EUROCONTROL

Pan-European Single Sky Directorate

Environment and Climate Change Section

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D2.3
European Aviation Fuel Burn and Emissions Inventory System for the European Environment Agency (for data from 2005)

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EUROCONTROL

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[1] "**EUROCONTROL**" is an abbreviation of "The European Organisation for the Safety of Air Navigation".
[2] "**ETC/ATM**" is an abbreviation of "The European Topic Centre on Air Pollution and Climate Change Mitigation".
[3] "**EEA**" is an abbreviation of "The European Environment Agency".

0. Summary

0.1 The work done

Each year, under contract with the European Commission's Directorate-General for Climate Action (**DG CLIMA**), EUROCONTROL produces estimates of:

a. the total mass of each of the types of fuel – specifically jet fuel and aviation gasoline (**avgas**) - that were burnt during the previous calendar year in the engines of the aircraft that made "relevant" flights [4] for each one of the 28 states that are members of the European Union (**EU**) as well as for the EU as a whole and
b. the total mass of each of the following species of interest, namely:
    - carbon dioxide (CO_2),
    - carbon monoxide (CO),
    - methane (CH_4),
    - nitrous oxide (N_2O),
    - all the volatile organic compounds (**VOC**s) other than methane, which are known collectively as non-methane VOCs (**NMVOC**s),
    - nitric oxide (NO) and nitrogen dioxide (NO_2), which are known collectively as the mono-nitrogen oxides (**NO_X**),
    - sulphur dioxide (SO_2) and sulphur trioxide (SO_3) which are known collectively as the mono-sulphur oxides (**SO_X**),
    - the four polycyclic aromatic hydrocarbon (**PAH**) compounds that are known collectively as 4-PAH[5],
    - particulate matter (**PM**) with an aerodynamic diameter [6] of less than 2.5 micrometres (**$PM_{2.5}$**),
    - PM with an aerodynamic diameter of less than 10 micrometres (**PM_{10}**), and
    - PM with an aerodynamic diameter of any size (**PM_{total}**)

   that were emitted into the atmosphere as a result of the combustion of these masses of jet fuel and avgas.

Turbojet, turbofan, and turboprop aircraft engines burn jet fuel while reciprocal (piston) aircraft engines burn avgas.

This work is done to support the states that are members of the EU:

> "*in the maintenance and provision of data to improve the quality of the reporting of emissions inventories*".

The flights that are relevant to the work done in 2018 were made during the calendar years 2005 to 2017 inclusive. (i.e. 13 years-worth of flights).

For its own needs, and using its own budget, EUROCONTROL has previously also produced estimates of the total masses of each of the types of fuel burnt and each of the species of interest emitted for the years from 2005 to 2016 inclusive for the 16 states that are members of the European Civil Aviation Conference (**ECAC**) but not members of the EU. In doing so, EUROCONTROL was able to provide the EEA with estimates of these masses for the years

[4] The meaning of "relevant" flights is defined in Section 3.1.
[5] 4-PAH was named POM4PAH in previous versions of this document.
[6] The aerodynamic diameter of an irregular particle is defined as the diameter of the spherical particle with a density of 1000 kg/m^3 and the same settling velocity as the irregular particle.

from 2005 to 2016 for the five states that are members of the EEA but not members of the EU. EUROCONTROL is continuing this service in 2018.

0.2 Purpose of this document

The purpose of this document is to describe both the procedure by which these estimates are produced and the tools and databases that are used to do the calculations. The procedure, which is carried out once a year, is called "The Fuel Burn and Emissions Inventory System (**FEIS**) procedure" in this document.

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1. Abbreviations, acronyms, and definitions

1.1 Abbreviations and acronyms

The following abbreviations and acronyms are used in this document.

Abbreviation/acronym	Meaning	Description
2D	2-dimensional	Latitude and longitude
2KP	2nd Commitment Period for the Kyoto Protocol	A commitment period for a protocol to the UNFCCC
3D	3-dimensional	Latitude, longitude, and altitude
4D	4-dimensional	Latitude, longitude, altitude, and time
AEED	Aircraft Engine Emissions Databank	An ICAO database.
AEM	(The) Advanced Emission Model	A EUROCONTROL tool.
APU	Auxiliary power unit	An aircraft component.
Avgas	Aviation gasoline	
BADA	(The) Base of Aircraft Data	A EUROCONTROL database.
BFFM2	2nd Boeing fuel flow method	A method developed by Boeing.
CCD	Climb-cruise-descent	
CEO	Current engine option	An Airbus term.
CLRTAP	(The) Convention on Long-range Trans-boundary Air Pollution	A UN ECE convention.
CODA	(The) Central Office for Delay Analysis	A EUROCONTROL unit.
DAC	Double annular combustor	An engine component.
DG CLIMA	(The) Directorate-General for Climate Action	A directorate-general of the European Commission.
DG MOVE	(The) Directorate-General for Mobility and Transport	A directorate-general of the European Commission.
EASA	(The) European Aviation Safety Agency	A DG MOVE agency.
ECOSOC	(The) Economic and Social Council	A principal organ of the UN.
EEA	(The) European Environment Agency	An EU agency.
EMEP	(The) European Monitoring and Evaluation Programme	A UN ECE programme.
ETC/ATM	(The) European Topic Centre on Air Pollution and Climate Change Mitigation	A topic centre of the EEA.
EU	European Union	A multi-national polity.
EUROCONTROL	(The) European Organisation for the Safety of Air Navigation	A European organisation.
FEIS	(The) Fuel Burn and Emissions Inventory System	
FOCA	(The) Federal Office of Civil Aviation	A Swiss organisation.

Abbreviation/acronym	Meaning	Description
GE	General Electric	An aircraft engine manufacturer.
HC	Hydrocarbon	
hh:mm:ss	Hours-minutes-seconds	
ICAO	(The) International Civil Aviation Organisation	A specialised agency of the UN.
IFR	Instrument flight rules	
IPCC	(The) Inter-governmental Panel on Climate Change	A panel established by the UNEP and the WMO.
IUPAC	(The) International Union of Pure and Applied Chemistry	
LTO	Landing and take-off	
NEO	New engine option	An Airbus term.
NMOC	(The) Network Manager Operations Centre	A current EUROCONTROL unit.
NMVOC	Non-methane volatile organic compound	Any compound of carbon, other than: • metallic carbides or carbonates • carbon monoxide • carbon dioxide • carbonic acid • ammonium carbonate • methane that participates in atmospheric photochemical reactions.
NOI	Not of interest	
NO_X	(Mono-)nitrogen oxides	NO and NO_2
OG	Organic gas	
PAH	Polycyclic aromatic hydrocarbon	
Paris CDG	Paris Charles de Gaulle Airport	Located near Paris, France.
PM	Particulate matter	
$PM_{2.5}$	PM with an aerodynamic diameter of less than 2.5 micrometres	
PM_{10}	PM with an aerodynamic diameter of less than 10 micrometres	
$PM_{non-vol}$	Non-volatile PM	
PM_{total}	All PM	
$PM_{vol-org}$	Organic volatile PM	
$PM_{vol-sul}$	Sulphuric volatile PM	
POM	Polycyclic organic matter	
SO_X	(Mono-)sulphur oxides	SO_2 and SO_3
STP	Standard temperature and pressure	A temperature of 273.15 K and an absolute pressure of exactly 100 kPa.
UHC	Unburnt hydrocarbon	
UNO	(The) United Nations	

Abbreviation/acronym	Meaning	Description
	Organization	
UNEP	(The) United Nations Environment Programme	A programme of the UN General Assembly.
UNFCCC	(The) UN Framework Convention on Climate Change	A UN convention.
UN ECE	(The) UN Economic Commission for Europe	A regional commission of the ECOSOC.
VFR	Visual flight rules	
VOC	Volatile organic compound	Any compound of carbon, other than: • metallic carbides or carbonates, • carbon monoxide, • carbon dioxide, • carbonic acid, and • ammonium carbonate that participates in atmospheric photochemical reactions.
WMO	(The) World Meteorological Organization	A specialised agency of the UN.
YYMMDD	Year-month-day	

1.2 Definitions

The following terms are used in this document..

Term	Definition
Actual aircraft	An aircraft that actually made a flight in the real world. For the purposes of the FEIS procedure, an actual aircraft is considered to be composed of an airframe of a particular type and one or more engines (which are all of the same type).
Actual type of aircraft	The type of an actual aircraft.
Actual type of airframe	The type of the airframe of an actual aircraft. For the purposes of the FEIS procedure, it is designated by an ICAO *type-of-aircraft* code.
Actual type of engine	The type of the engine(s) of an actual aircraft. For the purposes of the FEIS procedure, it is designated by a *type-of-engine* name.
Airport	An airport, aerodrome, or heliport.
BADA type of aircraft	The type of an aircraft for which data is available in the BADA database. It is designated by an ICAO *type-of-aircraft* code.
BADA type of engine	The type of the engine(s) associated with a BADA type of aircraft in the BADA database. It is designated by a BADA *type-of-engine* name.
BADA *type of engine* name	A string of characters that designates a type of engine in the BADA database.
DB type of engine	A type of engine for which fuel consumption and emissions data is available in an aircraft engine emissions database. It is designated by a DB *type-of-engine* designator, which is just a string of characters and which can be a DB *type-of-engine* name or a DB *type-of-engine* code.
DB *type of engine* code	A DB *type of engine* designator.
DB *type of engine* designator	A string of characters that designates a DB type of engine. The string can be a DB *type-of-engine* name or a DB *type of engine* code.
DB *type of engine* name	A DB *type of engine* designator.
EUROCONTROL airspace	The airspace above EUROCONTROL territory.
EUROCONTROL territory	The combined European territories of the 41 member states of EUROCONTROL.
FEIS aircraft	A (possibly non-existant) aircraft that is composed of an airframe that is designated by an ICAO *type-of-aircraft* code and one or more engines that are all of the same type, which is a DB type of engine.
FEIS type of aircraft	The type of an FEIS aircraft. It is designated by an FEIS *type-of-aircraft* code. The FEIS types of aircraft were created by the EUROCONTROL FEIS team for the purposes of the FEIS procedure.

Term	Definition
FEIS *type-of-aircraft* code	A code that was defined by the EUROCONTROL FEIS team for the purposes of the FEIS procedure and that consists of a string of 4, 5, or 6 characters where the first 2, 3, or 4 characters are an ICAO *type-of-aircraft* code, the next character is a "-", and the last character is an upper-case letter of the alphabet . Only some of the possible 4-, 5-, and 6-character strings are valid.
FEIS type of airframe	The type of the airframe of an FEIS aircraft. It is designated by an ICAO *type-of-aircraft* code.
FEIS type of engine	The type of the engine(s) of an FEIS aircraft. It is designated by a DB *type-of-engine* code.
Gate	The gate or parking area.
ICAO *type of aircraft* code	A code that was defined by ICAO and that consists of a string of 2, 3, or 4 alphanumeric characters. Not all 2-, 3-, and 4-alphanumeric-character strings are valid.
Polity	A polity is generally understood to designate any geographic area that has a corresponding government. Therefore, a polity can be a super-state, like the EU, or one of its subordinate civil authorities, such as a state, province, region, county, municipality, city, district, etc.
4-PAH	A group of four PAHs specified by the UN ECE, namely: • benzo[a]pyrene, • benzo[b]fluoranthene, • benzo[k]fluoranthene, and • indeno(1,2,3-cd)pyrene.
7-PAH	A group of seven PAHs specified by the UN ECE, namely: • 4-PAH, • benz[a]anthracene, • chrysene, and • dibenz[a,h]anthracene.
16-PAH	A group of 16 PAHs specified by the UN ECE, namely: • 7-PAH, • acenaphthene, • acenaphthylene, • anthracene, • benzo[ghi]perylene, • fluoranthene, • fluorine, • naphthalene, • phenanthrene, and • pyrene.
PRISME type of aircraft	The type of an actual aircraft as recorded in the PRISME database.
PRISME type of airframe	The type of the airframe of an actual aircraft as recorded in the PRISME database. It is designated by a PRISME *type-of-airframe* code. It is not necessarily the same as the actual type of the airframe of that aircraft but is usually assumed to be so.

Term	Definition
PRISME *type of airframe* code	A designator that consists of a string of 2, 3, or 4 alphanumeric characters that should be, but is not always, the same as an ICAO *type-of-aircraft* code.
PRISME type of engine	The type of the engine(s) of an actual aircraft as recorded in the PRISME database. It is designated by a PRISME *type-of-engine* name.
PRISME *type of engine* name	A string of characters that designates a type of engine in the PRISME database.
Species of interest	One of the following gaseous species or types of PM • carbon dioxide, • carbon monoxide, • methane, • nitrous oxide, • the NMVOCs, • NO_X, • SO_X, • 4-PAH, • $PM_{2.5}$, and • PM_{10}.
type of engine name	A string of characters that designates a type of engine.
Types of fuel	Jet fuel and avgas.

1.3 Chemical formulae

The following chemical compounds, which are listed here with their **IUPAC** [7] names (if different), and chemical formulae. They are colour-coded as follows:

- greenhouse gases (i.e. those that contribute directly to the greenhouse effect due to their positive radiative forcing) are marked with a green square (■),
- VOCs are marked with a red dot (●), and
- other organic gases (**OGs**) are marked with a black star (★).

Chemical compound	Type	*IUPAC name(s)*	Chemical formula
1,3-butadiene	★	Buta-1,3-diene	$CH_2{=}CHCH{=}CH_2$
Acetaldehyde	●	Ethanal	CH_3CHO
Acrolein	●	Prop-2-enal	$CH_2{=}CHCHO$
Benzene	★		C_6H_6
Carbon dioxide	■		CO_2
Carbon monoxide			CO
Ethylbenzene	★		$C_6H_5CH_2CH_3$
Formaldehyde	★	Methanal	CH_2O
Methane	★		CH_4
Nitric oxide			NO
Nitrogen dioxide			NO_2
Nitrous oxide	■	Dinitrogen monoxide	N_2O
Propionaldehyde	★	Propanal	CH_3CH_2CHO
Styrene	●	Phenylethene	$C_6H_5CH{=}CH_2$
Sulphur dioxide			SO_2
Sulphur trioxide			SO_3
Sulphuric acid			H_2SO_4
Toluene	★	Methylbenzene	$C_6H_5CH_3$
Water (vapour)	■		H_20
Xylene	★	1,2-dimethylbenzene 1,3-dimethylbenzene 1,4-dimethylbenzene	$C_6H_4(CH_3)_2$

Table 1: The chemical formulae of certain chemical compounds.

[7] "**IUPAC**" is an acronym of "**(The) International Union of Pure and Applied Chemistry**".

2. Background

In this section, the reason why the FEIS procedure was developed is described.

2.1 The EU, the EEA, EUROCONTROL, and ECAC

The EU is a political and economic union of 28 member states [8] whose territories are located mainly in Europe. The 7 principal decision-making bodies, or institutions, of the EU include the European Commission, which is responsible for proposing legislation, implementing decisions, and managing the day-to-day business of the EU. The European Commission is divided into a number of directorates-general, one of which is DG CLIMA, whose mission includes monitoring national emissions by EU member countries [**1**].

In contrast to the institutions of the EU, the agencies of the EU are de-centralised bodies that have been set up to accomplish specific tasks. One such agency is the EEA, which has 33 member states and whose task is:

> *"to provide sound, independent information on the environment. We are a major information source for those involved in developing, adopting, implementing and evaluating environmental policy, and also the general public."* [**2**].

EUROCONTROL is an international organisation that is:

> "*committed to building, together with our partners, a Single European Sky that will deliver the air traffic management (ATM) performance required for the twenty-first century and beyond."* [**3**]

EUROCONTROL has 41 member states and it has signed comprehensive agreements with 2 other states. It is not an agency of the EU; indeed the EU is also a member of EUROCONTROL.

ECAC is an inter-governmental organisation that was set up by ICAO and the Council of Europe. It has 44 member states. ECAC promotes:

> "*the continued development of a safe, efficient and sustainable European air transport system*" [**4**].

2.1.1 The member states of the EU, the EEA, EUROCONTROL, and ECAC

The 28 states that are members of the EU, the 33 states that are members of the EEA, the 41 states that are members of EUROCONTROL, and the 44 states that are members of ECAC are listed together in Figure 1 below.

[8] Since 1 July, 2013, when the Republic of Croatia joined the EU.

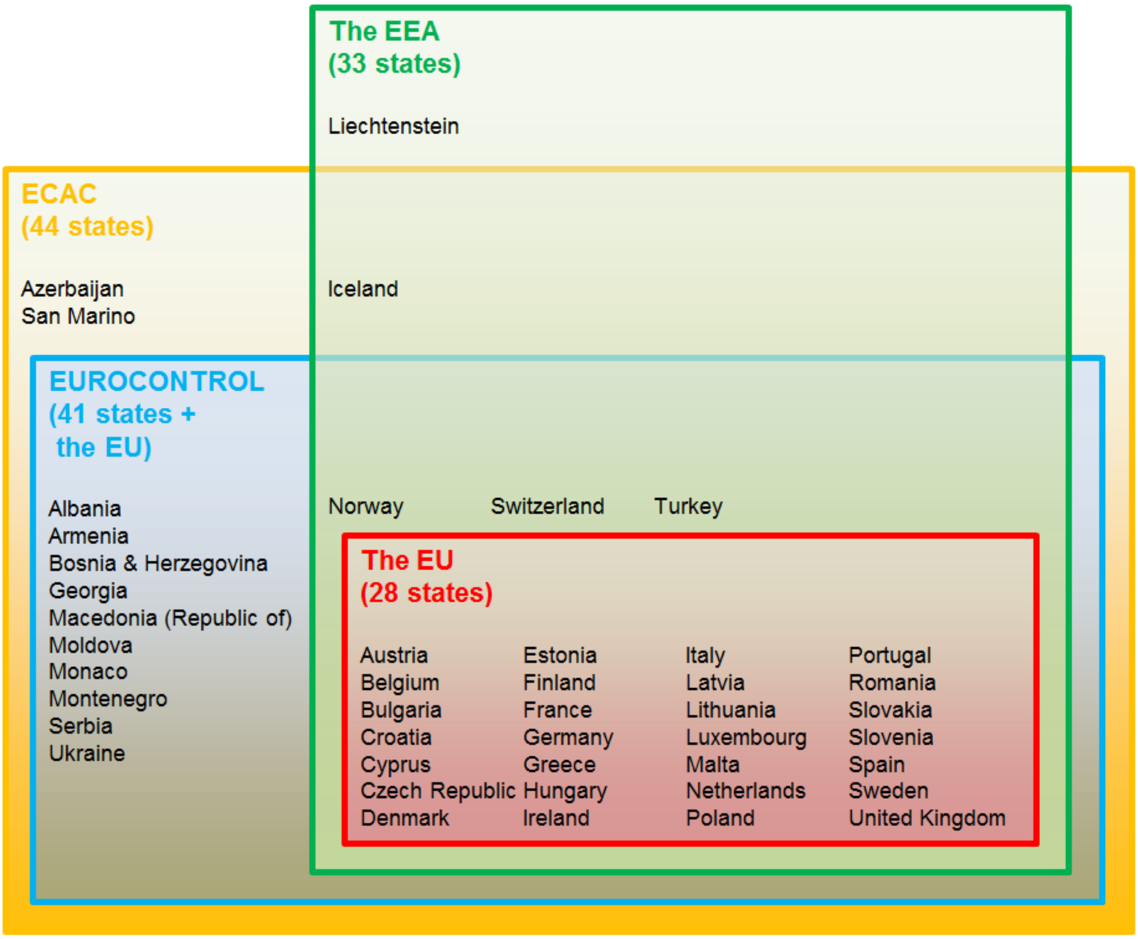

Figure 1: A Venn diagram showing the member states of the EU, the EEA, EUROCONTROL, and ECAC.

As can be seen, all the 28 member states of the EU are members of both the EEA and EUROCONTROL. The EEA has 5 additional member states, 3 of which are members of EUROCONTROL and 2 of which are not. Of the 2 EEA member states that are not members of EUROCONTROL, one is a member of ECAC.

2.1.2 EUROCONTROL Airspace

EUROCONTROL airspace is defined to be the sum of the European airspace of the 41 member states of EUROCONTROL. In this document, European airspace is considered to be the airspace that is above continental Europe and the islands that are nearby, which include:

- the British Isles (Great Britain, Ireland, the Channel Islands, the Isle of Man, etc),
- the Croatian islands (Cres, Krk, etc),
- Cyprus,
- the Danish islands (Zealand, Funen, etc),
- the Estonian islands (Saaremaa, Hiiumaa, etc),
- the French islands (Corsica, etc),
- the Greek islands (Crete, Lesbos, Rhodes, Corfu, etc),
- the Italian islands (Sardinia, Sicily, etc),
- the Maltese archipelago,
- the Norwegian islands (Svalbard, etc),

- the Spanish islands (the Balearic Islands, etc), and
- the Swedish islands (Gotland, etc),

as well as the nearby oceanic islands such as

- the Canary Islands,
- Madeira, and
- the Azores.

Some of the member states of EUROCONTROL, such as the French Republic and the Kingdom of Denmark, have some territory that is outside Europe and hence these states have airspace that is outside European airspace and hence outside EUROCONTROL airspace.

The extent of the EUROCONTROL airspace is shown in Figure 2 below.

