	ITC	Trent 772	0.00	0.000	0.031	1.472	2.30	1.49	2.72	18.1	396.1	245.6	31.5	4.7
ADD1/C34		Trent 875	0.00	0.000	0.000	1.794	2.12	1.48	2.72	19.8	371.9	245.6	33.0	4.7
ADD1/C35		Trent 877	0.00	0.000	0.000	1.562	2.31	1.53	2.59	18.6	401.7	264.2	34.3	4.8
ADD1/C36		Trent 884	0.00	0.000	0.000	1.116	3.08	1.87	2.27	17.0	513.3	318.7	38.7	5.6

ICAO Page Number	**Combustor**	**Engine Identification**	**HC Emission Factor (kg/h)**				**CO Emission Factor (kg/h)**				**NO_x Emission Factor (kg/h)**			
			T/O	**C/O**	**App**	**Idle**	**T/O**	**C/O**	**App**	**Idle**	**T/O**	**C/O**	**App**	**Idle**
ADD1/C37		Trent 892	0.14	0.000	0.000	0.756	3.94	2.23	2.05	14.1	643.3	371.6	41.7	5.8
		Trent 895	0.29	0.000	0.000	1.057	3.92	2.18	2.04	17.5	693.3	393.8	43.1	6.1
		Textron Lycoming												
C144		ALF 502L-2	0.03	0.027	0.077	1.142	0.58	0.35	1.68	7.8	19.3	14.0	2.7	0.6
C145		ALF 502R-3	0.07	0.055	0.106	1.012	0.54	0.52	3.12	6.9	14.0	10.3	2.3	0.5
C146		**ALF 502R-5**	0.08	0.056	0.081	0.792	0.39	0.27	2.64	6.0	17.2	11.2	2.5	0.6
C147		**LF507-1F, -1H**	0.01	0.011	0.047	0.770	0.26	0.32	1.73	6.2	18.7	12.8	2.5	0.5
		ZMKB												
C148		D-36	0.00	0.000	0.000	0.000	1.14	0.77	2.05	0.0	59.3	42.2	6.8	0.0

APPENDIX E

EMISSION FACTORS FOR NON-JET ENGINES – FAA DATA

The FAA is that recommended for estimating the emissions from non-jet engines. Appendix E contains recent FAA data from the 1995 version of their database, new engines or updated data can be attained from FAA (US Federal Aviation Administration http://www.faa.gov).

This is a subset of the FAA data as it does not include jet engines.

Table 16: Non-Jet Engine Emission Factors from the FAA Database

FAA ID Number	Engine Maker[1]	Engine Identification	HC Emission Factor (kg/h)				CO Emission Factor (kg/h)				NO_x Emission Factor (kg/h)			
			T/O	C/O	App	Idle	T/O	C/O	App	Idle	T/O	C/O	App	Idle
220	GE	CT7-5	0.364	0.338	0.216	0.243	0.909	0.914	0.859	1.912	5.02	4.47	1.118	0.119
182	GE	T58-GE-5	0.000	0.317	5.866	0.317	0.000	2.250	2.250	10.233	0.00	2.90	2.901	0.091
148	P&W	PT6A-27	0.000	0.000	2.619	0.214	0.193	0.218	2.273	3.341	1.50	1.27	0.817	0.127
149	P&W	PT6A-41	0.405	0.436	6.769	2.812	1.181	1.395	4.310	7.679	1.85	1.62	0.576	0.131
253	P&W	R-985-AN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.000
157	RR	TYNE	1.302	1.191	3.007	1.217	0.538	0.596	5.117	18.505	12.30	11.44	4.084	0.216
225	RR	DART RDA10	0.000	0.000	1.685	0.000	1.687	1.836	6.590	7.840	3.30	2.39	0.625	0.303
226	RR	DART RDA7	0.641	0.622	4.448	0.001	2.051	1.978	9.758	17.011	3.59	2.54	0.264	0.130
469	TEX LYC	T53-L-11D	0.000	0.089	4.084	0.089	0.000	0.924	0.924	1.907	0.00	2.27	2.268	0.091

N otes:

1. The engine makers are; GE – General Electric, RR Rolls Royce, P&W – Pratt & Whitney, TEX LYC - Textron Lycoming