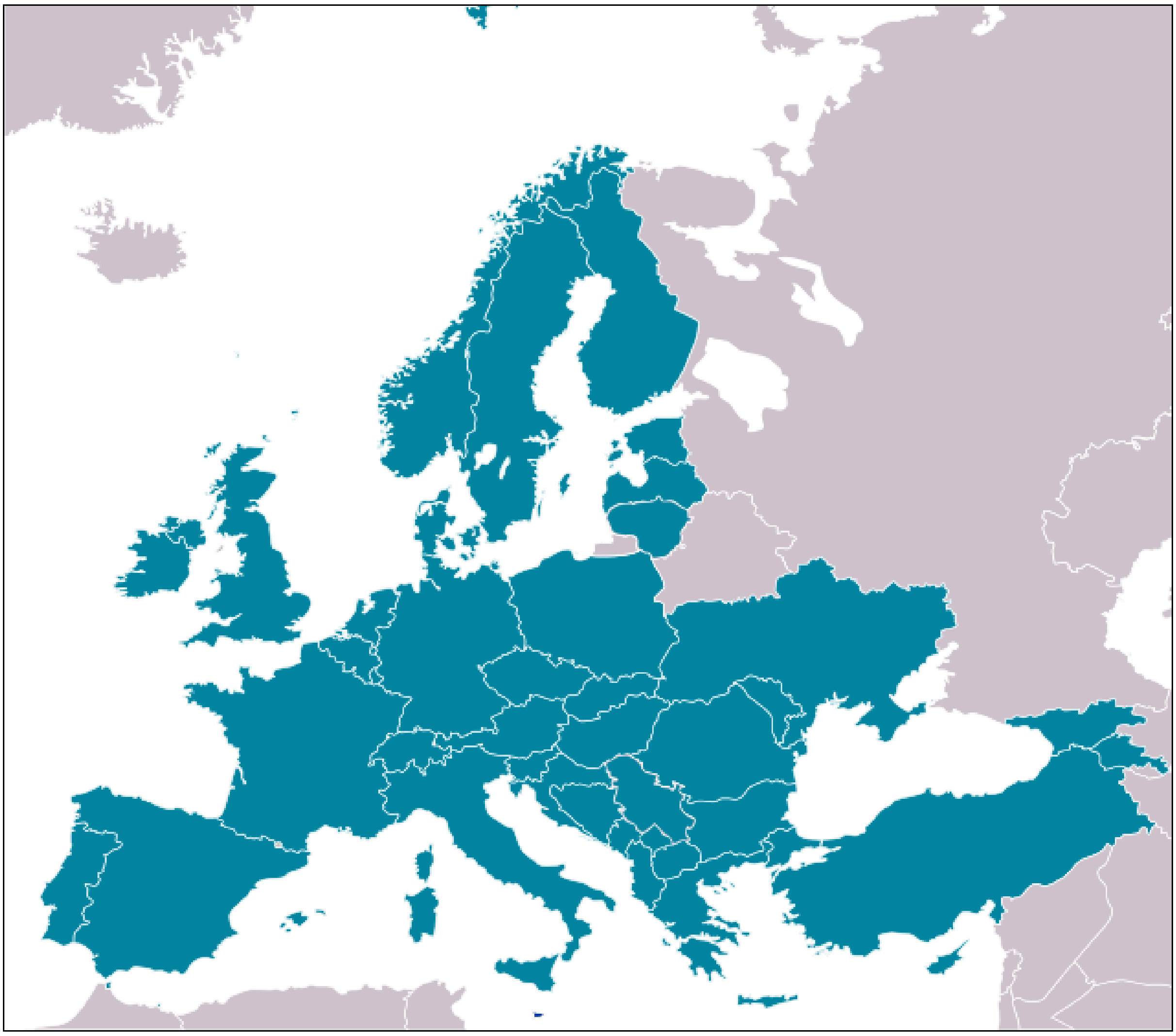

Figure 2: EUROCONTROL airspace. (The Canary Islands, Madeira, and the Azores are not shown.)

2.2 The United Nations Organization and its environmental conventions

The United Nations Organization (**UNO**) is an inter-governmental organisation that was established after the Second World War to promote international co-operation and to create and maintain international order. The UNO set up a group of specialized agencies, related organizations, funds, and other entities, such as convention secretariats, that manage the conventions of the UNO. One of the specialized agencies is the International Civil Aviation Organization (**ICAO**) whose mission is to:

> "*serve as the global forum of States for international civil aviation.*" [**5**]

2.2.1 The United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (**UNFCCC**) is one of the conventions of the UNO. It is an international environmental treaty that has the aim of:

> "*stabilising greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*".

All the members of the EEA, and consequently all the members of the EU, as well as the EU itself, are parties to the UNFCCC. According to [**6**], Article 12.1(a) of the UNFCCC requires that each party shall communicate a national inventory of anthropogenic emissions of all greenhouse gases that are not controlled by the Montreal Protocol.

As a minimum requirement, a national inventory of anthropogenic emissions for the UNFCCC shall contain information on the following, so-called direct, greenhouse gases, namely:

- carbon dioxide,
- methane, and
- nitrous oxide,

as well as on some compounds containing fluorine (F) atoms that are not of interest in this document as they are not emitted by aircraft engines.

Annex I parties to the UNFCCC, which includes all the member states of the EEA, shall also provide information about the following species, which have an indirect effect on the greenhouse effect:

- carbon monoxide,
- NO_X,
- NMVOCs, and
- SO_X.

2.2.2 The Convention on Long-range Trans-boundary Air Pollution

The five principal organs of the UNO include the Economic and Social Council (**ECOSOC**), whose purpose is to promote international economic and social co-operation and development. The United Nations Economic Commission for Europe (**UN ECE**) is one of the five regional commissions that reports to the ECOSOC. The UN ECE directs the European Monitoring and Evaluation Programme (**EMEP**), which implements the

Convention on Long-range Trans-boundary Air Pollution (**CLRTAP**). The purpose of this convention is to protect the environment from being polluted and to reduce and prevent air pollution.

All the members of the EEA as well as the EU itself are parties to the CLRTAP, and, as such, are required to report on the substances for the years set forth in the protocols that they have ratified and that have entered into force.

The CLRTAP species that are of interest in this document are:

- NO_X,
- NMVOCs,
- SO_X,
- carbon monoxide,
- $PM_{2.5}$,
- PM_{10},
- all PM, whatever its size, and
- 4-PAH.

In any particular year, each party has to report its figures for the year two years before. So, for example, in 2016, the parties reported their figures for 2014. The Republic of Croatia is the state that joined the EU most recently, which it did in 2013. Consequently, from 2015 onwards, the figures reported by the EU have included the figures reported by Croatia.

2.3 Emissions from aircraft

The emissions produced by aircraft come mainly from the combustion of fuels. Both jet fuel and avgas are basically mixtures of various hydrocarbon (**HC**) compounds. HC compounds are organic compounds that consist entirely of hydrogen (H) and carbon (C) atoms.

According to [**7**], an aircraft (on the ground or in flight) with its engine(s) and/or auxiliary power unit (**APU**) in operation burns fuel and emits various gaseous and particulate species, including:

- carbon dioxide,
- water vapour,
- methane, and
- nitrous oxide,

as well as

- carbon monoxide,
- NMVOCs,
- SO_X,
- PM,
- NO_X, and some other gases.

Carbon dioxide accounts for approximately 70% of the emissions while water vapour makes up most of the rest. Very little or no methane [9] and nitrous oxide are generated by modern aircraft engines and the carbon monoxide, NMVOCs, SO_X, NO_X, other gases, and PM make up together about 1% of the emissions.

[9] Indeed modern aircraft engines can be a sink for methane in the atmosphere, the concentration of methane in the ambient air being greater than in the exhaust gases.

The masses of NO_X, carbon monoxide, and unburnt HCs (**UHCs**) that are emitted by an aircraft engine vary as a function of the thrust that is generated by that engine. Consequently, it is necessary to know the emission indices (the mass of the species emitted per unit mass of the fuel burnt) for these species as a function of fuel flow.

The water vapour and carbon dioxide are generated as a direct result of the oxidation of the carbon and hydrogen that is found in the fuel by the oxygen that is in the ambient atmosphere. The SO_X emissions depend directly on the sulphur content of the fuel used. The emitted masses of all three of these species are directly proportional to the mass of fuel burnt.

The emitted masses of benzene (C_6H_6) and all of the VOCs and OGs, and all the species derived from the VOCs and the OGs, are proportional to the mass of UHCs emitted.

Emissions of PM result from the incomplete combustion of the fuel.

Aircraft with engines in operation are, therefore, one of the sources of the species of interest to the UNFCCC and the CLRTAP. Consequently, all the member states of the EEA have to estimate the masses of the species of interest that are emitted by the aircraft that make "relevant" flights in their airspace.

2.4 Flights

Air traffic can be divided into three categories, namely:

- civil and military flights flying under instrument-flight-rule (**IFR**) conditions,
- civil and military flights flying under visual-flight-rule (**VFR**) conditions, and
- operational military flights.

Before an IFR flight can begin, a flight plan has to be filed with the relevant authorities; A VFR flight that has already begun can be converted to an IFR flight by filing a flight plan with the relevant authorities while the associated aircraft is in the air.

2.4.1 What is a flight?

For the purposes of this document, the path through space and time that an aircraft follows, from the moment that it leaves the gate [10] at the departure airport until the moment that it comes to a final stop at the gate of the arrival airport, is called a flight.

A flight can be considered to be split into the following stages and associated phases:

[10] The gate should be understood to mean either the gate or the parking area from where the aircraft departs.

Stage	Phase	Scope
Take-off	1) Taxi out	To the runway
	2) Take off	Along the runway
	3) Climb out	Up to a height [11] of 3,000 feet above the ground
En-route	4) Climb	From a height of 3,000 feet above the ground up to the cruise flight level
	5) Cruise	At the cruise flight level (perhaps with small climbs and/or descents)
	6) Initial descent	Down to a height of 3,000 feet above the ground
Landing	7) Final approach	From a height of 3,000 feet above the ground down to the runway
	8) Landing	Along the runway
	9) Taxi in	From the runway

Table 2: The stages and phases of a flight

The sequence of phases is indicated in Figure 3 below.

Taken together, Phases 1, 2, and 3 of a flight make up the take-off stage, Phases 4, 5, and 6 make up the en-route stage (which is also called the climb-cruise-descent (**CCD**) stage), and Phases 7, 8, and 9 make up the landing stage. Phases 7, 8, and 9 of a particular flight of an aircraft and Phases 1, 2, and 3 of the next flight of that same aircraft are known as a landing and take off (**LTO**) cycle.

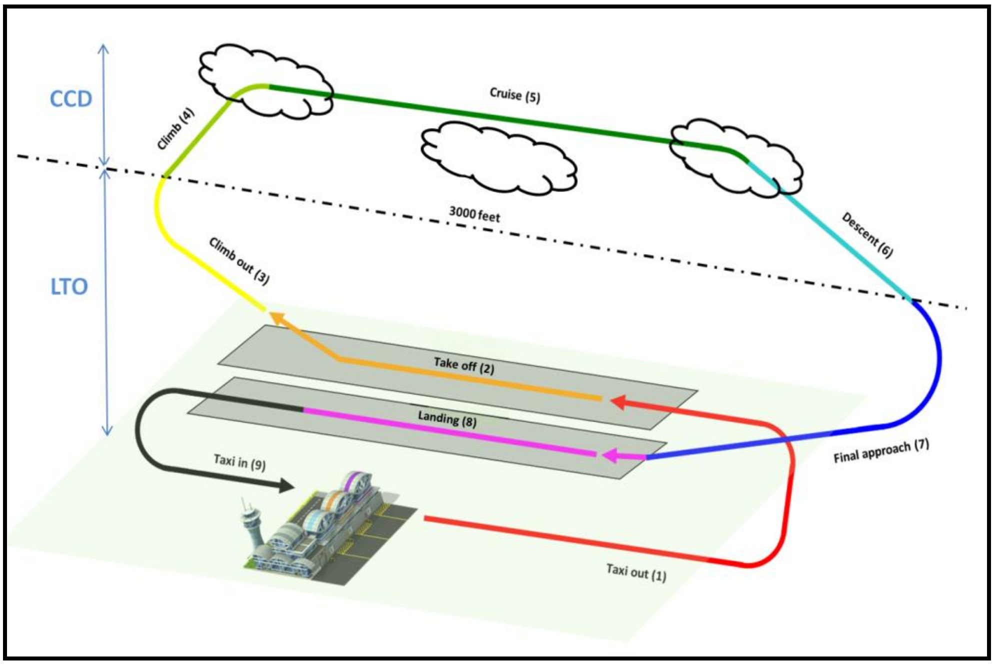

Figure 3: The phases of a flight from gate to gate (based on a figure originally found in the 2009 version of [7]).

[11] According to ICAO, altitude is defined as "*the vertical distance of a level, a point, or an object considered as a point, measured from the mean sea level*", height is defined as "*the vertical distance of a level, a point, or an object considered as a point, measured from a specific datum*", such as the surface of the Earth, and elevation is defined as "*the vertical distance of a point or a level, on or fixed to the surface of the Earth, measured from mean sea level*. So elevation is the altitude of the ground or a building.

ICAO has defined a set of default engine modes of operation, each associated with a specific engine thrust setting and a time spent in that mode, for the various phases of the LTO cycle.

Phase(s)	Engine mode	Thrust setting	Time spent in mode	
			(seconds)	(hh:mm:ss)
1) Taxi out	Idle	7%	1,140	00:19:00
2) Take off	Take off	100%	42	00:00:42
3) Climb out	Climb out	85%	132	00:02.12
7) Final approach	Approach	30%	200	00:03:20
8) Landing	Approach	30%	40	00:00:40
9) Taxi in	Idle	7%	420	00:07:00

Table 3: Default ICAO LTO cycle engine thrust settings and times in mode.

2.4.2 Internal (domestic) and external (international) flights

For the purposes of reporting for a particular geographic region, which can be the territory of a particular state or the combined territories of several states or some other region, every flight can be classified as being:

- an internal flight,
- an external flight, or
- a flight that is not of interest (**NOI**).

An internal flight is a flight for which both the departure airport and the arrival airport are located in the same geographic region. When the geographic region is the territory of a particular state, an internal flight is known as a domestic flight.

An external flight is a flight for which the departure airport is in one geographic region and the arrival airport is in another geographic region. When each one of the two geographic regions is the territory of a state, an external flight is known as an international flight.

Any flight that passes through the airspace above a particular geographic region but that neither starts from nor ends in that region is a flight that is not of interest for the purposes of reporting for that geographic region.

So how is a particular flight classified in a particular region ?

Consider three regions, Region **X**, Region **Y**, and Region **Z**. Airports **A**$_X$ and B$_X$ are located in Region **X**, Airports **C**$_Y$ and **D**$_Y$ are located in Region **Y**, and Airport **E**$_Z$ is located in Region **Z**. See **Error! Reference source not found.** below (in which neither Region **Z** nor Airport **E**$_Z$ is shown).

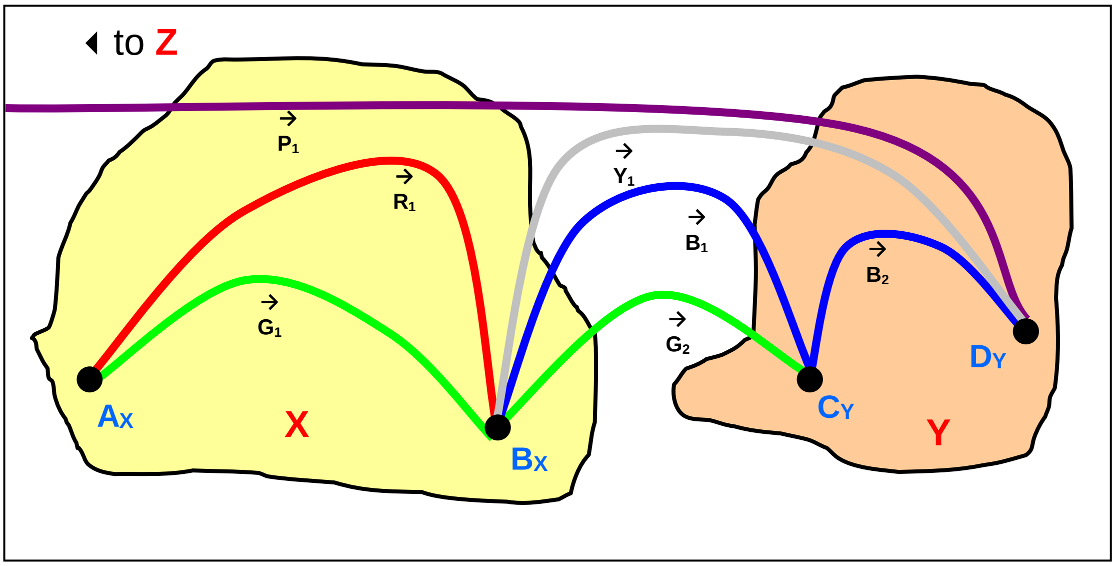

Figure 4: Flight scenarios

According to Table 2.9 of Section 2.5.1.3 of the Good Practice Guidance of the Intergovernmental Panel on Climate Change (**IPCC**) [**8**], there are six situations that need to be envisaged when determining if a flight is an internal or an external one. The contents of the table from that document are reproduced below using terminology appropriate to **Error! Reference source not found.**. Flights **B_1** and **B_2** are shown in **blue**, Flights **G_1** and **G_2** are shown in **green**, Flight **R_1** is shown in **red**, Flight **Y_1** is shown in **grey**, and Flight **P_1** is shown in **purple**.

Scenario		Flight	For X	For Y
1)	A flight from A_X to B_X.	**R_1**	Internal	NOI
2)	A flight from B_X to D_Y.	**Y_1**	External	NOI
3)	A flight from A_X to B_X (**G_1**), where no passengers or freight are dropped off or loaded, followed by a flight of the same aircraft from B_X to C_Y (**G_2**).	**G_1**	External	NOI
		G_2	External	NOI
4)	A flight from A_X to B_X (**G_1**), where no passengers or freight are dropped off but some passengers or freight are loaded, followed by a flight of the same aircraft from B_X to C_Y (**G_2**).	**G_1**	External	NOI
		G_2	External	NOI
5)	A flight from A_X to B_X (**G_1**), where some passengers or freight are dropped off and some other passengers or freight are loaded, followed by a flight of the same aircraft from B_X to C_Y (**G_2**).	**G_1**	Internal	NOI
		G_2	External	NOI
6)	A flight from B_X to C_Y (**B_1**), where no passengers or freight are dropped off or loaded, followed by a flight of the same aircraft from C_Y to D_Y (**B_2**).	**B_1**	External	NOI
		B_2	External	NOI

Table 4: The definition of internal (domestic) and external (international) flights according to the IPCC.

For the sake of completeness, the following five situations can be added to this table:

Scenario		Flight	For X	For Y
7)	A flight from A_X to B_X (**G_1**), where some passengers or freight are dropped off but no passengers or freight are loaded, followed by a flight of the same aircraft from B_X to C_Y (**G_2**).	**G_1**	Internal	NOI
		G_2	External	NOI
8)	A flight from B_X to C_Y (**B_1**), where some passengers or freight are dropped off but no passengers or freight are loaded, followed by a flight of the same aircraft from C_Y to D_Y (**B_2**).	**B_1**	External	NOI
		B_2	NOI	Internal
9)	A flight from B_X to C_Y (**B_1**), where no passengers or freight are dropped off but some passengers or freight are loaded, followed by a flight of the same aircraft from C_Y to D_Y (**B_2**).	**B_1**	External	NOI
		B_2	NOI	Internal
10)	A flight from B_X to C_Y (**B_1**), where some passengers or freight are dropped off and some other passengers or freight are loaded, followed by a flight of the same aircraft from C_Y to D_Y (**B_2**).	**B_1**	External	NOI
		B_2	NOI	Internal
11)	A flight from E_Z to D_Y.	**P_1**	NOI	NOI

Table 5: Additional definitions of internal (domestic) and external (international) flights.

For Region **X**, it can be seen that Flight **G_1** is classified as an internal flight in Scenarios 5 and 7 and as an external flight in Scenarios 3 and 4. If no information is available about the numbers of passengers boarding or alighting from the aircraft at Airport **B_X**, there is no way to distinguish between Scenarios 3), 4), 5), and 7) for Flight **G_1** and hence no way to know if **G_1** should be classified as an internal flight or an external flight. Also, for Region **Y**, Flight **B_2** is classified as an internal flight in Scenarios 8, 9, and 10 and as a NOI flight in Scenario 6. Again, if no information is available about the numbers of passengers boarding or alighting from the aircraft at Airport **C_Y**, there is no way to distinguish between Scenarios 6), 8), 9), and 10) for Flight **B_2** and hence no way to know if Flight **B_2** should be classified as an internal flight or a NOI flight.

For practical reasons, in a move away from the IPCC method, in the FEIS procedure, if the departure and arrival airports are located in the same region of interest, the flight is classified as an internal flight. If not, the flight is classified as an external flight. Thus, for Region **X**, Flights **G_1** and **R_1** are always classified as internal flights and Flights **B_1**, **G_2**, and Y_1 are always classified as external flights. For Region **Y**, Flight **B_2** is always classified as an internal flight. And for Region **Z**, Flight **P_1** is always classified as an external flight.

2.4.3 Modelling a flight

A flight can be split into 3 sections, namely:

- a ground section at the departure airport,
- an airborne section between the departure and arrival airports, and
- another ground section at the arrival airport.

The ground section at the departure airport consists of the route followed by the aircraft from the moment it leaves the gate until the moment it takes off; this is the taxi-out phase.

Similarly, the ground section at the arrival airport consists of the route followed by the aircraft from the moment it lands until the moment it stops at the gate; this is the taxi-in phase.

The airborne section consists of the path through the air followed by the aircraft from the moment it takes off until the moment that it lands. The projection of the three-dimensional (**3D**) path onto the ground gives the two-dimensional (**2D**) route over the ground followed by the aircraft during the airborne section.

If the time that the aircraft passed each point of the 3D path is known, you have the actual four-dimensional (**4D**) trajectory of the aircraft, which includes the take-off, climb out, climb, cruise, initial descent, final approach, and landing phases.

Usually, the actual 4D trajectory of a flight is not precisely known but it too can be modelled in a number of ways, the simplest of which is to assume that the 2D path over the ground is the great circle between the nominal locations of the departure and arrival airports. Another way to model a 4D trajectory is as a sequence of straight-line segments, each segment connecting two 4D points together, as indicated in Figure 5. A 4D point is fully specified by specifying both its 3D position (its latitude, longitude, and flight level) and the time that the aircraft was at that position. The 4D points can be derived from the points of a route network, the points found in a flight plan, or radar plots from a radar tracking system.

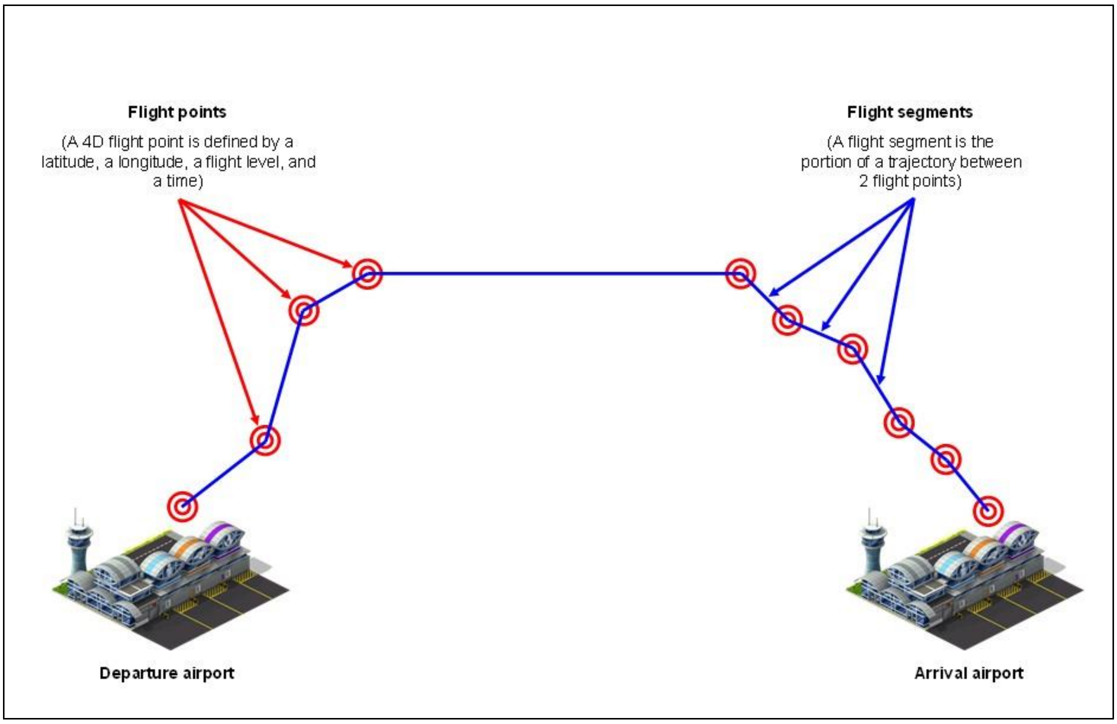

Figure 5: The notion of flight point and flight segment.

2.5 Reporting

2.5.1 Reporting to the UNFCCC

When reporting to the UNFCCC, the masses of the emissions due to internal civil flights in all phases of flight need to be included in a party’s “national” emissions totals and the masses of emissions due to departing external flights need to be reported in a separate annex. The masses of emissions of arriving external civil flights do not have to be counted by the reporting party. These allocation rules have to be applied irrespective of the nationality of the associated airline.

Once again, consider three regions, Region **X**, Region **Y**, and Region **Z**, in which Airports **A**$_X$, **B**$_X$, **C**$_Y$, **D**$_Y$, and **E**$_Z$ are located. See **Error! Reference source not found. Error! Reference source not found.** in which **Z**, **C**$_Y$, and **E**$_Z$ are not shown.

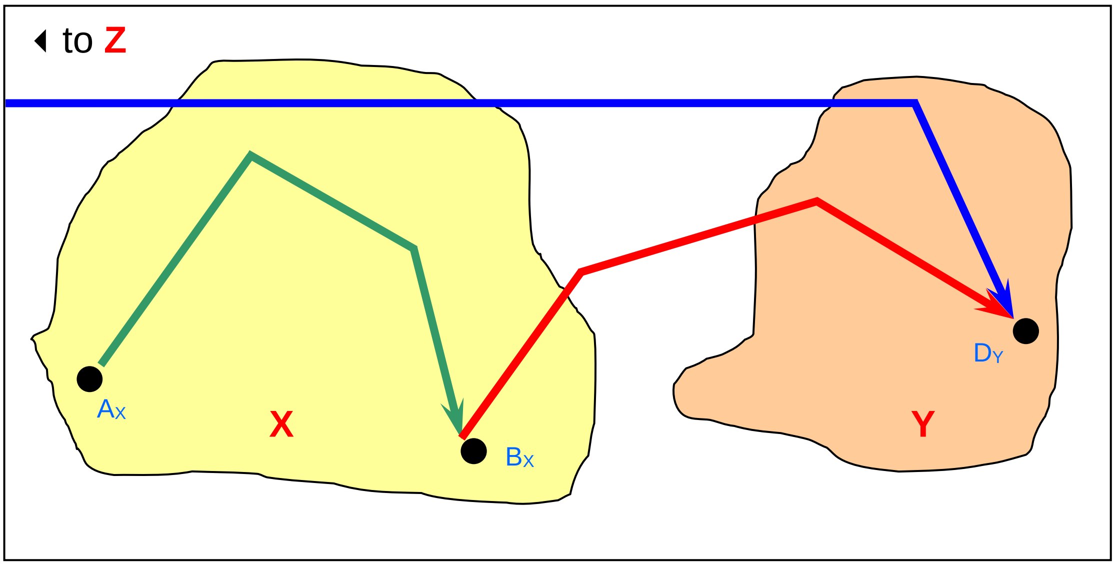

Figure 6: Reporting to the UNFCCC

The masses of the emissions during the internal flight from Airport **A**$_X$ to Airport **B**$_X$ (represented by the green flight segments) have to be included in the **national emissions totals** for Region **X**.

The masses of the emissions during the external flight from Airport **B**$_X$ to Airport **D**$_Y$ (represented by the red flight segments) have to be included in the **separate annex** for Region **X**.

The masses of the emissions during the external flight from Airport **E**$_Z$ (in Region **Z**) to Airport **D**$_Y$ (represented by the blue flight segments) are <u>not</u> reported by Region **Y** (but they are included in the **separate annex** for Region **Z** if Region **Z** is a region that reports to the UNFCCC).

So, for the case of Region **X**, in the same way as for any other region, two totals are calculated, namely:

- the **national emissions total** for Region **X** and
- the **separate annex** for Region **X**.

2.5.2 Reporting to the CLRTAP

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

- external (international) airport traffic (LTO cycles below 3,000 feet),
- external cruise traffic (above 3,000 feet),
- internal (domestic) airport traffic (LTO cycles below 3,000 feet), and
- internal cruise traffic (above 3,000 feet).

When reporting to the CLRTAP, the masses of all aviation emissions during the LTO cycle (i.e. within 3,000 feet of the ground) need to be included in a region's "national" totals irrespective of whether the flight is internal or external (but note that the internal component has to be reported separately from the external component) and the masses of the emissions emitted above 3,000 feet need to be reported separately (again being split between internal and external totals).

Thus, regarding the situation shown in **Error! Reference source not found.**:

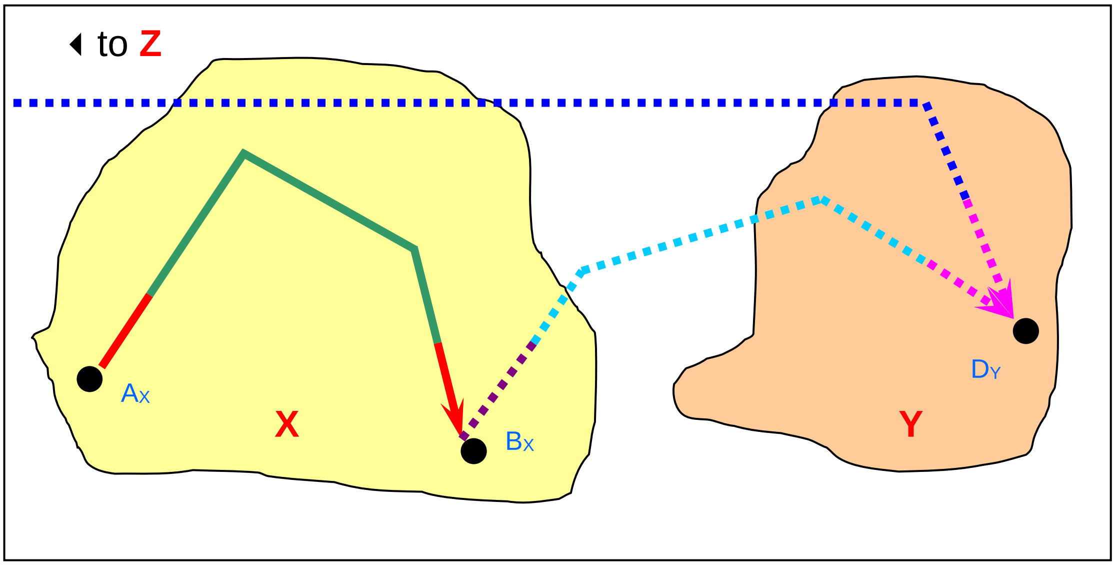

Figure 7: Reporting to the CLRTAP

the masses of the emissions below 3,000 feet for the internal flight from Airport **Ax** to Airport **Bx** (represented by the solid red flight segments) have to be included in the **internal (domestic) LTO-cycle-total** for Region **X**.

The masses of the emissions below 3,000 feet for the initial part of the external flight from Airport Bx to Airport **Dy** (represented by the dashed violet flight segment) have to be included in the **external (international) LTO-cycle-total** for Region **X**.

The masses of the emissions below 3,000 feet for the final parts of both the external flight from Airport **Bx** to Airport **Dy** and the external flight from Region **Z** that arrives at Airport **Dy** (represented by the dashed purple flight segments) have to be included in the **external (international) LTO-cycle-total** for Region **Y**.

The masses of the emissions above 3,000 feet for the internal flight from Airport **Ax** to Airport **Bx** (represented by the solid green flight segments) have to be included in the **internal (domestic) cruise stage total** for Region **X**.

The masses of the emissions above 3,000 feet for the external flight from Airport **Bx** to Airport **Dy** (represented by the dashed light blue flight segments) have to be included in the **external (international) cruise stage total** for Region **X**.

The masses of the emissions above 3,000 feet for the international flight from Airport **Ez** (in Region **Z**) to Airport **Dy** (represented by the dashed dark blue flight segments) are not reported by Region **Y** (but they are reported in the **external (international) cruise stage total** for Region **Z** if Region **Z** is a region that reports to the CLRTAP).

So, for the case of Region **X**, in the same way as for any other region, four totals are calculated, namely:

- the **internal (domestic) LTO-cycle-total** for Region **X**,
- the **external (international) LTO-cycle-total** for Region **X**,
- the **internal (domestic) cruise stage total** for Region **X**, and
- the **external (international) cruise stage total** for Region **X**.

2.6 The calculation of emissions

Both the UNFCCC and CLRTAP define three methods of increasing complexity for calculating the emissions due to aviation depending on the data that is available as well as the importance of aviation emissions with reference to the national totals. See Section 3.6 of Volume 2 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [**9**] for more information.

2.6.1 Types of calculation

2.6.1.1 Tier 1 calculations

Tier 1 calculations are based on the quantity of fuel sold for aviation purposes (which can be split between the stages of the LTO cycle and the en-route stage) for internal/domestic and external/international aviation separately.

2.6.1.2 Tier 2 calculations

Tier 2 calculations are performed if it is possible to obtain information on the number of LTO cycles per type of aircraft but there is no information available on the distances flown in the en-route stage. The types of aircraft used for both internal and external aviation need to be known as well as the number of LTO cycles performed by the various types of aircraft.

2.6.1.3 Tier 3 calculations

Tier 3 calculations are based on actual flight trajectory data.

To perform Tier 3A calculations, the departure and arrival airports and the type of aircraft have to be known for each flight. Average fuel consumption and emission data are assumed for the stages of the LTO cycle and various distances flown during the en-route stage are assumed for a representative array of aircraft categories.

The fact that the mass of emissions varies in the different stages of flight is taken into account by the Tier 3A method. Also taken into account is the fact that the rate at which fuel is burnt is dependent on the distance flown, being relatively higher for shorter flights than for longer flights (due to the fact that more fuel is used per unit distance during the stages of the LTO cycle than during the en-route stage).

In the Tier 3B method, the masses of fuel burnt and emissions produced are calculated throughout the whole flight using aircraft- and engine-specific aerodynamic performance information. A sophisticated computer model is required to address all the equipment, performance, and trajectory variables and calculations for all flights in a given year.

3. The FEIS procedure

The goal of the FEIS procedure is to generate estimates of the total masses of both jet fuel and avgas burnt and of the species of interest emitted for the relevant flights during a particular calendar year that are as close as possible to the actual masses.

3.1 Relevant flights

For the FEIS procedure, a relevant flight for a particular polity [12] is a civil IFR flight (of either a fixed-wing aircraft or a helicopter) that departed from, or arrived at, an airport (or an aerodrome or a heliport) that is located in a relevant part of the territory of that polity. Flight plans exist for all IFR flights. See Appendix B for the list of airports that are located in the relevant parts of the territories of the relevant polities. Note that the Principality of Liechtenstein has just one heliport (Balzers heliport, whose ICAO code is **LSXB**). As there are no recorded IFR flights into or out of this heliport, nothing has to be calculated for the Principality of Liechtenstein in the FEIS procedure.

3.2 Some terminology

For the purposes of the FEIS procedure, and this document, an aircraft that actually made a relevant flight is referred to as an actual aircraft, which is considered to be composed of an airframe of a particular type and one or more engines each of the same type. Consequently, the type of an actual aircraft can be specified by specifying the type of its airframe and the type of its engine(s).

Obviously two aircraft with the same type of airframe but different types of engine(s) are of different types as are two aircraft with different types of airframe but the same type of engine(s).

If a particular string of characters is defined and then used to designate the type of an aircraft then that string of characters is a *type-of-aircraft* designator. Similarly, a *type-of-airframe* designator designates a particular type of airframe and a *type-of-engine* designator designates a particular type of engine.

The values that a type designator can take can be codes or names. In the Aircraft Engine Emissions Database (**AEED**) [**10**] for turbojet and turbofan engines, which is maintained by the European Aviation Safety Agency (**EASA**) on behalf of ICAO, each type of engine that has an entry in the database is designated by means of both a *type-of-engine* name and a *type-of-engine* code. As an example, a particular type of engine that is manufactured by CFM International is designated by the *type-of-engine* name **CFM56-5C2** and also by the *type-of-engine* code **1CM010**.

Similar databases, such as the confidential FOI [13] database (for turboprop engines) or the Federal Office of Civil Aviation (**FOCA**) database (for piston engines), contain emissions data. See Section 3.4.2.3 below for further information about aircraft-engine-emissions databases.

[12] A polity is generally understood to designate any geographic area that has a corresponding government. Therefore, a polity can be a super-state, like the EU, or one of its subordinate civil authorities, such as a state, province, region, county, municipality, city, district, etc.
[13] **FOI** is the Swedish Defence Research Agency.

ICAO has defined a set of *type-of-aircraft* codes whose purpose is to designate the different types of aircraft found in flight planning activities. See ICAO DOC 8643 [**11**]. Each ICAO *type-of-aircraft* code is a string of 2, 3, or 4 alphanumeric characters. Two examples are **A1**, which, for ICAO, designates the type of an aircraft that is known as a **Douglas Skyraider**, and **B744**, which, again for ICAO, designates the type of an aircraft that is known as a **Boeing 747 400**.

In the FEIS procedure, ICAO *type-of-aircraft* codes are used to designate types of airframe (and **not** types of aircraft), which, of course, can also be designated by *type-of-airframe* names like **Airbus A340-200**, and either *type-of-engine* names, such as **CFM56-5C2** [14], or *type-of-engine* codes, such as **1CM010**, are used to designate types of engine.

So, for example, if an aircraft is composed of an airframe, of the type designated by the *type-of-airframe* name **Airbus A340-200**, and engines, of the type designated by the *type-of-engine* name **CFM56-5C2**, then the type of the airframe of this aircraft is also designated by the ICAO *type-of-aircraft* code **A342** and the type of the engines of this aircraft is also designated by the *type-of-engine* code **1CM010**. Consequently, the type of this aircraft can be designated by any one of the following pairs of designators:

- {**Airbus A340-200**, **CFM56-5C2**},
- {**Airbus A340-200**, **1CM010**},
- {**A342**; **CFM56-5C2**}, and
- {**A342**, **1CM010**}.

If flight-plan data about the flight of an actual aircraft is recorded in the PRISME database (see Section 3.4.2.1 below) then that data contains designators of both the supposed type of the airframe of the actual aircraft (referred to as the PRISME type of the airframe) and the supposed type of the engine(s) of the actual aircraft (referred to as the PRISME type of the engine(s)). A PRISME type of airframe is designated by a PRISME *type-of-airframe* code that is supposed to be equal to an ICAO *type-of-aircraft* code and a PRISME type of engine is designated by a PRISME *type-of-engine* name.

In an ideal world, for an actual aircraft of the type designated by the pair {**A342**, **CFM56-5C2**}, the PRISME *type-of- airframe* code would have the value **A342** and the PRISME *type-of-engine* name would have the value **CFM56-5C2**. Sometimes, though, in the real world, the PRISME *type-of-airframe* code does not correctly designate the type of the airframe of the actual aircraft and/or the PRISME *type-of-engine* name does not correctly designate the type of the engine(s) of the actual aircraft.

The types of engine for which data exists in one of the aircraft engine emissions databases are referred to in this document as DB types of engine. Each DB type of engine is designated in the databases by a DB *type-of-engine* name and a possibly a DB *type-of-engine* code. Thus, for example, as mentioned above, one of the types of engine that has an entry in the AEED is designated by the DB *type-of-engine* name **CFM56-5C2** and by the DB *type-of-engine* code **1CM010**. As there are no DB *type-of-engine* codes assigned to types of engine that have entries in the FOCA and FOI databases, *type-of-engine* codes have been arbitrarily assigned by the EUROCONTROL FEIS team to the types of engine that have entries in these two databases.

Although a particular type of aircraft can be specified by specifying the type of its airframe and the type of its engine(s), another way to designate it is by means of a *type-of-aircraft* designator. The EUROCONTROL FEIS team has defined a set of FEIS *type-of-aircraft*

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[14] **CFM56-5C2** is the name of a type of engine manufactured by CFM International.

codes to designate types of aircraft that have an airframe of a type designated by an ICAO *type-of-aircraft* code and one or more engines of a type designated by a DB *type-of-engine* name/code.

An FEIS *type-of-aircraft* code is a string of characters that is constructed by concatenating:

- an ICAO *type-of-aircraft* code,
- a dash, and
- a single upper-case letter of the alphabet.

An example of an FEIS *type-of-aircraft* code is **A320-A**. Consequently, any one type of airframe, designated by a particular ICAO *type-of-aircraft* code, **XXXX**, could be associated with as many as 26 different FEIS *type-of-aircraft* codes, **XXXX-A**, **XXXX-B**, to **XXXX-Z**, each one designating an aircraft with an airframe of type **XXXX** but with different DB types of engine. Initially, a maximum of 14 different DB types of engine were associated with any one particular type of airframe and so it will be possible to define further types of aircraft with the same type of airframe and new DB types of engine in the future.

Another database that is used in the FEIS procedure is the BADA database. (See Section 3.4.2.4 below for more information about the BADA database.) The types of aircraft for which data exists in the BADA database are referred to as BADA types of aircraft; each BADA type of aircraft, which is designated by an ICAO *type-of-aircraft* code, is associated with one, and only one, type of engine (its BADA type of engine).

Once again, in an ideal world, every PRISME *type of airframe* code would be the same as an ICAO *type-of-aircraft* code that, itself, would designate a type of aircraft that has an entry in the BADA database. And every PRISME *type-of-engine* name would designate a type of engine that has an entry in at least one of the engine-emissions databases. In practice though, this is far from the case.

3.3 An overview of the FEIS procedure

Because information about the trajectory followed by an actual aircraft when it is below 3,000 feet is not usually available, in the FEIS procedure only that part of the trajectory from the moment that the actual aircraft climbs above a height of 3,000 feet just after take off until the moment that it descends below 3,000 feet just before landing is determined as accurately as possible.

Consequently, each relevant flight is split into 3 stages, namely:

- a **take-off** stage, at the departure airport, from the moment that the actual aircraft leaves the gate until the moment that it reaches a height [15] of 3,000 feet,
- a **cruise** stage, from the moment that the actual aircraft climbs above a height of 3,000 feet after take-off until the moment that it descends below a height of 3,000 feet just prior to landing, and
- a **landing** stage, at the arrival airport, from the moment that the actual aircraft descends below a height of 3,000 feet until it comes to a stop at its gate.

The way that the masses of the jet fuel and avgas burnt and the corresponding masses of the species of interest emitted are calculated for the take-off and landing stages is different from the way that they are calculated for the cruise stage, as will be shown in Section 3.4.1.4. The calculation used in the FEIS procedure is a mix of a Tier 3A and Tier 3B calculation. For the LTO stages, a Tier 3A calculation is performed with the assumption that the LTO stages are

[15] Height is measured from ground level.

described by an ICAO LTO cycle but with the default ICAO taxi-in and taxi-out times being replaced by more accurate values if available. Average fuel consumption and emission data are assumed for each FEIS type of aircraft.

For the en-route stage, a Tier 3B calculation is performed in which the masses of the jet fuel and avgas burnt and the masses of some of the species of interest emitted are calculated on a flight segment by flight segment basis. The masses of the remaining species of interest emitted are then calculated.

For a particular calendar year being considered, the first thing to do is to determine which flights are relevant and then to obtain some data about each of those relevant flights.

There are several sources for this data. The main source is EUROCONTROL's PRISME database, which contains the corrected flight plan for each flight for which the trajectory has at least a part that is inside EUROCONTROL airspace.

Other sources of flight data include the publicly-available databases of scheduled flights such as the OAG and Innovata flight schedule databases. OAG and Innovata are air travel intelligence companies that provide data about scheduled flights.

Once a relevant flight has been identified, the 4D trajectory of the actual aircraft in the cruise stage of the flight is determined as precisely as possible. Now, in the PRISME database, the corrected flight plan for a flight contains a description of the part of the trajectory that the actual aircraft followed that occurred in EUROCONTROL airspace. So, the corrected flight plan concerning a flight from Paris Charle de Gaulle (**CDG**) Airport to Vienna International Airport contains a description of the whole trajectory flown whereas the corrected flight plan concerning a flight from Paris CDG to John F. Kennedy International Airport in New York contains a description of only that part of the trajectory flown in EUROCONTROL airspace; the rest of the trajectory, at least that part that is above 3,000 feet, has to be estimated. And if a flight has a trajectory that is entirely outside EUROCONTROL airspace, such as a flight from Pointe-à-Pitre International Airport, which is located on the island of Guadeloupe, to Aimé Césaire International Airport, which is located on the island of Martinique, then there would be no corrected flight plan in the PRISME database. The existence of a flight such as this last one would be deduced from the scheduled flight data provided by sources (such as the OAG and Innovata databases mentioned above) other than EUROCONTROL's databases and the whole trajectory above 3,000 feet has to be estimated.

For details of the calculations for the take-off and landing stages of a flight, see Section 3.4.1.4.1.

Once the (cruise stage part of the) 4D trajectory of an actual aircraft has been determined, the mass of fuel that was burnt and the masses of the species of interest emitted by the actual aircraft can be estimated for each of the 3 stages of the flight.

The rate that fuel is burnt and the engine emission data that are required to perform these calculations are mainly derived from the data stored in a number of aircraft engine emissions databases, namely the AEED for turbojet and turbofan engines, the FOI database for turboprop engines, and the FOCA database for piston engines.

For the cruise stage only, the FEIS procedure uses EUROCONTROL's Advanced Emission Model (**AEM**) to determine the masses of the jet fuel and avgas that were burnt as well as the masses of some of the species of interest that were emitted. This subset of the species of interest is referred to as the AEM species.

The AEM makes use of Version 3.13 of the BADA database. The BADA database currently contains rate of fuel burn data for 519 types of aircraft, each type of aircraft being associated with one specific type of engine in the BADA database.

To perform the emissions calculations, the engine emissions data mentioned above (such as that derived from the AEED) and the rate of fuel burn data from the BADA database are modified in accordance with the atmospheric conditions at the altitude of the aircraft making the flight by using a method known as the Boeing Fuel Flow Method 2 (**BFFM2**) [**12**].

By summing the mass of jet fuel and avgas that was burnt, and the masses of the AEM species that were emitted, for each and every one of the relevant flights during the calendar year being considered, the total annual masses of jet fuel and avgas burnt and of the AEM species emitted can be estimated. The total annual masses of the other species of interest that were emitted can then be derived from this data.

This FEIS procedure is shown schematically in Figure 8 below.

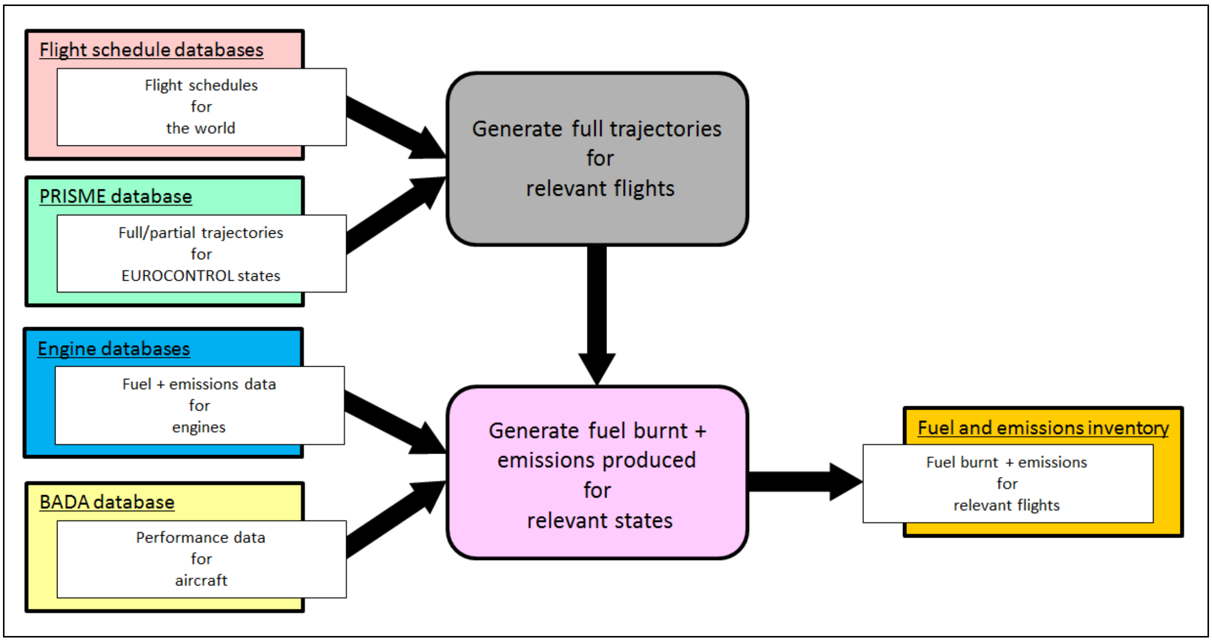

Figure 8: A system model of the FEIS procedure.

3.4 Tools and databases used in the FEIS procedure

3.4.1 The AEM

The AEM [**13**] is one of the models that have been "*approved for use*" by the Modelling and Databases Group [**14**] of ICAO's Committee on Aviation Environmental Protection and so is suitable for conducting studies for them.

Using precise flight trajectory information combined with more detailed information about fuel flow and specific engine emissions both for the stages of the LTO cycle and the en-route stage, for a particular phase or segment of the flight of an aircraft, the AEM produces an estimate of the mass of fuel burnt by the main engines of that aircraft and the corresponding masses of certain gaseous and particulate emissions that are produced by the burning of that fuel. No account is taken of the use of any APU in the aircraft.

Information about the aircraft trajectory is provided to the AEM in the form of a flight data input file and the resulting masses of fuel burnt and AEM species emitted are recorded in the output file.

Below 3,000 feet, the fuel burn calculation is based on the ICAO LTO cycle. As seen in Table 3 on Page 22, the ICAO LTO cycle covers four modes of engine operation and six phases of flight.

3.4.1.1 Species for which emitted masses are estimated

Estimates of the emitted masses of the following species are generated by the AEM:

- carbon dioxide,
- NO_X,
- 1,3-butadiene,
- acrolein,
- ethylbenzene,
- non-volatile PM [16] (**$PM_{non\text{-}vol}$**),
- volatile sulphuric PM [18], (**$PM_{vol\text{-}sul}$**),
- the seven PAH compounds, which includes the four 4-PAH compounds, that are known collectively as 7-PAH[19],
- styrene,
- UHCs,
- the xylenes.
- carbon monoxide,
- SO_X,
- acetaldehyde,
- benzene,
- formaldehyde,
- volatile organic PM [17] (**$PM_{vol\text{-}org}$**),
- propionaldehyde,
- the sixteen PAH compounds, which includes the seven 7-PAH compounds, that are known collectively as 16-PAH[20],
- toluene,
- water vapour, and

Note that, of the species of interest, the AEM does <u>not</u> generate estimates of the emitted masses of:

- NMVOCs,
- methane,
- nitrous oxide,
- 4-PAH,
- $PM_{2.5}$,
- PM_{10}, or
- PM_{total}

as is indicated in Figure 9 below. Nevertheless, estimates of these quantities can be made (as is shown in Section 3.5.6 below).

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[16] Non-volatile PM is essentially soot, but it can also be dust or metal or ceramic particles.
[17] Volatile organic particulate matter is created by nucleation around organic compounds.
[18] Sulphuric particulate matter is created by nucleation around sulphuric acid (H_2SO_4).
[19] 7-PAH was named POM7PAH in previous versions of this document.
[20] 16-PAH was named POM16PAH in previous versions of this document.

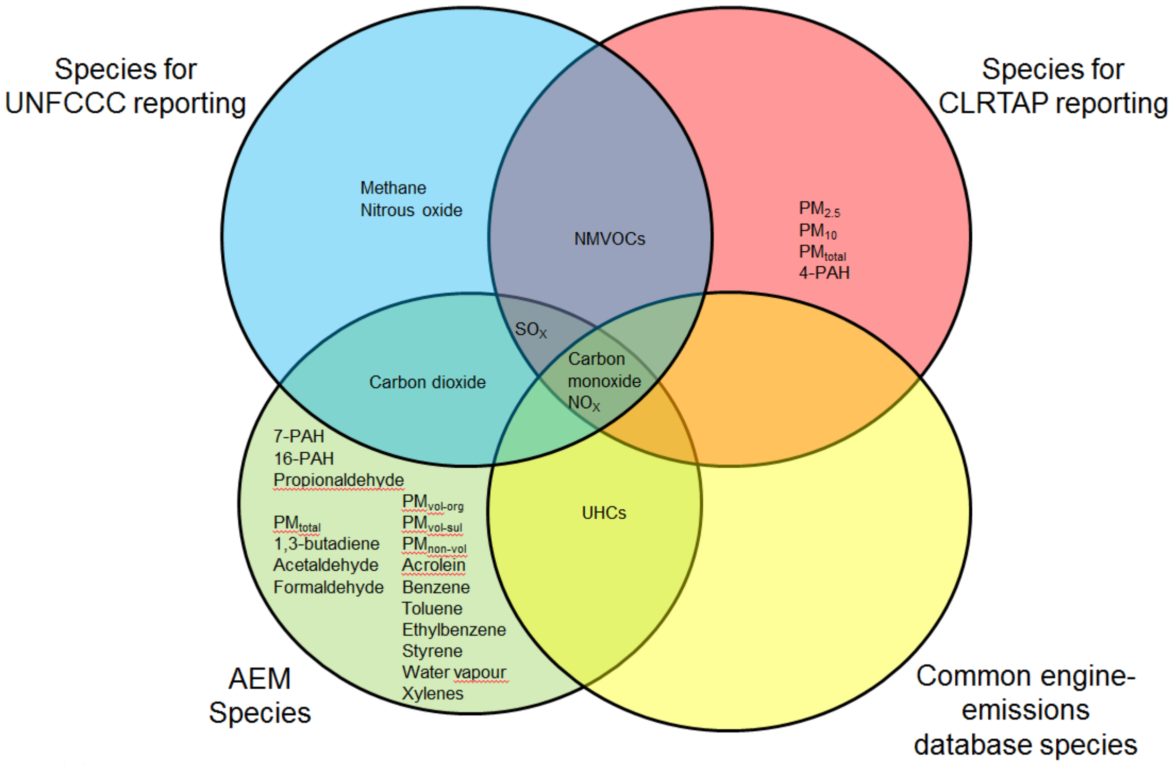

Figure 9: A Venn diagram showing the species required for CLRTAP and UNFCCC reporting, as well as the AEM species and the emissions database species. Note that PM_{total} is required for CLRTAP reporting and is also an AEM species.

3.4.1.2 The information required by the AEM

The AEM has to be supplied with information about various entities.

In this section, the colour of each bullet point indicates the input file that is the source of the information. The input files are described in the next section (Section 3.4.1.3).

3.4.1.2.1 Information about the type of aircraft

The information that is required about the actual aircraft is:

- the type of the airframe of the aircraft,
- the type of the engine powering the aircraft,
- the number of engines powering the aircraft, and
- the rate at which fuel is burnt [in kilograms per minute] by this type of aircraft (or a similar type as decided by expert judgment) as a function of the altitude [in flight levels] and attitude (climbing, cruising, or descending) of the aircraft.

3.4.1.2.2 Information about the type of engine

The information that is required about the type of engine(s) powering the actual aircraft is:

- the rate at which fuel is burnt [in kilograms per second] by one engine of that type when the power setting is 7%, 30%, 85%, and 100% of the maximum power setting
- the rate [in kilograms per second] at which:
  - carbon monoxide,
  - UHCs,
  - NO_X,
  - $PM_{non-vol}$,
  - $PM_{vol-org}$, and
  - $PM_{vol-sul}$

  are emitted by one engine when the power setting is 7%, 30%, 85%, and 100% of the maximum power setting.

3.4.1.2.3 Information about the flight

The information that is required about the flight is:

- the identity of the flight,
- the identity of the departure airport,
- the identity of the destination airport, and
- the trajectory of the aircraft during the cruise stage of the flight.

The trajectory of the aircraft during the cruise stage is modelled as a sequence of straight-line segments. The information that is required about each segment of the trajectory is:

- the identifier of the segment of the cruise stage of the flight,
- the 3D location of the start of the segment,
- the date and time that the aircraft was at the start of the segment,
- the 3D location of the end of the segment,
- the date and time that the aircraft was at the end of the segment, and
- the aircraft attitude (climb, cruise, or descent) during the segment.

A 3D location is specified by:

- a latitude [in degrees East],
- a longitude [in degrees North], and
- an altitude [in flight levels]

A date is expressed in the year-month-day (**YYMMD**) format and a time is expressed in the hour-minute-second (**hhmmss**) format.

3.4.1.2.4 Information about the departure airport

The information that is required concerning the departure airport is:

- the relevant taxi-out time at that airport,
- the ICAO default duration of the take-off phase, and
- the ICAO default duration of the climb-out phase.

3.4.1.2.5 Information about the arrival airport

Similarly, the information that is required concerning the arrival airport is:

- the relevant taxi-in time at that airport,
- the ICAO default approach time, and
- the ICAO default landing time.

3.4.1.2.6 Information about the atmosphere

The atmosphere is modelled by the ICAO standard atmosphere and so:

- the pressure [in Pascals],
- the temperature [in Kelvins], and
- the relative humidity

have to be provided as functions of altitude [in flight levels].

3.4.1.2.7 Information about engine exhausts

Concerning the gaseous species found in the exhaust of aircraft engines, the masses [in kilograms] of:

- carbon dioxide,
- SO_X,
- water vapour, and
- VOCs

that are emitted for every kilogram of fuel that is burnt have to be provided.

Similarly, the masses [in kilograms] of:

- acetaldehyde,
- acrolein,
- 7-PAH,
- 16-PAH,
- styrene, and
- OGs

that are emitted for every kilogram of VOC that is emitted have to be provided as do the masses [in kilograms] of

- benzene,
- buta-1,3-diene,
- ethyl benzene,
- formaldehyde,
- propionaldehyde,
- toluene, and
- the xylenes

that are emitted for every kilogram of the OGs that is emitted.

3.4.1.3 The AEM input and output files

All the data that the AEM requires is read in from a set of input files. The fuel burnt and emissions data that the AEM produces is written out to an output file.

The main AEM input files (which are colour-coded in this document as indicated by the bullet points here) are:

- the AEM flight data file, which usually, but not necessarily, has the file extension ***.so6***,
- the AEM aircraft descriptions file, (***ACT_PRF.aircraft_engine.txt***),
- the AEM engine emissions data file (***ACT_PRF.ENGINE_LTO_VALUES.txt***),
- the AEM BADA data file (***ACT_PRF.BADA_FUEL_BURN.txt***),
- the AEM airport time-in-mode data file (***APT.airport_time_in_mode.txt***),
- the AEM system constants file (***AEM.CONSTANT_PARAMS.txt***),
- the AEM VOC-TOG constants file (***AEM.VOCTOG_CONSTANTS.txt***), and
- the AEM ICAO standard atmosphere data file (***AEM.STANDARD_ATMOS.txt***).

Other input files are:

- the AEM airport data file (***APT.AIRPORT_DATA.txt***),
- the AEM AERO2K taxi times file (***AERO2K_TaxiTimes.txt***), and
- the AEM specific aircraft type times in mode file (***Aircraft_Specific_Time_in_mode.txt***).

The results of the fuel burnt and emissions calculations are recorded in the AEM output file.

Note that the names of these input files were fixed a long time ago and don't necessarily accurately represent the data that the files now contain.

All these files are indicated in Figure 10 below and are described in the following sections.

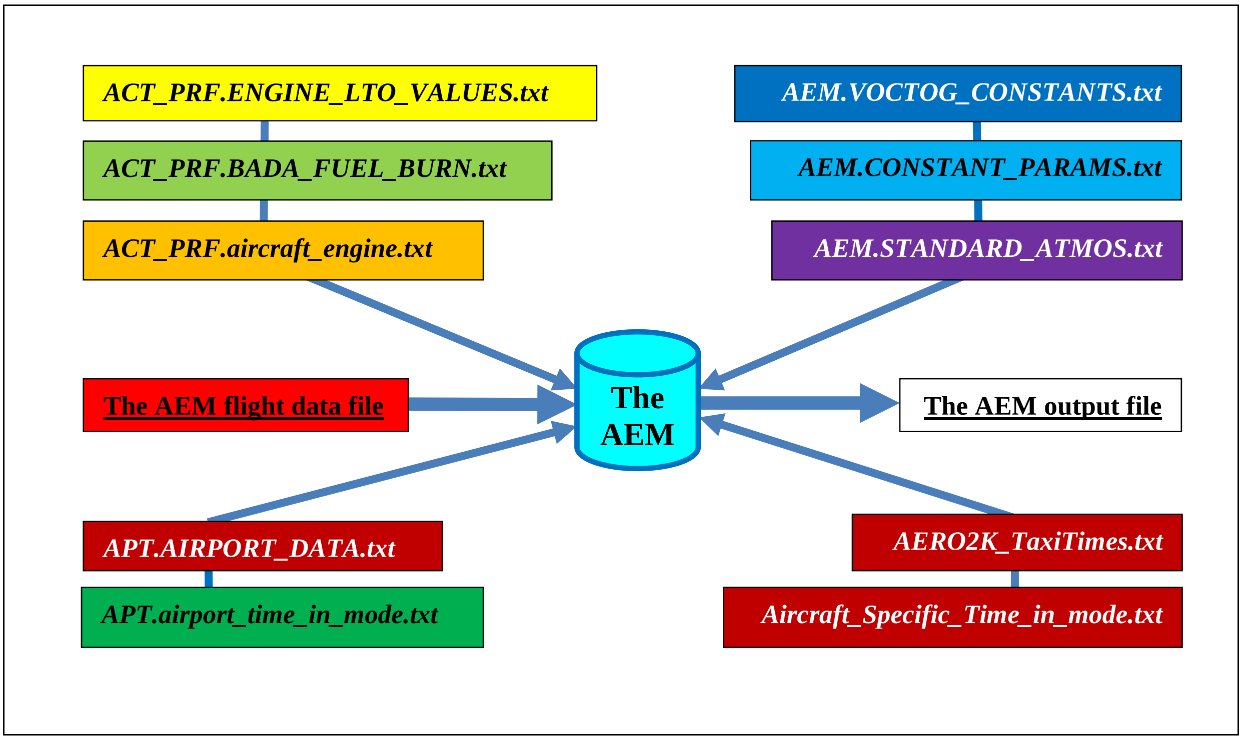

Figure 10 : The input and output files for the AEM

3.4.1.3.1 The flight data input file (■)

The flight data input file is a text file that usually has the filename extension .so6. It contains information about all the segments of all the flights that the AEM will process.

Each record in this file contains information about one particular segment of one particular flight plus some more general data about that flight. The general data includes:

- a designator of the flight (which is usually the call sign of the flight),
- a designator of the airport from which the flight departed, and
- a designator of the airport at which the flight arrived

while the data about the particular segment includes:

- a designator of the segment,
- the sequence number of the segment in the flight, the first segment in the flight having a sequence number of 1, the second a sequence number of 2, and so on,
- the type of the segment, which is one of taxi-out, take-off, climb-out, climb, cruise, descent, final approach, landing, or taxi-in,
- information about the start of the segment,
- information about the end of the segment, and
- the distance flown on the segment.

The information about the start of a segment includes:

- the date and time at which the segment started,
- the 3D location of the start point of the segment, specified by a latitude, a longitude, and a flight level,
- the ground speed and the rate of climb at the start of the segment, and
- the rate of fuel burn at the start of the segment.

Similarly, the information about the end of the segment includes:

- the date and time at which the segment ended,
- the 3D location of the end point of the segment, specified by a latitude, a longitude, and a flight level,
- the ground speed and the rate of climb at the end of the segment, and
- the rate of fuel burn at the end of the segment.

3.4.1.3.2 The ACT_PRF.aircraft_engine.txt file (■)

To be able to estimate the mass of jet fuel and avgas that was burnt by an actual aircraft following a particular trajectory, the AEM has to be provided with the type of the airframe of the aircraft, the number of engines of the aircraft, the type of those engines, and a designator of an equivalent BADA type of aircraft.

The association between a type of aircraft and the number of engines powering that type of aircraft, the type of those engines, and the equivalent BADA type of aircraft are made in the ACT_PRF.aircraft_engine.txt file.

Each record in this type of file contains information about one particular type of aircraft, namely:

- a *type-of-aircraft* designator that designates the type of the aircraft,
- a *type-of-engine* designator that designates the type of engine powering this type of aircraft,
- the number of engines powering this type of aircraft, and
- a BADA *type-of-aircraft* designator that designates an equivalent BADA type of aircraft.

The *type-of-engine* designator must designate a type of engine for which fuel burn and emissions data is available in the ACT_PRF.ENGINE_LTO_VALUES.txt file (see Section 3.4.1.3.3 below). Similarly, the BADA *type-of-aircraft* designator must designate a type of aircraft for which data is available in the ACT_PRF.BADA_FUEL_BURN.txt file (see Section o below).

Note that, as any particular type of aircraft can have at most one entry in this file, a particular type of aircraft is associated with one (and only one) type of engine. One type of engine, however, can be associated with one or more types of aircraft in this file.

Again, note that each type of aircraft in this file is associated with just one BADA type of aircraft.

In the FEIS procedure, the *type-of-aircraft* designators in this file are FEIS *type-of-aircraft* codes and the *type-of-engine* designators are DB *type-of-engine* codes

3.4.1.3.3 The ACT_PRF.ENGINE_LTO_VALUES.txt file (■)

This file contains the rate of fuel burn and emissions data for many types of engine, each of which is identified by a *type-of-engine* designator that can be, but does not have to be, the same as a *type-of-engine* designator found in the ACT_PRF.aircraft_engine.txt file.

Each record in this file contains information about one particular type of engine, namely:

- a *type-of-engine* designator that designates this type of engine,
- the rates at which fuel is burnt [in kilograms per second] by this type of engine at each of the 4 standard ICAO LTO cycle thrust settings, namely
  - 7% of maximum thrust,
  - 30% of maximum thrust,
  - 85% of maximum thrust, and
  - maximum thrust, and
- the rates at which the following species are emitted [in kilograms per second] by this type of engine at each of the 4 standard ICAO LTO cycle thrust settings:
  - carbon monoxide,
  - UHCs,
  - NO_X,
  - $PM_{non\text{-}vol}$,
  - $PM_{vol\text{-}org}$, and
  - $PM_{vol\text{-}sul}$.

In the FEIS procedure, the *type-of-engine* designators in this file are DB *type-of-engine* codes.

3.4.1.3.4 The ACT_PRF.BADA_FUEL_BURN.txt file (■)

This file contains attitude- and altitude-dependent rate of fuel burn data for many types of aircraft, each of which is identified by a *type-of-aircraft* designator. It is one of these *type-of-aircraft* designators that is found in each record of the ACT_PRF.aircraft_engine.txt file.

Each record in this file contains:

- a *type-of-aircraft* designator that designates the type of aircraft for which this data is valid,
- an attitude, which can be one of climb, cruise, or descent,
- a weight category, which is always nominal,
- a flight level,
- the rate of fuel burn for this type of aircraft in that attitude at that flight level, and
- the Mach number of this type of aircraft in that attitude at that flight level.

In the FEIS procedure, the type-of-aircraft designators are ICAO *type-of-aircraft* codes.

3.4.1.3.5 The AEM.CONSTANT_PARAMS.txt file (■)

This file contains the constants that are used in the calculations.

Each record in this file contains information about one particular constant, namely:

- the type of the constant,
- the value of the constant,
- a description of the constant, and
- the units of the constant.

Six of the records in this file contain the default ICAO LTO cycle times in mode:

```
TaxiOut;       1140;     ICAO average taxi out time;       seconds
TakeOffTime;     42;     ICAO average take off time;       seconds
ClimbOutTime;   132;     ICAO average climb out time;      seconds
ApproachTime;   200;     ICAO average approach time;       seconds
LandingTime;     40;     ICAO average landing time;        seconds
TaxiIn;         420;     ICAO average taxi in time;        seconds
```

Other records include the following emission indices:

```
KgCO2PerKgFuel;  3.15;    CO2 emitted per KG of fuel burnt; kg
KgH20PerKgFuel;  1.237;   H2O emitted per KG of fuel burnt; kg
KgSOxPerKgFuel;  0.00084; SOX emitted per KG of fuel burnt; kg
```

These emission indices come from Table 2 in [**13**] where it is stated that these are "*average values obtained from an intensive literature review*".

The mass of carbon dioxide emitted per kilogram of jet fuel burnt (3.15 kg per kg, equivalent to 3 150 kg per tonne) is also listed as is the emission factor for CO_2 for the en-route stage found in Table 3-3 of Section 1.A.3.a of Part B of [**7**]. The mass of carbon dioxide emitted per kilogram of avgas burnt is 3.05 kg per kg.

3.4.1.3.6 The AEM.VOCTOG_CONSTANTS.txt file

This file contains the multiplying constants that are used in the calculations of the estimates of the amounts of some VOCs and OGs emitted.

Each record in this file contains information about one particular constant, namely:

- the class of the constant, which is always 6,
- the name of the constant, and
- the value of the constant.

This file contains the following records:

```
6;HC_to_VOC_Multiplier;     1.15
6;VOC_Acetaldehyde;         0.04315
6;VOC_Acrolein;             0.02473
6;VOC_POM_16-PAH;           0.00006829
6;VOC_POM_7-PAH;            0.000007234
6;VOC_Styrene;              0.00312
6;VOC_to_TOG_Multiplier;    1.00870
6;TOG_Butadiene;            0.01687
6;TOG_Benzene;              0.01681
6;TOG_Ethylbenzene;         0.00174
6;TOG_Formaldehyde;         0.12310
6;TOG_Propionaldehyde;      0.00727
6;TOG_Toluene;              0.00642
6;TOG_Xylene;               0.00448
```

Once the mass of UHCs emitted has been estimated, the mass of VOCs emitted is estimated by multiplying the estimated mass of UHCs emitted by 1.15. Then, the mass of acetaldehyde emitted is estimated by multiplying the estimated mass of VOCs emitted by 0.04315, the mass of acrolein emitted is estimated by multiplying the estimated mass of VOCs emitted by 0.02473, and so on.

The mass of OGs emitted is estimated by multiplying the estimated mass of VOCs emitted by 1.00870. Once the mass of OGs emitted has been estimated, the mass of 1,3-butadiene emitted is estimated by multiplying the estimated mass of OGs emitted by 0.01687, and so on.

3.4.1.3.7 The APT.airport_time_in_mode.txt file (■)

There are three sources of airport-taxi-time data for the AEM. These are:

- the ***APT.airport_time_in_mode.txt*** file (■),
- the ***AERO2K_TaxiTimes.txt*** file (■), and
- the ***AEM.CONSTANT_PARAMS.txt*** file (■) (described in Section o above).

The ***APT.airport_time_in_mode.txt*** file contains airport-specific taxi-in and taxi-out times for a number of airports.

Each record in this file contains information about one particular airport, namely:

- an *airport* designator that identifies the airport,
- a taxi-out time, and
- a taxi-in time.

In the FEIS procedure, a taxi time for a particular airport is one of the following:

- the annual average taxi-in or taxi-out time as determined by EUROCONTROL's Central Office for Delay Analysis (**CODA**),
- the annual average taxi-in or taxi-out time based on the CODA data as determined by the EUROCONTROL FEIS team, or
- the ICAO default taxi-in or taxi-out time.

3.4.1.3.8 The AEM output file

The results of the AEM calculations are stored in an output file (usually, but not necessarily, having the file extension ***.so6***). A separate record is output for each phase of the take-off and landing stages as well as for each segment in the en-route stage.

Each record of this file contains:

- a designator of the identity of the flight,
- a designator of the take-off phase (1, 2, or 3) or the landing phase (7, 8, or 9), if the aircraft is below 3,000 feet, or, if the aircraft is at or above 3,000 feet, a designator of the attitude (4, 5, or 6) during the segment, and
- the mass [in kilograms] of fuel burnt by the aircraft during that phase/segment

as well as the corresponding masses [in kilograms] of:

- acetaldehyde,
- acrolein,
- benzene,
- 1,3-butadiene,
- carbon dioxide,
- carbon monoxide,
- ethyl benzene,
- formaldehyde,
- NO_X,
- $PM_{non\text{-}vol}$,
- $PM_{vol\text{-}org}$,
- $PM_{vol\text{-}sul}$,
- 7-PAH,
- 16-PAH,
- propionaldehyde,
- SO_X,
- styrene,
- toluene,
- UHCs,
- water vapour, and
- xylenes

emitted by the aircraft during that phase/segment.

3.4.1.4 The AEM calculations above and below 3,000 feet

The way the AEM performs its calculations for the take-off and landing stages of a flight is different from how it does it for the cruise stage of that flight, as is indicated in the following table.

<table>
<tr><th>Height (feet)</th><th>Fuel Burnt</th><th>NO_X, UHCs, and CO</th><th>CO_2, H_2O, and SO_X</th><th>VOCs</th></tr>
<tr><td>>= 3,000 (cruise stage)</td><td>BADA data</td><td>BFFM2</td><td rowspan="2">Proportional to the mass of fuel burnt</td><td rowspan="2">Proportional to the mass of UHCs generated</td></tr>
<tr><td>< 3,000 (take-off and landing stages)</td><td colspan="2">The AEED and other databases</td></tr>
</table>

Table 6: The AEM method of calculation above and below 3,000 feet

3.4.1.4.1 Below 3,000 feet – the take-off and landing stages

Because information about trajectories below 3,000 feet is not sufficiently accurate, the calculation of the amount of jet fuel and avgas that was burnt during the stages of the LTO cycle is based on the durations of the various phases of the ICAO LTO cycle with the fuel burn rate given by the engine emission databases for the particular type of engine associated with the aircraft.

A “standard” LTO cycle lasts for a total of 32 minutes and 54 seconds of which for 26 minutes the engines are in idle mode while taxiing out before taking off and taxiing in after landing (19 minutes and 7 minutes respectively). But for many airports in Europe, the time spent with the engine thrust set to idle is different from the 26 minutes of the ICAO LTO cycle and so the ICAO default taxi-in and taxi-out times are replaced where possible by more reasonable times.

3.4.1.4.2 At or above 3,000 feet – the cruise stage

At or above 3,000 feet, the AEM uses the segments (defined by two consecutive points) of the flight trajectory to calculate the mass of fuel burnt. See Figure 5 above.

As the trajectory information stored in the PRISME database does not contain the actual rate of fuel burn or the actual weight of the aircraft, these data cannot be provided to the AEM as an input. The rate of fuel burn is therefore determined using the BADA performance data.

Emission calculations are based on the values found in the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** file but the emission factors and fuel flows are adapted to the atmospheric conditions at altitude by using the BFFM2 which was initially developed by The Boeing Company. The BFFM2 makes it possible to estimate the masses of the emissions for the NO_X, UHC, and carbon monoxide species. The emissions of water vapour and carbon dioxide are a direct result of the oxidation, by the oxygen in the atmosphere, of the carbon and hydrogen contained in the fuel. The SO_X emissions depend directly on the sulphur content of the fuel used. The masses emitted of all three of these species are directly proportional to the mass of fuel burnt.

3.4.2 Databases used in the FEIS procedure

3.4.2.1 PRISME - Flights within EUROCONTROL Airspace

Each flight that has occurred in the airspace of a member state of EUROCONTROL is associated with a radar trajectory (i.e. a sequence of radar plots) that begins either when the flight enters the airspace of that state or, if the departure airport of the flight is located in the territory of that state, sometime after the flight departed. Similarly, a radar trajectory finishes either when the flight leaves the airspace of that state or, if the arrival airport of the flight is located in the territory of that state, sometime before the flight arrived.

The best (non-state-level) description at the European level of an actual flight trajectory is the one that is contained in the corrected flight plan that is known by EUROCONTROL’s Network Manager Operations Centre (**NMOC**) - which used to be called the Central Flow Management Unit. All these corrected flight plans are kept in the PRISME database, which contains the corrected flight plan for every relevant flight whose 3D path through space was at least partially within EUROCONTROL airspace.

A relevant flight is any flight that flew under instrument flight rules - a so-called IFR flight – and includes relevant helicopter flights. Some IFR flights are operational military flights but these flights can easily be identified and excluded from further calculations. All non-IFR flights are also excluded from further calculations.

For the years from 2005 to 2017, there are approximately 125,800,000 flight records in the PRISME database, each of which contains, amongst others, the following fields:

- AIRCRAFT_TYPE
- ENG_TYPE
- PF_ENGINE_NBR
- ACFT_MODEL_NAME
- ACFT_SERIES_NAME

The AIRCRAFT_TYPE field contains a PRISME *type-of-airframe* code that should identify the actual type of the aircraft that made the flight. Usually, the AIRCRAFT_TYPE field contains a value that is an ICAO *type-of-aircraft* code but it sometimes contains a value that is not an ICAO *type-of-aircraft* code.

The ENG_TYPE field contains a PRISME *type-of-engine* name that should designate the type of the engine(s) of the actual aircraft. As this field contains a *type-of-engine* name and not a *type-of-engine* code, it is difficult to know if a name is a valid name or not. Earlier, reference was made to a type of engine known by its *type-of-engine* name as **CFM56-5C2**. But it is quite possible for this type of engine to be identified in the PRISME database by **CFM-56-5C2** or **CFM56-5-C2**, etc. Clearly all of these names (seem to) designate the same type of engine. But if the PRISME *type-of-engine* name was, say, **CFM-56-5C2B**, it is not immediately obvious if this designating a different type of engine or if a mistake has been made.

The PF_ENGINE_NBR field should contain the number of engines of the actual aircraft.

The ACFT_MODEL_NAME contains a PRISME *type-of-aircraft-family* code that should designate the family of the type of the actual aircraft. For example, all actual aircraft of which the airframe is designated by the ICAO *type-of-aircraft* code **A320** [21] that have current engine option (**CEO**) types of engine should have the value **A320** in the ACFT_MODEL_NAME field whereas those with new engine option (NEO) types of engine should have the value **A320 NEO** in the ACFT_MODEL_NAME field. Similarly, all actual aircraft of which the airframe is designated by the ICAO type-of-aircraft code **B734** [22], **B735** [23], etc should have the value **B737** in the ACFT_MODEL_NAME field.

The ACFT_SERIES_NAME field contains a PRISME *sub-type-of-aircraft* designator that should identify the sub-type of the actual aircraft. For types of aircraft made by Airbus, the value in this field should depend on the type of engine fitted to the aircraft whereas for types of aircraft made by Boeing, the value in this field should depend on the company that first bought the aircraft.

From 2005 to 2017 inclusive, 942 different PRISME types of airframe were associated with all the relevant flights for which data exists in the PRISME database. 706 different PRISME types of engine (one of which is the “unspecified” type) were associated with the 942 different PRISME types of airframe giving a total of 1,128 different combinations of PRISME type of aircraft and PRISME type of engine.

The values in the ACFT_MODEL_NAME and ACFT_SERIES_NAME fields can be used to correct seemingly incorrect values in the AIRCRAFT_TYPE and/or ENG_TYPE fields. As an example to show how PRISME data can be corrected, in PRISME there actually are records with the following data:

- AIRCRAFT_TYPE = **B789**
- ACFT_MODEL_NAME = **A350**
- ACFT_SERIES_NAME = **A350 941**
- ENG_TYPE = **TRENT XWB**

Now **B789** is an ICAO *type-of-aircraft* code that designates a Boeing 787-900 type of airframe and **A350** is a *type-of-aircraft-family* code for an Airbus A350 type of airframe. Given that the aircraft series is **A350 941** and the engine type is **TRENT XWB** [24], which is a type of engine found on **Airbus A350** aircraft but not **Boeing 787-900** aircraft, it is likely that the airframe is actually of type **Airbus A350-900** and so the value of AIRCRAFT_TYPE should be **A359**, and not **B789**.

[21] **A320** is an ICAO *type-of-aircraft* code that designates, amongst others, an **Airbus A320** type of airframe.
[22] **B734** is an ICAO type-of-aircraft code that designates, amongst others, a **Boeing 737-400** type of airframe.
[23] **B735** is an ICAO type-of-aircraft code that designates, amongst others, a **Boeing 737-500** type of airframe.
[24] **TRENT XWB** is the name of a type of engine manufactured by Rolls-Royce.

3.4.2.2 Scheduled flight databases - Flights outside EUROCONTROL Airspace

The data stored in the PRISME database for a particular flight is limited to that part of the 3D trajectory that is in EUROCONTROL airspace; this means that the description of the portion of any trajectory that is outside the EUROCONTROL airspace either needs to be obtained from another source of data or it has to be generated based on the best estimate of the flight trajectory.

If the trajectory of a flight was entirely outside EUROCONTROL airspace, the whole trajectory has to be estimated. There would be no data about this flight in the PRISME database and so the existence of a flight such as this last one could only be deduced from examining scheduled flight data.

The FEIS procedure uses OAG and Innovata scheduled flight data.

3.4.2.3 Aircraft engine emission databases

The rate that fuel is burnt and the engine emission data that are required to perform these calculations are mainly derived from the data stored in a number of aircraft engine emissions databases; one such database is the AEED for turbojet and turbofan engines. Other similar databases contain data for turboprop engines (such as the FOI confidential database) and for piston engines (such as the FOCA database).

In 2017, emissions data was available for:

- 418 types of turbofan or turbojet engine,
- 117 types of turboprop engine, and
- 20 types of piston engine, of which 4 types are generic types

making a total of 555 different types of engine in all.

The aircraft engine emissions data is stored in the ACT_PRF.AIRCRAFT_LTO_ENGINES.txt file (■).

3.4.2.4 The BADA database

For the calculation of the mass of fuel that was burnt during the en-route stage of a flight, the AEM makes use of Version 3.14 of a EUROCONTROL database known as the BADA database. This database contains rate of fuel burn data for 222 types of aircraft; 220 of these types are designated by ICAO *type-of-aircraft* codes and the remaining two types are generic types of aircraft. A further 923 types of aircraft that are designated by ICAO *type-of-aircraft* codes are equated with these 222 types of aircraft so that, in total, the BADA database contains data about 1,143 types of aircraft that are designated by ICAO *type-of-aircraft* codes and 2 generic types of aircraft. Each one of these 1,143 BADA types of aircraft is associated with one, and only one, BADA type of engine, (of which there are 204 different ones, some of which are not DB types of engine). The BADA data is stored in the ACT_PRF.BADA_FUEL_BURN.txt file (■).

3.5 The FEIS procedure in detail

The FEIS procedure consists of the following steps:

1. If necessary, define the (new) FEIS types of aircraft
2. Select the period of time and geographic scope of interest.

3. Get information about the relevant flights that occurred during that period of time for that geographic scope and generate the flight data .so6 input file.
    a. Generate the AEM flight data input file.
    b. Process the flight schedule data for the relevant flights.
    c. Select the relevant flights.
    d. Determine the trajectory of each relevant flight.
4. Set up the other input files for the AEM.
5. Calculate the masses of jet fuel and avgas burnt and the masses of the AEM species emitted by the relevant flights using the AEM.
6. Calculate the masses of the remaining species of interest that were emitted.

3.5.1 Define the (new) FEIS *type-of-aircraft* codes

In an ideal world, every PRISME *type of airframe* code would be the same as an ICAO *type-of-aircraft* code that, itself, would designate a type of aircraft that has an entry in the BADA database. And every PRISME *type-of-engine* name would designate a type of engine that has an entry in at least one of the engine-emissions databases. In practice though, this is far from the case. The first consequence of this is that the AEM cannot process flight data based directly on the data stored in the PRISME database. Sometimes the PRISME *type-of-engine* name has to be replaced by a *type-of-engine* name that designates a type of engine for which emissions data exists i.e. a DB type of engine. And sometimes the equivalent BADA type of aircraft is different from the PRISME type of aircraft. This is why FEIS types of aircraft were defined.

The FEIS *type-of-aircraft* designators were initially defined as follows.

The PRISME database stores information about every IFR flight that departed from, or arrived at, or both departed from and arrived at, an airport that is located in a relevant part of the territory of one of the 33 member states of the EEA (see Appendix B) from 2005 onwards [25].

The relevant fields in a PRISME flight data record concerning an actual aircraft are:

- AIRCRAFT_TYPE, which is supposed to designate the type of its airframe, and
- ENG_TYPE, which is supposed to designate the type of its engine(s).

[25] It should be noted that although the Republic of Estonia joined EUROCONTROL only in 2015, data is available for the years before 2015 about domestic flights in the Republic of Estonia as well as about international flights to the Republic of Estonia from, and from the Republic of Estonia to, states that are not members of EUROCONTROL because the Republic of Estonia had previously signed data-sharing agreements with EUROCONTROL. The same is true of Iceland, which is the only significant member state of the EEA that is not a member state of EUROCONTROL.

So, for example, if a relevant flight was flown by an **Airbus A340-200** powered by four **CFM56-5C2** engines then the type of aircraft associated with that flight should be specified by:

- AIRCRAFT_TYPE = **A342**
- ENG_TYPE = **CFM56-5C2**

in the PRISME database.

The data record of each flight is checked and any record with incomplete or inconsistent data is removed and is not considered further in the rest of the calculations. This includes any record that contains:

- a marker that the flight was an operational military flight
- a departure airport identified by the code **AFIL** [26]
- a departure airport or an arrival airport identified by the code **ZZZZ**, an unrecognised code, or no code at all,
- a value in AIRCRAFT_TYPE that is not a recognised ICAO *type-of-aircraft* code and cannot be corrected or is missing altogether, or
- a departure and/or arrival date and time with an unrecognised value or no value at all.

In an ideal world, the value stored in AIRCRAFT_TYPE would always designate a type of airframe that was the same as the type of the airframe of the actual aircraft and the value stored in ENG_TYPE would always designate a type of engine that was the same as the type of engine of the actual aircraft. Sometimes, though, this is not the case.

For example, if the value stored in ENG_TYPE designates a type of engine that is not valid for the type of airframe that is designated by the value stored in AIRCRAFT_TYPE then the value stored in AIRCRAFT_TYPE is incorrect or the value stored in ENG_TYPE is incorrect or possibly the values stored in both AIRCRAFT_TYPE and ENG_TYPE are incorrect.

In such a case, two other fields in a PRISME data record can be used to try to correct the data stored in AIRCRAFT_TYPE and ENG_TPYE. These two fields are:

- ACFT_MODEL_NAME, which is supposed to designate the family of the type of the actual aircraft and should have a value such as **A330** for an aircraft with an **Airbus A330-200** type of airframe, and
- ACFT_SERIES_NAME, which is supposed to identify the sub-type of the actual aircraft and can have a value such as **A330-223** for an aircraft with an airframe of a type designated by **Airbus A330-200** and engines of a type designated by **Trent 772B-60** [27].

An example of how PRISME data can be corrected was provided in Section 3.4.2.1 above. Here is a second example:

- AIRCRAFT_TYPE = **A320**
- ACFT_MODEL_NAME = **A321 NEO**
- ACFT_SERIES_NAME = **A321 271n**
- ENG_TYPE = **PW1133G-JM**

Now **A320** is an ICAO *type-of-aircraft* code that designates an **Airbus A32**0 type of airframe and **A321 NEO** is a *type-of-aircraft-family* code that designates an **Airbus A321** type of

[26] An AFIL flight plan is filed while the aircraft is airborne and leads from the aircraft's current position to the destination. Consequently, the identity of the departure airport is unknown.
[27] **Trent 772B-60** is the name of a type of engine manufactured by Roll-Royce.

airframe. Given that the aircraft series has the value **A321 271n** and the engine type has the value **PW1133G-JM** [28], which is a type of engine found on aircraft with both **Airbus A320** and **Airbus A321** types of airframe, it is likely that the airframe is actually of type **Airbus A321** and so the value of AIRCRAFT_TYPE should be **A321**, and not **A320**.

Having corrected, if deemed necessary, the values stored in the AIRCRAFT_TYPE fields, the PRISME database was then inspected and any record that had a value in the AIRCRAFT_TYPE field that contained any of the following ICAO *type-of-aircraft* codes was removed from further calculations:

- **MEEE** (a generic type of aircraft that has two or more engines),
- **SEEE** (a generic type of aircraft that has one engine),
- **SOL1** (Solar Impulse 1 – an aircraft that has electric motors),
- **SOL2** (Solar Impulse 2 – an aircraft that has electric motors),
- **TJJJ** (a generic type of aircraft that has one or more turbo-jet engines),
- **TPPP** (a generic type of aircraft that has one or more turboprop engines),
- **ULAC** (a generic type of microlight aircraft),
- **ZZZZ** (an unknown type of aircraft), or
- **ZZZ** (which probably should be ZZZZ).

Then, the number of flights between 2005 and 2016 inclusive was calculated for every PRISME type of aircraft, a PRISME type of aircraft being specified by a combination of a PRISME *type-of-airframe* code and a PRISME *type-of-engine* name. For every PRISME type of airframe (designated by an ICAO *type-of-aircraft* code such as **A320**) the most common PRISME types of engine that are also DB types of engine, and for which there were at least 50 flights in total during the 12 years, were retained. There were therefore three categories of PRISME type of airframe:

1. those that were associated with one or more DB types of engine for at least 50 flights each in total during the 12 years,
2. those that were associated with one or more DB types of engine for at most 49 flights each in total during the 12 years, and
3. those that were associated with no DB types of engine.

3.5.1.1 Category 1

For each PRISME type of airframe that was associated with one or more DB type of engine for at least 50 flights each in total during the 12 years, an FEIS *type-of-aircraft* code, made up by concatenating the relevant ICAO *type-of-aircraft* code plus a dash plus the upper-case letter "A", was associated with the most common DB type of engine that powered the aircraft with that PRISME type of airframe. Thus, for example, the FEIS *type-of-aircraft* designator **A320-A** designates an aircraft with an **Airbus A320** type of airframe and engines of type **CFM56-5B4/P** [29] (whose equivalent code in the AEED is **3CM026**) while the FEIS *type-of-aircraft* code **A321-A** designates an aircraft with an Airbus A321 type of airframe and engines of type **V2533-A5** [30] (whose equivalent code in the AEED is **3IA008**).

An FEIS *type-of-aircraft* code with the suffix "-B" was associated with the 2nd-most common DB type of engine that powered the PRISME type of airframe. Thus, the FEIS *type-of-aircraft* code **A320-B** designates an aircraft with an **Airbus A320** type of airframe and

[28] **PW1133G-JM** is the name of a type of engine manufactured by Pratt & Whitney.
[29] **CFM56-5B4/P** is the name of a type of engine manufactured by CFM International.
[30] **V2533-A5** is the name of a type of engine manufactured by International Aero Engines.

engines of type **V2527-A5** [31] (whose equivalent code in the AEED is **1IA003**) type of engines.

Similar associations were made for each PRISME type of airframe up to FEIS *type-of-aircraft* codes with the suffix "-N", which were associated with the 14th most common DB type of engine (if there were 14 DB types of engine associated with that PRISME type of airframe with at least 50 flights in total). So, for example, the FEIS *type-of-aircraft* code **B762-N** designates an aircraft with a **Boeing 767-200** type of airframe and engines of type **CF6-80C2B7F** [32] (whose equivalent code in the AEED is **2GE055**).

Aircraft in the **Airbus 320** family, that each have an airframe whose type is designated by the ICAO *type-of-aircraft* code **A320**, were recorded as being powered by 13 different PRISME types of engine or the type of engine was unspecified. Some of the PRISME types of engine, like **LEAP-1A26** [33], are not DB types of engine. See Table 7 below in which the DB types of engine are marked with a red asterisk (*****).

PRISME type-of-engine name	CEO or NEO engine	Number of flights (2005-2016)	FEIS type-of-aircraft designator
CFM56-5B4/P *	CEO	5,373,968	**A320-A**
V2527-A5 *	CEO	3,464,845	**A320-B**
CFM56-5-A1 *	CEO	2,084,333	**A320-C**
CFM56-5B4/2P *	CEO	1,752,344	**A320-D**
CFM56-5B6/P *	CEO	948,912	**A320-E**
Unspecified	-	446,527	Assigned to **A320-A**
CFM56-5A3 *	CEO	408,815	**A320-F**
CFM56-5B4/2 *	CEO	368,889	**A320-G**
V2527E-A5 *	CEO	201,809	**A320-H**
V2500-A1 *	CEO	196,522	**A320-I**
CFM56	CEO	8,605	Assigned to **A320-A**
PW1127G-JM *	NEO	5,850	**A320-J**
LEAP-1A26	NEO	4,481	Assigned to **A320-J**
CFM56-5B4/3 *	CEO	2	Assigned to **A320-A**

Table 7: PRISME types of engine powering aircraft with the Airbus A320 type of airframe between 2005 and 2016 inclusive.

The total number of flights made by aircraft with an **A320** PRISME type of airframe between 2005 and 2016 inclusive was 15,265,902. The total number of flights made by aircraft with both the **A320** PRISME type of airframe and one of the 10 PRISME type of engine that is also a DB type of engine (and for which the number of flights was 50 or more) was 14,806,287. So, the 10 FEIS types of **Airbus A320** aircraft listed in the table above cover 96.99% of all flights by aircraft with airframes of type **A320** recorded in the PRISME database. The remaining 3.01% of the **Airbus A320** flights were associated with an aircraft with a relevant DB engine. The 446,527 A320 flights for which no type of engine was specified in the PRISME database (2.92% of all the **Airbus A320** flights) were assigned a (possibly) incorrect **CFM56-5B4/P** type of engine (this being the engine associated with the FEIS type of aircraft **A320-A**). The 4,481 **Airbus A320** flights that were recorded as having been made by aircraft powered by the **LEAP-1A26** type of engine were assigned the FEIS

[31] **V2527-A5** is the name of a type of engine manufactured by International Aero Engines.
[32] **CF6-80C2B7F** is the name of a type of engine manufactured by General Electric.
[33] **LEAP-1A26** is the name of a type of engine manufactured by CFM International.

type-of-aircraft code of **A320-J** because both the **LEAP-1A26** and the **PW1127G-JM** types of engine are both new generation engines that are used on the NEO types of Airbus aircraft.

In the previous version of the FEIS procedure, in which a single type of engine was assigned to each ICAO type of aircraft, only 19.5% of all the **Airbus A320** flights between 2005 and 2014 inclusive were known to be assigned the correct type of engine.

3.5.1.2 Category 2

For those PRISME type of airframes that were associated with at one or more DB types of engine for at most 49 flights each in total during the 12 years, an FEIS *type-of-aircraft* code, made up by concatenating the relevant ICAO *type-of-aircraft* code plus a dash plus the upper-case letter "A", was associated with the most common DB type of engine that powered the aircraft with that PRISME type of airframe. All PRISME types of aircraft with such a PRISME type of airframe were associated with this FEIS type of aircraft.

Aircraft in the **McDonnell Douglas DC-8-50** family, that all have the ICAO *type-of-aircraft* code **DC85**, were recorded as being powered by one PRISME type of engine or the type of engine was unspecified. The particular type of engine, **JT3D-3B/Q** [34], is a DB type of engine. See Table 8 below.

PRISME type-of-engine name	Number of flights (2005-2016)	FEIS type-of-aircraft designator
JT3D-3B/Q *	18	**DC85-A**
Unspecified	8	Assigned to **DC85-A**

Table 8: PRISME types of engine powering aircraft with McDonell Douglas DC-8-50 type of airframe between 2005 and 2016 inclusive.

3.5.1.3 Category 3

For those PRISME types of airframe that were associated with no DB types of engine, an FEIS *type of aircraft* code, made up by concatenating the relevant ICAO *type-of-aircraft* code plus a dash plus the upper-case letter "A", was associated with a relevant DB type of engine, as selected using expert judgement. . In practice, this meant finding a DB type of engine with a power rating that was as close as possible to the power rating of the type of engine that powered the actual type of aircraft identified by the ICAO *type-of-aircraft* code of the PRISME type of airframe.

Once the FEIS *type-of-aircraft* codes had been defined, every PRISME type of aircraft (corrected if needed) could be associated with one. See Appendix 5.C for some examples of actual associations between PRISME types of aircraft and FEIS types of aircraft.

3.5.1.4 Defining additional FEIS *type-of-aircraft* codes

For the 2018 work there are 1,154 different FEIS *type-of-aircraft* designators, covering 895 different ICAO types of aircraft/PRISME types of airframe, 344 different DB types of engine, and being associated with 192 different BADA types of aircraft.

It is a simple task to add further FEIS *type-of-aircraft* codes as required in the future. If a new type of engine is used to power a type of aircraft that has an airframe that is designated by a particular ICAO *type-of-aircraft* code for which one or more FEIS *type-of-aircraft* codes have already been defined, it will be necessary to define a new FEIS *type-of-aircraft* code

[34] **JT3D-3B/Q** is the name of a type of engine manufactured by Pratt & Whitney.

that is constructed from that ICAO *type-of-aircraft* code plus a dash plus the first un-used upper-case letter for that ICAO *type-of-aircraft* code. For example, in 2018 there are now eleven FEIS *type-of-aircraft* codes that are used to designate **Airbus A320** types of aircraft, namely **A320-A**, **A320-B**, **A320-C**,…, **A320-K**. The eleventh code, **A320-K**, was defined this year because enough flights were made by A320s with **CFM56-5B4/3** engines. If it is necessary to define a 12th FEIS *type-of-aircraft* code, it will be **A320-L.**

3.5.2 Select the period of time and geographic scope of interest

The next step in the FEIS procedure is to select the period of time and geographic scope of interest for which the masses of jet fuel and avgas burnt and the species of interest emitted have to be estimated. The period of time of interest is always a specific calendar year, such as 2016. The years for which the FEIS procedure has been applied so far run from 2005 to 2017 inclusive (i.e. 13 years). The geographic scope of interest is usually the whole of the relevant territories of the 33 members of the EEA.

3.5.3 Get information about the relevant flights that occurred during that period of time

For each relevant flight, the following data is required:

- the identity of the flight (such as the call sign of the flight),
- the identity of the airport from which the actual aircraft departed,
- the identity of the airport at which the actual aircraft arrived,
- the type of the airframe of the actual aircraft,
- the number of engines that powered the actual aircraft,
- the type of the engine(s) that powered the actual aircraft, and
- a description of the 4D trajectory followed by the aircraft during the en-route stage of the flight (i.e. the part where the aircraft was above a height of 3,000 ft).

This information can be obtained from a number of sources, the principal one of which is EUROCONTROL's PRISME database, which contains a corrected flight plan for each civil IFR flight in EUROCONTROL airspace.

Other sources of information include the publicly-available databases of scheduled flight data, such as the OAG and Innovata flight schedule databases.

3.5.3.1 Generate the AEM flight data input file

Any record with a value in AIRCRAFT_TYPE that contains any of the following ICAO *type-of-aircraft* codes is removed from further calculations: **MEEE**, **SEEE**, **SOL1**, **SOL2**, **TJJJ**, **TPPP**, **ULAC**, **ZZZ**, or **ZZZZ.**

The next step is to assign an FEIS *type-of-aircraft* designator to the data record.

At the end of this process, the PRISME data record of each relevant flight will have been corrected, if necessary and if it is possible so to do, and the type of aircraft that made the flight will be identified by an FEIS *type-of-aircraft* code that specifies the airframe by means of an ICAO *type-of-aircraft* code and the type of engine by means of a DB *type-of-engine* code.

Next, the ground speed at every waypoint is calculated and stored. After that, the distance from the previous waypoint and the total distance travelled so far are calculated for each waypoint.

3.5.3.2 Processing the flight schedule data

First, the airline, type of aircraft, and departure and arrival airport codes are converted to ICAO codes. Then, the departure and arrival times (in Greenwich Mean Time) for each flight are determined.

Finally, a great circle trajectory from the departure airport to the arrival airport is created for each flight.

3.5.3.3 Select the relevant flights

Select the civil IFR flights (of either a fixed-wing aircraft or a helicopter) that departed from, or arrived at, an airport that is located in a relevant part of the selected geographic scope of interest during the selected year.

3.5.3.4 Determine the trajectory of each relevant flight

3.5.3.4.1 Completing the trajectories

For each flight, no matter what the source, a trajectory point is created at the point where the aircraft climbs through 3,000 feet after taking off and another point is created where the aircraft descends through 3,000 feet just before landing.

Then all missing flight segments between these 2 new points are identified. Finally, all missing flight segments are created.

3.5.3.4.2 Merging the trajectories

All the flights are processed to find duplicate flights (i.e. those flights with the same departure airport, arrival airport, flight identifier, and flight date) and duplicate flights are merged to give a “best” trajectory for each flight. For example, flight plan data about a flight from, say, Paris, France, to New York, USA, could exist in the NMOC data and a re-constructed trajectory could be associated with the flight schedule. See Figure 11 below.

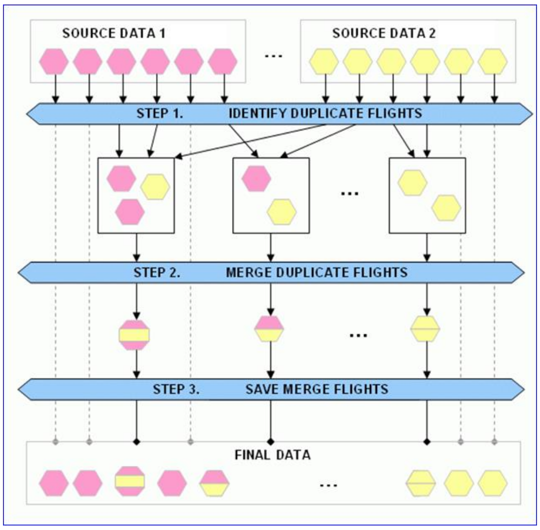

Figure 11: Merging duplicate flights.

3.5.3.4.3 Additional corrections for airports with certain ICAO codes

For 25 of the 33 member states of the EEA it is straight forward to determine which airports are located in the relevant territory over which the state has sovereignty. For example, every airport whose 4-letter ICAO code begins with **LO** (such as **LOWW** – Vienna International airport) is located in the territory of the Republic of Austria. Similarly, every airport whose code begins with **EB** is located in the territory of the Kingdom of Belgium, every airport whose code begins with **LB** is located in the territory of the Republic of Bulgaria, and every airport whose code begins with **LD** is located in the territory of the Republic of Croatia.

As for airports that are located in the territory of the the *de jure* [35] Republic of Cyprus, their ICAO codes all begin with **LC**. But one airport, Ercan International Airport, whose ICAO code is **LCEN**, and one air base, Geçitkale Air Base, whose ICAO code is **LCGK**, are located in the territory of the *de facto* [36] Turkish Republic of Northern Cyprus and this region is not currently considered as being a part of the territory of the Republic of Cyprus as far as the EU is concerned. Consequently, both Ercan International Airport and Geçitkale Air Base are considered as being located outside the territory of the EU and flights to, or from, these airports have to be re-classified as domestic or international as appropriate. Another airport with a code beginning with **LC** is RAF Akrotiri, whose ICAO code is **LCRA**. Again, this airport is considered to be located outside the territory of the EU. And so, all airports whose ICAO code begins with **LC**, apart from those airports whose ICAO code is **LCEN** or **LCRA**, are located in the territory of the *de facto* Republic of Cyprus.

The airports to be included in and excluded from the relevant territories of the 33 member states of the EEA are listed in Appendix B.

3.5.4 Set up the other input files

3.5.4.1 The ACT_PRF.BADA_FUEL_BURN.txt file

Version 3.13 of the BADA database provides performance and fuel burn data for 194 BADA types of aircraft, each associated with one of 180 different BADA types of engine.

The BADA performance table provides information about the rate at which fuel is burnt for a particular type of aircraft at a particular flight level in a particular flight attitude (climb, cruise, or descent). This information is stored in the AEM BADA reference table data file, ***ACT_PRF.BADA_FUEL_BURN.txt***.

3.5.4.2 The ACT_PRF.aircraft_engine.txt file

Between 2005 and 2016 inclusive, all the relevant flights are associated with just 1,022 different FEIS types of aircraft. Each of these FEIS types of aircraft needs to be associated with one of the 194 BADA types of aircraft for which data exists in the BADA database. For the AEM, the associations between the FEIS types of aircraft and the BADA types of aircraft are stored in the ***ACT_PRF.aircraft_engine.txt*** file.

[35] *De jure* means “according to the law”.
[36] *De facto* means “in practice or actuality, but not officially established”.

For the FEIS procedure, the ACT_PRF.aircraft_engine.txt file must contain one (and only one) record for each FEIS type of aircraft. So, each record contains:

- a valid FEIS *type-of-aircraft* designator, which designates the FEIS type of aircraft and which contains a valid ICAO *type-of-aircraft* designator,
- a valid DB *type-of-engine* code, which identifies the FEIS type of engine,
- a number of engines, and
- a valid ICAO *type-of-aircraft* designator, which designates the associated BADA type of aircraft.

The type of engine that is associated with the FEIS type of aircraft is designated by a DB *type-of-engine* code (for turbofan and turbojet types of engine) or by an arbitrary code, assigned by the EUROCONTROL FEIS team (for turboprop and piston types of engine). The only constraint on how to identify a particular DB type of engine is that the same code is also used to identify it in the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** file.

Example entries in the ***ACT_PRF.aircraft_engine.txt*** file are:

```
…
A23-A;  FOCA-9;  1; EV97
…
A320-A; 3CM026;  2; A320
A320-B; 1IA003;  2; A320
A320-C; 1CM008;  2; A320
…
A320-J; 15PW105; 2; A320
A321-A; 3IA008;  2; A321
A321-B; 3CM025;  2; A321
…
…
B762-N; 2GE055;  2; B762
…
```

As can be seen in the first line in the table above, the FEIS type of aircraft that is designated by the FEIS *type-of-aircraft* designator **A23-A** is associated with the BADA type of aircraft that is designated by the ICAO *type-of-aircraft* designator **EV97**. The ICAO *type-of-aircraft* designator **A23** designates an aircraft of type **Aeropract A-23 Dragon**. But the BADA database does not contain data for such a type of aircraft and so the FEIS type of aircraft designated by **A23-A** cannot be associated with the **Aeropract A-23 Dragon** BADA type of aircraft. Consequently, expert judgment has to be used to select another BADA type of aircraft that matches as closely as possible the relevant characteristics of the **Aeropract A-23 Dragon** type of aircraft.

Now the **A23-A** FEIS type of aircraft has a single engine. The type of this engine is designated by the *type-of-engine* code **FOCA-9**. This code designates a 64 horse-power **Rotax 582 DCDI** type of piston engine. Now there are no types of aircraft in the BADA database that are powered by one engine of this type and/or power.

The ICAO *type-of-aircraft* designator **EV97** designates an **Evektor EV-97 EuroStar** type of aircraft. The **EV97** FEIS type of aircraft also has a single engine. The type of this engine is designated by the *type-of-engine* code **FOCA-10**. This code designates an 80 horse-power **Rotax 912** type of piston engine. And the BADA database contains an entry for the **Evektor EV-97 EuroStar** type of aircraft. In terms of fuel usage, an 80 horse power engine probably burns a bit more fuel (in this case avgas) than a 64 horse power engine for the same thrust/power setting. Nevertheless, the **EV97** type of aircraft is the closest match to the **A23** type of aircraft and so the **A23-A** FEIS type of aircraft is associated to the **EV97** BADA type of aircraft.

3.5.4.3 The ACT_PRF.ENGINE_LTO_VALUES.txt file

The carbon monoxide, UHCs, NO_X, and fuel burn figures are derived from the data stored in the AEED or the other emissions databases.

For each type of turbofan or turbojet engine, the AEED contains:

- the rate at which fuel is burnt [in kilograms per second] by one engine when the thrust is set to 7%, 30%, 85%, and 100% of the maximum thrust,
- the name of this type of engine,
- whether this type of engine is a turbofan or a mixed turbofan one,
- the manufacturer of this type of engine,
- the type of the combustor of this type of engine,
- the by-pass ratio of this type of engine,
- the maximum smoke number of this type of engine, and
- the masses [in grams] of:
  - carbon monoxide,
  - NO_X, and
  - UHCs

  that are emitted when one kilogram of fuel is burnt by one engine when the thrust is set to 7%, 30%, 85%, and 100% of the maximum thrust.

So, for example, if:

- *spc* is a gaseous species and can have one of the following values: **carbon monoxide | NO_X | UHCs**
- *eng* is a particular type of engine for which fuel flow and emissions data exist in one of the engine emissions databases,
- *thr* is a thrust setting that can have a value between **0%** and **100%**, **100%** being the maximum thrust setting possible,
- rfb(*eng, thr*) is the rate at which fuel is burnt [in kilograms per second] by an engine of type *eng* when the thrust is set to *thr*,
- ei(*spc*, *eng*, *thr*) is the mass [in grams] of *spc* that is emitted when one kilogram of fuel is burnt by an engine of type *eng* when the thrust is set to *thr*, and
- rse(*spc*, *eng*, *thr*) is the rate at which *spc* is emitted [in kilograms per second] by an engine of type *eng* when the thrust is set to *thr*

then

$$\text{rse}(spc, eng, thr) = \text{rfb}(eng, thr) \times \text{ei}(spc, eng, thr) / 1000$$

Before performing this calculation, the following corrections are applied:

- If ei(*spc, eng, thr*) is equal to 0 for all four values of *thr* then set all of the ei(*spc, eng, thr*) values to 0.0001.
- If ei(*spc*, *eng*, **100%**) is equal to 0 then set ei(*spc*, *eng*, **100%**) to 0.0001.
- If ei(*spc*, *eng*, **85%**) is equal to 0 then set ei(*spc*, *eng*, **85%**) to 0.0001.
- If ei(*spc*, *eng*, **30%**) is equal to 0 and ei(*spc*, *eng*, **7%**) is not equal to 0 then set ei(*spc*, *eng*, **30%**) to 0.001.
- If ei(*spc*, *eng*, **7%**) is equal to 0 then set ei(*spc*, *eng*, **7%**) to 0.0001.

Finally, set rfb(**1ZM001** [37], **7%**) to 0.1.

The various rse(*spc*, *eng*, *thr*) settings when *thr* is set to **7%**, **30%**, **85%**, and **100%** are stored in the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** file.

In addition, for each type of engine, the AEED may contain some or all of the smoke numbers for one engine when the thrust is set to **7%**, **30%**, **85%**, and **100%** of the maximum thrust. If a smoke number is expressed as <0.nnn then it is replaced with 0.nnn. If there are no smoke numbers for a particular engine then the maximum smoke number for that engine is replaced by the maximum smoke number of all the engines (which is currently **66.2**).

Appendix 5.F describes how these numbers are used to determine the rates of emission of the various types of PM (for inclusion in the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** file).

For the other types of engine - turboprop and piston - the relevant databases are used to create other entries in the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** file. Often, however, required data is missing.

3.5.4.4 The APT.airport_time_in_mode.txt file

This file contains the annual average taxi-out and taxi-in times for many airports worldwide. Each record in this file contains:

- the average taxi-out time [in seconds] for that airport, and
- the average taxi-in time [in seconds] for that airport.

Now for European airports, taxi times are recorded and analysed by EUROCONTROL's CODA, which produces an annual list of average measured taxi-out and taxi-in times for a large number of airports with more than 100 arrivals and/or departures per year. So, for those airports for which measured average taxi times exist, by putting these values into the ***APT.airport_time_in_mode.txt*** file, the ICAO default taxi-out and taxi-in times can be replaced with the measured average times in the calculations of the FEIS procedure.

For all of the years from 2005 to 2017 inclusive, the average taxi-out and taxi-in times for each airport for each year are now set as follows.

Consider those airports that are located in the territory of a member state of the EEA and for which CODA has determined an average taxi-in time for 2017. These airports are grouped by numbers of arrivals; the first group contains those airports that had 100 arrivals or fewer during the year, the second contains those airports with more than 100 but fewer than 1,001 arrivals during the year, and so on. (See Table 9 and Table 10 for the other groups.) The average taxi-in time for each group is calculated.

This procedure is repeated for the years from 2005 until 2016.

[37] **1ZM001** is the codes for a type of engine manufactured by ZMKB.

Table 9 lists the annual average taxi-in time for airports that are located in a member state of the EEA for which CODA has determined taxi-in times.

Year	Average taxi-in time (seconds)					
	Airports with a **minimum** of =>	1	101	1,001	5,001	10,001
	and a **maximum** of => arrivals in the year	100	1,000	5,000	10,000	50,000
2005		258	258	250	254	274
2006		274	274	240	275	280
2007		284	284	235	275	278
2008		276	276	249	278	282
2009		279	279	257	278	287
2010		278	278	265	270	287
2011		270	270	261	272	278
2012		282	282	265	269	281
2013		283	283	269	275	284
2014		296	296	263	264	284
2015		245	295	252	260	283
2016		300	300	253	272	285
2017		283	283	258	271	291

Table 9: The average taxi-in times for airports for which CODA has determined an average taxi-in time that are located in the territory of a member state of the EEA as a function of the year and the number of arrivals.

Now, if, for a given airport in 2017, CODA has determined an average taxi-in time then the taxi-in time for that airport is set to that value determined by CODA. If CODA has not determined an average taxi-in time then, if the airport is located in the territory of one of the member states of the EEA or EUROCONTROL, use the number of arrivals during 2017 at that airport to select the relevant average taxi-in time for 2017 from Table 9. Otherwise, use the ICAO default taxi-in time value (of 420 seconds).

The taxi-out times for 2005 to 2017 are set in a similar manner. The ICAO default taxi-out time is 1,140 seconds.

Table 10 lists the annual average taxi-out time for airports that are located in a member state of the EEA or EUROCONTROL for which CODA has determined taxi-out times.

Year	Average taxi-out time (seconds)					
	Airports with a **minimum** of =>	1	101	1,001	5,001	10,001
	and a **maximum** of => departures in the year	100	1,000	5,000	10,000	50,000
2005		519	519	426	469	567
2006		498	498	393	475	558
2007		492	492	388	479	560
2008		450	450	416	492	565
2009		457	457	426	501	575
2010		459	459	443	497	597
2011		434	434	432	491	570
2012		451	451	448	495	592
2013		479	479	453	517	600
2014		466	466	454	519	605
2015		277	478	440	509	597
2016		490	490	450	531	606
2017		452	452	450	541	631

Table 10: The average taxi-out times for airports for which CODA has determined an average taxi-out time that are located in the territory of a member state of the EEA or EUROCONTROL as a function of the year and the number of departures.

To get a feel for how the average taxi times change from one year to the next, here are the average taxi-out and taxi-in times for Paris CDG Airport for the years 2005 until 2017 inclusive:

Year	Average taxi-out time (seconds)	Average taxi-in time (seconds)
2005	1,131	564
2006	1,064	590
2007	1,021	586
2008	1,054	594
2009	1,025	575
2010	1,052	569
2011	951	574
2012	947	571
2013	953	566
2014	929	574
2015	923	585
2016	967	594
2017	929	587

3.5.5 Calculating the mass of fuel burnt and the masses of species emitted

At the end of the process described above, a best estimate of the 4D trajectory for every relevant flight during the year exists. Then, the mass of fuel that was burnt and the masses of certain species emitted during the LTO cycle and the cruise stage of every relevant flight are calculated by processing the trajectories with AEM.

By adding the mass of fuel burnt during Phases 1, 2, and 3 together, the mass of fuel burnt during the take-off stage of the LTO cycle is determined for each flight. Similarly, by adding the mass of fuel burnt during Phases 7, 8, and 9 together, the mass of fuel burnt during the landing stage of the LTO cycle is determined for each flight.

For the cruise stage, the AEM calculates the mass of fuel that was burnt and the masses of certain species that were emitted on a flight-segment by flight-segment basis for each flight. Consequently, to know the total mass of fuel burnt and the total masses of certain species emitted during the whole cruise stage, it is sufficient to add together the values for all the flight segments. Details of the calculations can be found in Appendix 5.E.

If:

- **m(Fuel, A_j, X_{dep})** is the mass of fuel burnt in the take-off stage by Aircraft $\mathbf{A_j}$ taking off from an airport that is located in **X**,
- **m(Fuel, A_j, Y_{arr})** is the mass of fuel burnt in the landing stage by Aircraft $\mathbf{A_j}$ landing at an airport that is located in **Y**, and
- **m(Fuel, A_j, X>Y)** is the mass of fuel burnt in the cruise stage by Aircraft $\mathbf{A_j}$ that took off from an airport that is located in X, and that landed at an airport that is located in **Y** (where **X** and **Y** can be the same)

then the total mass of fuel burnt during the flight is given by:

$$\mathbf{m(Fuel, A_j, X_{dep}) + m(Fuel, A_j, X{>}Y) + m(Fuel, A_j, Y_{arr})}$$

3.5.5.1 Reporting for the UNFCCC

As mentioned in Section 2.5, to generate a report for a particular region X for the UNFCCC, two totals have to be calculated for the mass of each relevant species (see Appendix 5.D) emitted and for the mass of fuel burnt, namely:

- **the national emissions total for X** and
- **the separate annex for X**.

Now if

- **m(S_i, A_j, X_{dep})** is the mass of Species $\mathbf{S_i}$ emitted in the take-off stage by Aircraft $\mathbf{A_j}$ taking off from an airport that is located in **X**,
- **m(S_i, A_j, Y_{arr})** is the mass of Species $\mathbf{S_i}$ emitted in the landing stage by Aircraft $\mathbf{A_j}$ landing at an airport that is located in **Y**, and
- **m(S_i, A_j, X>Y)** is the mass of Species $\mathbf{S_i}$ emitted in the cruise stage by Aircraft $\mathbf{A_j}$ that took off from an airport that is located in X, and that landed at an airport that is located in **Y** (where **X** and **Y** can be the same)

and $\mathbf{S_1}$ to $\mathbf{S_{28}}$ are as listed in Appendix D, then **the national emissions total for X** for $\mathbf{S_i}$ is given by summing, for all relevant aircraft, $\mathbf{A_j}$, that departed from an airport that is located in X and that arrived at an airport that is also located in X,

$$\mathbf{m(S_i, A_j, X_{dep}) + m(S_i, A_j, X{>}X) + m(S_i, A_j, X_{arr})}$$

and **the separate annex for X** for $\mathbf{S_i}$ is given by summing, for all relevant aircraft, $\mathbf{A_j}$, that departed from an airport that is located in X and that arrived at an airport that is located in Y (where **Y** is not the same as **X**),

$$\mathbf{m(S_i, A_j, X_{dep}) + m(S_i, A_j, X{>}Y) + m(S_i, A_j, Y_{arr})}$$

The relevant species for UNFCCC reporting are:

- carbon dioxide ($\mathbf{S_5}$),
- carbon monoxide ($\mathbf{S_6}$),
- methane ($\mathbf{S_{10}}$),
- nitrous oxide ($\mathbf{S_{11}}$),
- NMVOCs ($\mathbf{S_{12}}$),
- NO_X ($\mathbf{S_{13}}$), and
- SO_X ($\mathbf{S_{14}}$).

The emitted masses of Species $\mathbf{S_5}$, $\mathbf{S_6}$, $\mathbf{S_{13}}$, and $\mathbf{S_{14}}$ are estimated by the AEM. The emitted masses of Species $\mathbf{S_{10}}$, $\mathbf{S_{11}}$, and $\mathbf{S_{12}}$ have to be calculated as shown in Section 3.5.6.

3.5.5.2 Reporting for the CLRTAP

As mentioned in Section 2.5.2, to generate a report for the CLRTAP, four totals have to be calculated for the mass of each relevant species (see Appendix 5.D) emitted and for the mass of fuel burnt, namely:

- **the internal (domestic) LTO-cycle-total for X**,
- **the external (international) LTO-cycle-total for X**,
- **the internal (domestic) cruise stage total for X**, and
- **the external (international) cruise stage total for X**

then, using the terms listed above, **the internal (domestic) LTO-cycle-total for X** for $\mathbf{S_i}$ is given by summing, for all relevant aircraft, $\mathbf{A_j}$, that departed from an airport that is located in **X** and that arrived at an airport that is located in **X**:

$$\mathbf{m(S_i, A_j, X_{dep}) + m(S_i, A_j, X_{arr})}$$

the external (international) LTO-cycle-total for X is given by summing, for all relevant aircraft, $\mathbf{A_j}$, that departed from an airport that is located in **X** and that arrived at an airport that is located in **Y** and all relevant aircraft, $\mathbf{A_k}$, that departed from an airport that is located in **Y** and that arrived at an airport that is located in **X** (where Y is not the same as **X**):

$$\mathbf{m(S_i, A_j, X_{dep}) + m(S_i, A_k, Y_{arr})}$$

the internal (domestic) cruise stage total for X is given by summing, for all relevant aircraft, $\mathbf{A_j}$, that departed from an airport that is located in **X** and that arrived at an airport that is located in **X**:

$$\mathbf{m(S_i, A_j, X{>}X)}$$

and **the external (international) cruise stage total for X** is given by summing, for all relevant aircraft, $\mathbf{A_j}$, that departed from an airport that is located in **X** and that arrived at an airport that is located in **Y** (where **Y** is not the same as **X**):

$$\mathbf{m(S_i, A_j, X{>}Y)}$$

The relevant species for CLRTAP reporting are

- carbon monoxide (**S_6**),
- NMVOCs (**S_{12}**),
- NO_X (**S_{13}**),
- SO_X (**S_{14}**),
- $PM_{2.5}$ (**S_{16}**),
- PM_{10} (**S_{17}**), and
- 4-PAH (**S_{22}**).

The emitted masses of Species **S_6**, **S_{13}**, and **S_{14}** are estimated by the AEM. The emitted masses of Species **S_{12}**, **S_{16}**, **S_{17}**, and **S_{22}** have to be calculated as shown in Section 3.5.6.

3.5.6 Calculation of the masses of methane, nitrous oxide, NMVOCs, $PM_{2.5}$, PM_{10}, PM_{total}, and 4-PAH emitted

The emitted masses of methane (**S_{10}**), nitrous oxide (**S_{11}**), NMVOCs (**S_{12}**), $PM_{2.5}$ (**S_{16}**), PM_{10} (**S_{17}**), PM_{total} (**S_{19}**), and 4-PAH (**S_{22}**) are not estimated by the AEM. Nevertheless, these amounts can be estimated as shown in the following sections.

3.5.6.1 Methane

The mass of methane (**S_{10}**) emitted during a flight can be estimated by assuming an emission index of 0.000214 kg per kg of fuel burnt for the LTO cycle [38] and an emission index of 0 in the cruise phase [39].

Thus **m(methane, A_j, X_{dep})**, the mass of methane emitted in the take-off stage by Aircraft **A_j** departing from an airport that is located in **X**, is given by:

$$\mathbf{m(methane,\ A_j,\ X_{dep}) = 0.000214 \times m(Fuel,\ A_j,\ X_{dep})}$$

Similarly, **m(methane, A_j, Y_{arr})**, the mass of methane emitted in the landing stage by Aircraft **A_j** arriving at an airport that is located in **Y**, is given by:

$$\mathbf{m(methane,\ A_j,\ Y_{arr}) = 0.000214 \times m(Fuel,\ A_j,\ Y_{arr})}$$

and **m(methane, A_j, X>Y)** the mass of methane emitted in the cruise stage by Aircraft Aj that departed from an airport that is located in **X** and that arrived at an airport that is located in **Y** (where **X** and **Y** can be the same), is 0.

3.5.6.2 Nitrous oxide

The mass of nitrous oxide (**S_{11}**) emitted during a flight can be estimated by assuming an emission index of 0.0000856 kg per kg of fuel burnt for all phases of flight [40].

Thus **m(nitrous oxide, A_j, X_{dep})**, the mass of nitrous oxide emitted in the take-off stage by Aircraft **A_j** departing from an airport that is located in **X**, is given by:

$$\mathbf{m(nitrous\ oxide,\ A_j,\ X_{dep}) = 0.0000856 \times m(Fuel,\ A_j,\ X_{dep})}$$

[38] This emission index assumes that the net energy content of an average jet fuel is 42.8 MJ/kg and that the emission factor for methane in the LTO stage is 5 kg/TJ.
[39] This emission index assumes that no methane is emitted in the cruise stage.
[40] This emission index assumes that the net energy content of an average jet fuel is 42.8 MJ/kg and that the emission factor for nitrous oxide in all stages of flight is 2kg/TJ.

Similarly, **m(nitrous oxide, A_j, Y_{arr})**, the mass of nitrous oxide emitted in the landing stage by Aircraft $\mathbf{A_j}$ arriving at an airport that is located in **Y**, is given by:

$$\mathbf{m(nitrous\ oxide, A_j, Y_{arr}) = 0.0000856 \times m(Fuel, A_j, Y_{arr})}$$

and **m(nitrous oxide, A_j, X>Y)** the mass of nitrous oxide emitted in the cruise stage by Aircraft Aj that departed from an airport that is located in **X** and that arrived at an airport that is located in **Y** (where **X** and **Y** can be the same), is given by:

$$\mathbf{m(nitrous\ oxide, A_j, X{>}Y) = 0.0000856 \times m(Fuel, A_j, X{>}Y)}$$

3.5.6.3 NMVOCs

3.5.6.3.1 Up until 2016

Until the application of the FEIS procedure in 2017, a lower limit for the mass of NMVOCs ($\mathbf{S_{12}}$) emitted during a flight was estimated by summing the mass of all the species marked with a green tick (✓) as VOC in Appendix 5.D.

$\mathbf{m_{lower}(NMVOCs, A_j, X_{take\ off})}$, a lower limit for the mass of NMVOCs emitted in the take-off stage by Aircraft A_j departing from an airport that is located in **X**, can be estimated by:

$$\mathbf{m_{lower}(NMVOCs, A_j, X_{take\ off}) = \sum m(VOC_i, A_j, X_{take\ off})}$$

Similarly, $\mathbf{m_{lower}(NMVOCs, A_j, X_{landing})}$, a lower limit for the mass of NMVOCs emitted in the landing stage by Aircraft A_j arriving at an airport that is located in **X**, can be estimated by:

$$\mathbf{m_{lower}(NMVOCs, A_j, X_{landing}) = \sum m(VOC_i, A_j, X_{landing})}$$

and $\mathbf{m_{lower}(NMVOCs, A_j, X{>}Y)}$, a lower limit for the mass of NMVOCs emitted in the cruise stage by Aircraft A_j that departed from an airport that is located in **X** and that arrived at an airport that is located in **Y** (where **X** and **Y** can be the same), can be estimated by:

$$\mathbf{m_{lower}(NMVOCs, A_j, X{>}Y) = \sum m(VOC_i, A_j, X{>}Y)}$$

3.5.6.3.2 From 2017 onwards

As we do not know by how much these lower limits are underestimating the actual masses of the NMVOCs being emitted, in 2017 the mass of NMVOCs emitted is now estimated by simply multiplying the mass of UHCs emitted by 1.15.

3.5.6.4 $PM_{2.5}$, PM_{10}, and PM_{total},

The total mass of PM ($\mathbf{S_{19}}$) emitted during a flight is just the sum of the masses of $PM_{non\text{-}vol}$ ($\mathbf{S_{18}}$), $PM_{vol\text{-}org}$ ($\mathbf{S_{20}}$), and $PM_{vol\text{-}sul}$ ($\mathbf{S_{21}}$) emitted. Therefore,

$$\mathbf{m(PM_{total}, A_j, X_{take\ off}) = m(PM_{vol\text{-}org}, A_j, X_{take\ off}) + m(PM_{non\text{-}vol}, A_j, X_{take\ off}) + m(PM_{vol\text{-}sul}, A_j, X_{take\ off})}$$

$$\mathbf{m(PM_{total}, A_j, X_{landing}) = m(PM_{vol\text{-}org}, A_j, X_{landing}) + m(PM_{non\text{-}vol}, A_j, X_{landing}) + m(PM_{vol\text{-}sul}, A_j, X_{landing})}$$

$$\mathbf{m(PM_{total}, A_j, X{>}Y) = m(PM_{vol\text{-}org}, A_j, X{>}Y) + m(PM_{non\text{-}vol}, A_j, X{>}Y) + m(PM_{vol\text{-}sul}, A_j, X{>}Y)}$$

As all the PM emitted by aircraft engines has an aerodynamic diameter of less than 0.1 µm, the mass of PM_{10} (**S_{17}**) emitted is the same as the mass of $PM_{2.5}$ (**S_{16}**) emitted, which is the same as the mass of $PM_{0.1}$ (**S_{15}**) emitted, and all three are the same as the total mass of PM emitted, PM_{total} (**S_{19}**):

$$\mathbf{m(PM_{10}, A_j, X_{take\ off}) = m(PM_{total}, A_j, X_{take\ off})}$$
$$\mathbf{m(PM_{10}, A_j, X_{landing}) = m(PM_{total}, A_j, X_{landing})}$$
$$\mathbf{m(PM_{10}, A_j, X{>}Y) = m(PM_{total}, A_j, X{>}Y)}$$

$$\mathbf{m(PM_{2.5}, A_j, X_{take\ off}) = m(PM_{total}, A_j, X_{take\ off})}$$
$$\mathbf{m(PM_{2.5}, A_j, X_{landing}) = m(PM_{total}, A_j, X_{landing})}$$
$$\mathbf{m(PM_{2.5}, A_j, X{>}Y) = m(PM_{total}, A_j, X{>}Y)}$$

$$\mathbf{m(PM_{0.1}, A_j, X_{take\ off}) = m(PM_{total}, A_j, X_{take\ off})}$$
$$\mathbf{m(PM_{0.1}, A_j, X_{landing}) = m(PM_{total}, A_j, X_{landing})}$$
$$\mathbf{m(PM_{0.1}, A_j, X{>}Y) = m(PM_{total}, A_j, X{>}Y)}$$

3.5.6.5 4-PAH

In the absence of further information, an upper limit on the mass of 4-PAH (**S_{22}**) emitted can be set.

An upper limit for the mass of 4-PAH (**S_{22}**) emitted during a flight is equal to the mass of 7-PAH (**S_{23}**) emitted. Hence:

$$\mathbf{m_{upper}(4\text{-}PAH, A_j, X_{take\ off}) = m(7\text{-}PAH, A_j, X_{take\ off})}$$
$$\mathbf{m_{upper}(4\text{-}PAH, A_j, X_{landing}) = m(7\text{-}PAH, A_j, X_{landing})}$$
$$\mathbf{m_{upper}(4\text{-}PAH, A_j, X{>}Y) = m(7\text{-}PAH, A_j, X{>}Y)}$$

Currently, we do not know by how much these upper limits are overestimating the actual masses of the 4-PAHs being emitted.

3.6 Sources of inaccuracy in the FEIS procedure

The goal of the FEIS procedure is to generate estimates of the total masses of jet fuel and avgas burnt and the species of interest emitted during a particular year that are as close as possible to the actual masses. Just like other methods for estimating these values, the estimates produced by the FEIS procedure are subject to inaccuracies and consequently the values produced by the FEIS procedure could be different from the values produced by other methods.

As already stated above, in the FEIS procedure there can be a difference between the type of the actual aircraft that is associated with a particular flight and the types of aircraft for which fuel burn data is available that models that type of aircraft in the AEM. Also, there can be a difference between the type of engine that powers the actual type of aircraft that is associated with a particular flight and the type of engine that is associated with the type of aircraft that models it in the AEM.

Of course if part of the trajectory of a flight has to be generated there can be differences between the generated trajectory and the trajectory that was actually followed. In turn, these differences can lead to increased inaccuracies in the estimated masses.

Also, if a flight is not categorised correctly, or if some of the essential piece of information about it is missing, it could be incorrectly included in or excluded from the calculations.

Lastly, as only IFR flights are concerned by the FEIS procedure, all the other (non-IFR) flights being excluded from the calculations (in practice because EUROCONTROL has no record that they even occurred), the estimations generated by the FEIS procedure will be lower than they would have been if all types of civil flights had been included. In general, for most states, the amounts of jet fuel and avgas burnt by the excluded types of flights is small in comparison with that burnt by the IFR flights.

Given that (as shown in Figure 12 below):

- each relevant flight was flown by an actual type of aircraft composed of:
  - an actual type of airframe (designated by an ICAO *type-of-aircraft* code) and
  - one or more engines of the same actual type (designated by a *type-of-engine* name),
- the actual type of airframe is (possibly incorrectly) designated by a PRISME *type-of-airframe* code (which should itself be an ICAO *type-of-aircraft* code but sometimes is not),
- the actual type of engine(s) is (possibly incorrectly) designated by a PRISME *type-of-engine* name (which may or may not designate a DB type of engine),
- the PRISME type of aircraft is (possibly incorrectly) modelled by an FEIS type of aircraft (designated by an FEIS *type-of-aircraft* code), which is composed of:
  - an FEIS type of airframe (designated by an ICAO *type-of-aircraft* code) and
  - a DB type of engine (designated by a DB *type-of-engine* name), and
- the FEIS type of aircraft is (possibly incorrectly) modelled by a BADA type of aircraft, which is composed of:
  - a BADA type of airframe (designated by an ICAO *type-of-aircraft* code) and
  - a BADA type of engine (designated by a BADA *type-of-engine* name)

it is possible that:

- the PRISME type of airframe is different to the actual type of airframe, although experience shows that this is not very likely,
- the PRISME type of engine is different to the actual type of engine; this often happens,
- the DB type of engine is different to the PRISME type of engine (if rate of fuel burn and emissions data is not available for the PRISME type of engine),
- the BADA type of airframe is different to the FEIS type of airframe (if a BADA model of the FEIS type of airframe does not exist),
- the BADA type of engine is different to the FEIS type of engine, and
- the BADA type of engine is different to the PRISME type of engine.

Fortunately, for many of the most common actual types of aircraft making relevant flights:

- the PRISME *type-of-airframe* code correctly designates the type of the airframe of the actual aircraft,
- the PRISME type of airframe, the FEIS type of airframe, and the BADA type of airframe are all designated by the same ICAO *type-of-aircraft* code,
- the PRISME *type-of-engine* name correctly designates the type of the engine(s) of the actual aircraft, and
- the PRISME type of engine, the DB type of engine, and the BADA type of engine are all designated by the same DB *type-of-engine* name/code.

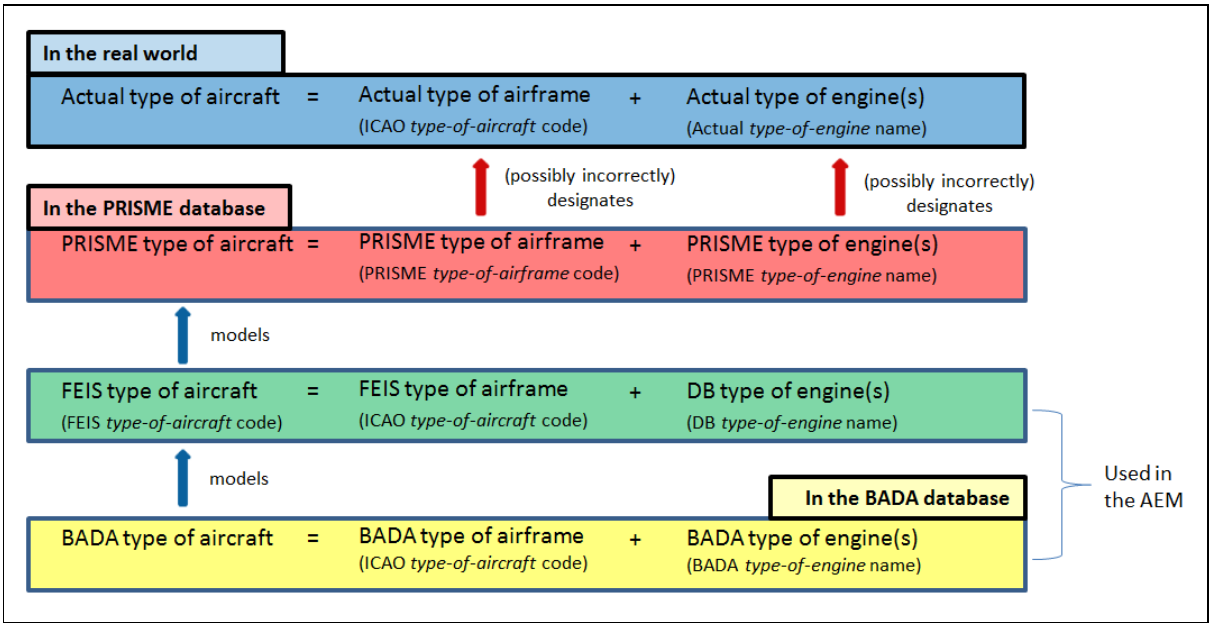

Figure 12: The relationships between actual, PRISME, FEIS, DB, and BADA types of aircraft, airframes, and engines.

3.7 What needs to be estimated each year

In each calendar year (Year *t*), the FEIS procedure is applied to the air traffic of the year before (Year *t-1*). So, in 2018, the masses of jet fuel and avgas burnt and species of interest emitted during the whole of 2017 were estimated.

If nothing essential in the FEIS procedure changes from Year *t-1* to Year *t*, it is only necessary to estimate the annual masses for the Year *t-1*, all the estimates for the previous years remaining valid. But if, for example, the relevant territory of a state changes, such as happened for the French Republic when Mayotte, which became a French overseas department on 31 March, 2011, was classified as an outermost region of the EU on 1 January, 2014, then all the estimates for the previous years for that region have to be re-calculated in order to maintain time-series consistency.

Other changes that require the estimates for previous years to be re-calculated include any changes to the input data for either types of aircraft or types of aircraft engine. See Section 3.7 for details of the changes that were made for the calculations that were performed in 2015, 2016, 2017, and 2018.

4. Modifications made to the FEIS procedure

In this section, the changes that were made to the FEIS procedure in a particular year and the changes that occurred in the real world in the year before are listed.

4.1 Modifications that were made to the FEIS procedure in 2018

In 2018, the estimates of the masses of the jet fuel and avgas burnt and species of interest emitted during 2017 were produced. This section lists the changes in the real world in 2017 or to the FEIS procedure used in 2018.

4.1.1 Geographic scope.

The only change to the geographic scope is that the British overseas territory of Montserrat is no longer included in the UK's coverage when the UK is party to the UNFCCC.

4.1.2 Types of aircraft

Some of the PRISME types of airframe (as designated by ICAO *type-of-aircraft* codes) of the aircraft that made relevant flights in 2017 had not made any relevant flights during the previous years (2005 to 2016 inclusive). These previously-unseen PRISME types of airframe (ICAO types of aircraft) are listed in the table below:

ICAO *type-of-aircraft* code	Type of aircraft		
	Manufacturer	Model	DB *type-of-engine* code
A19N	Airbus	A319neo	17CM082
A20N	Airbus	A320neo	17CM082
A21N	Airbus	A321neo	17CM083
A339	Airbus	A330-900	1PW027
B38M	Boeing	737 Max 8	18CM086
B39M	Boeing	737 Max 9	18CM084
B78X	Boeing	787-10 Dreamliner	12RR065
C55B	Cessna	550B Citation Bravo	1PW036
C68A	Cessna	Citation Latitude	7PW077
E290	Embraer	ERJ-190-300	11GE143
E295	Embraer	ERJ-190-400	11GE143
E530	Textron Airland	E530 Scorpion	1AS001
FA5X	Dassault	Falcon 5X	8RR043
G73T	Grumman	G-73T Turbo Mallard	FOI-21
KC39	Embraer	KC-390	14IA018
MRJ9	Mitsubishi	MRJ-90	3RR031
P212	Tecnam	P-2012 Traveller	FOCA-14
P40	Curtiss	P-40 Warhawk	FOCA-20
RV7	Van's	RV-7	FOCA-1
SF50	Cirrus	SF-50 Vision	1PW035
Y11	Harbin	Y-11	FOCA-19

Table 11: New ICAO *type-of-aircraft* codes needed for 2017 flights.

Each of these ICAO *type-of-aircraft* codes has at least one associated FEIS type of aircraft. For example, the A19N now has the associated FEIS *type-of-aircraft* code of **A19N-A**.

In addition, an FEIS *type-of-aircraft* code (**A10-A**, **A6-A**, etc) was created for each of the following PRISME types of airframe (designated by ICAO *type-of-aircraft* codes) although no relevant flights were finally associated with them, probably because the flights had been marked as military flights (which id likely as most of these types of aircraft are military aircraft) and so were not taken into account.

ICAO *type-of-aircraft* code	Type of aircraft		
	Manufacturer	Model	DB *type-of-engine* code
A10	Fairchild	A-10 Thunderbolt 2	1GE034
A6	Grumman	A-6 Intruder	1GE034
AJET	Dassault-Dornier	Alpha Jet	1PW037
ALO3	SUD	SA-316 Alouette 3	FOI-18
AMX	Aermacchi	AMX	8RR043
AN38	Antonov	An-38	FOI-109
AS55	Eurocopter	AS-355 Ecureuil 2	FOI-87
ATLA	Breguet	1150 Atlantic	FOI-85
B1	Rockwell	B-1 Lancer	1PW015
B2	Northrop	B-2 Spirit	1PW015
B412	Agusta	AB-412 Griffon	FOI-58
C101	CASA	C-101 Aviojet	1AS001
C135	Boeing	NC-135	1PW001
C160	Transall	C-160	FOI-85
C17	Boeing	C-17 Globemaster 3	1GE004
C270	Caudron	C-270 Luciole	FOCA-11
C27J	Alenia	C-27J Spartan	FOI-92
C295	CASA	C-295 Persuader	FOI-83
C2	Grumman	C-2 Greyhound	FOI-92
C5	Lockheed	C-5 Galaxy	5RR039
DC94	Douglas	DC-9-40	1PW008
E2	Grumman	E-2 Hawkeye	FOI-93
E3CF	Boeing	E-3F Sentry	4PW069
E3TF	Boeing	E-3BSentry	4PW069
E6	Boeing	E-6 Mercury	1CM001
EH10	Agusta Westland	EH-101 Merlin	FOI-9
EUFI	Eurofighter	Eurofighter 2000	8GE107
F15	McDonnell Douglas	F-15 Eagle	8GE103
F16	General Dynamics	F-16 Fighting Falcon	11GE140
F18S	McDonnell Douglas	FA-18 Super Hornet	8RR043
F1	Mitsubishi	F-1	7PW077
F260	Aermacchi	F-260E	FOCA-3
F35	Lockheed Martin	F-35A Lightning II	1IA004
F4	McDonnell Douglas	F-4 Phantom 2	8RR043
F5	Northrop	F-5 Tiger 2	1AS001
GAZL	Aerospatiale	SA-341 Gazelle	FOI-90
H47	Boeing	CH-47 Chinook	FOI-84

ICAO *type-of-*	Type of aircraft		
H53	Sikorsky	RH-53 Sea Stallion	FOI-1
H60	Sikorsky	AH-60 Black Hawk	FOI-60
HAR	McDonnell Douglas	AV-8 Harrier	4CM035
HAWK	British Aerospace	Hawk	14HN006
IL38	Ilyushin	Il-38	FOI-4
IR99	Avioane	IAR-99 Swift	1AS002
JAGR	SEPECAT	Jaguar	7PW077
K35E	Boeing	KC-135E Stratotanker	8CM059
K35R	Boeing	KC-135R Stratotanker	8CM059
L159	Aero	L-159 Albatros 2	16PW114
L70	Valmet	L-70 Vinka	FOCA-2
LYNX	Westland	Lynx	FOI-30
M28	PZL-Mielec	M-28 Skytruck	FOI-39
M339	Aermacchi	MB-339	1AS002
MF17	SAAB	MFI-17 Supporter	FOCA-2
MG21	Mikoyan	MiG-21	1GE034
MG29	Mikoyan	MiG-29	11GE141
MI24	MIL	Mi-24	FOI-68
MIR2	Dassault	Mirage 2000	1PW007
P1	Kawasaki	P-1	8GE107
P66T	Piaggio	P-166DL3	FOI-42
P8	Boeing	P-8 Poseidon	8CM065
PC7	Pilatus	PC-7 Astra	FOI-19
PUMA	Aerospatiale	CH-33 Puma	FOI-47
PZ3T	PZL-Okecie	PZL-130 Orlik	FOI-20
R135	Boeing	RC-135	8CM059
RF4	Fournier	RF-4	FOCA-9
RFAL	Dassault	Rafale	8RR043
S330	Schweizer	269D 330	FOI-87
SB05	SAAB	105	1PW037
SB35	SAAB	J35 Draken	5GE083
SB37	SAAB	JA37 Viggen	16PW116
SB39	SAAB	JAS39 Gripen	8GE113
SU17	Sukhoi	Su-17	11GE140
SU27	Sukhoi	Su-27	11GE140
T2	North American	T-2 Buckeye	1PW037
T37	Cessna	T-37	1PW035
T38	Northrop	T-38 Talon	1PW035
T6	North American	T-6 Texan	FOCA-19
TB30	Socata	TB-30 Epsilon	FOCA-4
TOR	British Aerospace	Tornado	4RR035
TS11	PZL-Mielec	TS-11 Iskra	1PW035
TUCA	Embraer	T-27 Tucano	FOI-20
U2	Lockheed	U-2	1PW003
UH1	Bell	EH-1 Iroquois	FOI-39
W3	PZL-Swidnik	W-3 Huzar	FOI-54

Table 12: Additional new ICAO *type-of-aircraft* codes for 2017 flights.

Some (legacy) FEIS types of aircraft that were defined in 2015 have been deleted because there are no relevant flights associated with them during the years 2005 to 2016 inclusive – many of these types of aircraft are military types of aircraft.

The types of aircraft designated by the ICAO *type-of-aircraft* codes in the table below are no longer processed in the FEIS procedure:

ICAO *type-of-aircraft* designator	Type of aircraft
A20	Douglas A-20 Havoc
AS26	Schleicher ASH-26E
ATL	Robin ATL
ATLA	Dassault 1150 Atlantic
B29	Boeing B-29 Superfortress
B2	Northrop Grumman B-2 Spirit
B412	Bell 412
B731	Boeing 737-100
B74D	Boeing 747-400 (domestic)
BASS	Beagle Basset
BE20	Beech 200 Super King Air
C04T	Cessna 404 Turbo Titan
C55B	Cessna 550B Citation Bravo
CA25	Commonwealth CA-25 Winjeel
CH64	Zenair CH-640 Zodiac
CJ1	Corby CJ-1 Starlet
CL44	Canadair CL-44 Forty Four
CRES	Pacific Aerospace Cresco
CVLP	Convair Convairliner
D6	Auster D-6
D7	Fokker D-7 Replica
D8	Fokker D-8 Replica
DH80	De Havilland DH-80 Puss Moth
DH83	De Havilland DH-83 Fox Moth
DH87	De Havilland DH-87 Hornet Moth
DH88	De Havilland DH-88 Comet Replica
DH89	De Havilland DH-89 Dragon Rapide
DHA3	De Havilland Australia DHA-3 Drover
DHC5	De Havilland Canada C-8 Buffalo
E45X	Embraer ERJ-145XR
EH10	Agusta Westland EH-101 Merlin
F20	Unknown (probably should be Dassault Falcon 20)
F8	Chance Vought F8 Crusader
FA62	Fairchild M-62 Cornell
G15T	Grob G-115T Acro
G4SG	Soko G-4 Super Galeb
G59	FIAT G-59
H40	Hoffmann H-40
HF20	MBB Hansa
HRZN	Raytheon 4000 Hawker Horizon

ICAO *type-of-aircraft* designator	Type of aircraft
J2	Piper J-2 Cub
JARO	Jackaroo Thruxton Jackaroo
JP10	Kestrel K-350 (former code)
JS3	Century Jetstream 3
KFIR	IAI Kfir
L10	Lockheed L-10 Electra
L60	Aero L-60 Brigadyr
MC90	Monocoupe 90
MG44	Mikoyan MiG 1-44
N262	Aerospatiale -262 Frégate
P40	Curtiss P-40 Warhawk
P50	Pottier P-50 Bouvreuil
P61	Northrop P-61 Black Widow
P63	Bell P-63 Kingcobra
P80	Pottier P-80
PL12	Transavia PL-12 Airtruk
PL2	Pazmany PL-2
PNR2	Alpi Pioneer 200
PO60	Potez 60 Sauterelle
R135	Boeing RC-135
R2TH	Rockwell Ranger 2000
R722	Boeing Super 727 (200)
RF4	Fournier RF-4
RV4	Van’s RV-4
S330	Schweizer 330
S4	Arctic S-4 Privateer
S62	Sikorsky S-62
SA05	K & S SA-105 Super Cavalier
SF23	Scheibe SF-23 Sperling
SF24	Scheibe SF-24 Motorspatz
SF36	Scheibe SF-36
SR71	Lockheed SR-71Blackbird
SU7	Sukhoi Su-7
SYMP	Symphony SA-160 Symphony
T144	Tupolev Tu-144
T22M	Tupolev Tu-22M
T37	Cessna T-37
T40	Turner T-40
T50	Cessna T-50 Bobcat
TB30	Socata TB-30 Epsilon
TRIN	Socata TB-20 Trinidad
TU95	Tuploev Tu-95
UH1	Bell EH-1 Iroquois
VISC	Vickers Viscount
W3	PZL-SWIDNIK W-3 Anakonda
WW23	IAI 1123 Westwind

ICAO *type-of-aircraft* designator	Type of aircraft
X319	Unknown
X320	Unknown
X738	Unknown
YK28	Yakovlev Yak-28
ZULU	Bul Zùlù

Table 13: ICAO *type-of-aircraft* codes that are no longer needed

Finally, in addition to the 104 FEIS *type-of-aircraft* codes xxxx-A that were defined for the ICAO types of aircraft listed in Table 11and Table 12, the following new FEIS *type-of-aircraft* codes were defined.

FEIS *type-of-aircraft* designator	DB *type-of-engine* code
A20N-B	18PW122
A21N-B	18PW125
A21N-C	18PW124
A319-L	3CM022
A320-K	8CM055
A321-H	8CM054
A321-I	3CM026
B738-I	11CM070
B744-H	4RR036
B74R-B	2GE041
B74R-C	3GE068
B74S-H	1PW023
B753-B	4PW073
B77W-D	5PW076
DC10-G	1GE003
DC3T-B	FOI-42
DC93-B	1PW007
DC93-C	1PW013
DC93-D	1PW010
DH8C-G	FOI-73
E145-C	6AL019

Table 14: Additional new FEIS type-of-aircraft codes for 2017 flights.

4.2 Modifications that were made to the FEIS procedure in 2017

In 2017, the estimates of the masses of the jet fuel and avgas burnt and species of interest emitted during 2016 were produced. This section lists the changes in the real world in 2016 or to the FEIS procedure used in 2017.

4.2.1 Geographic scope.

There was no change to the geographic scope in 2016.

4.2.2 Types of aircraft

Some of the PRISME types of airframe (as designated by ICAO *type-of-aircraft* codes) of the aircraft that made relevant flights in 2016 had not been seen during the previous years (2005 to 2015 inclusive). These previously-unseen PRISME types of airframe (ICAO types of aircraft) are listed in the table below:

ICAO *type-of-aircraft* code	Type of aircraft
A169	Agusta Westland AW-169
A35K	Airbus A350-1000 XWB
BCS1	Bombardier BD-500 C Series CS100
BCS3	Bombardier BD-500 C Series CS300
C240	Cessna T240 Corvalis TTx
C82S	Cessna T182 Turbo Skylane
C82T	Cessna TR182 Turbo Skylane RG
DA50	Diamond DA-50 Magnum
DA62	Diamond DA-62
E195	Embraer 195
ELIT	Epic Aircraft Epic Elite
F18H	Boeing Hornet
FA8X	Dassault Falcon 8X
GA5C	Gulfstream Aerospace G-7 Gulfstream G500
HDJT	Honda HondaJet
KEST	Farnborough F-1 Kestrel
PC24	Pilatus PC-24

Table 15: New ICAO *type-of-aircraft* codes for 2016.

Each of these ICAO *type-of-aircraft* codes has at least one associated FEIS type of aircraft. For example, the A169 now has the associated FEIS *type-of-aircraft* code of **A169-A**.

Conversely, some (legacy) FEIS types of aircraft that were defined in 2015 have been deleted because there are no relevant flights associated with them during the years 2005 to 2016 inclusive – many of these types of aircraft are military types of aircraft.

The types of aircraft designated by the ICAO *type-of-aircraft* codes in the table below are no longer processed in the FEIS procedure:

ICAO *type-of-aircraft* designator	Type of aircraft
A20	Douglas A-20 Havoc
AS26	Schleicher ASH-26E
ATL	Robin ATL
ATLA	Dassault 1150 Atlantic
B29	Boeing B-29 Superfortress
B2	Northrop Grumman B-2 Spirit
B412	Bell 412
B731	??? (Probably Boeing 737-100)
B74D	Boeing 747-400 (domestic)
BASS	Beagle Basset

ICAO *type-of-aircraft* designator	Type of aircraft
BE20	Beech 200 Super King Air
C04T	Cessna 404 Turbo Titan
C55B	Cessna 550B Citation Bravo
CA25	Commonwealth CA-25 Winjeel
CH64	Zenair CH-640 Zodiac
CJ1	Corby CJ-1 Starlet
CL44	Canadair CL-44 Forty Four
CRES	Pacific Aerospace Cresco
CVLP	Convair Convairliner
D6	Auster D-6
D7	Fokker D-7 Replica
D8	Fokker D-8 Replica
DH80	De Havilland DH-80 Puss Moth
DH83	De Havilland DH-83 Fox Moth
DH87	De Havilland DH-87 Hornet Moth
DH88	De Havilland DH-88 Comet Replica
DH89	De Havilland DH-89 Dragon Rapide
DHA3	De Havilland Australia DHA-3 Drover
DHC5	De Havilland Canada C-8 Buffalo
E45X	Embraer ERJ-145XR
EH10	Agusta Westland EH-101 Merlin
F20	???
F8	Chance Vought F8 Crusader
FA62	Fairchild M-62 Cornell
G15T	Grob G-115T Acro
G4SG	Soko G-4 Super Galeb
G59	FIAT G-59
H40	Hoffmann H-40
HF20	MBB Hansa
HRZN	???
J2	Piper J-2 Cub
JARO	Jackaroo Thruxton Jackaroo
JP10	???
JS3	Century Jetstream 3
KFIR	IAI Kfir
L10	Lockheed L-10 Electra
L60	Aero L-60 Brigadyr
MC90	Monocoupe 90
MG44	Mikoyan MiG 1-44
N262	Aerospatiale -262 Frégate
P40	Curtiss P-40 Warhawk
P50	Pottier P-50 Bouvreuil
P61	Northrop P-61 Black Widow
P63	Bell P-63 Kingcobra
P80	Pottier P-80
PL12	Transavia PL-12 Airtruk

ICAO *type-of-aircraft* designator	Type of aircraft
PL2	Pazmany PL-2
PNR2	Alpi Pioneer 200
PO60	Potez 60 Sauterelle
R135	Boeing RC-135
R2TH	???
R722	Boeing Super 727 (200)
RF4	Fournier RF-4
RV4	Van's RV-4
S330	Schweizer 330
S4	Arctic S-4 Privateer
S62	Sikorsky S-62
SA05	K & S SA-105 Super Cavalier
SF23	Scheibe SF-23 Sperling
SF24	Scheibe SF-24 Motorspatz
SF36	Scheibe SF-36
SR71	Lockheed SR-71Blackbird
SU7	Sukhoi Su-7
SYMP	Symphony SA-160 Symphony
T144	Tupolev Tu-144
T22M	Tupolev Tu-22M
T37	Cessna T-37
T40	Turner T-40
T50	Cessna T-50 Bobcat
TB30	Socata TB-30 Epsilon
TRIN	???
TU95	Tuploev Tu-95
UH1	Bell EH-1 Iroquois
VISC	???
W3	PZL-SWIDNIK W-3 Anakonda
WW23	IAI 1123 Westwind
X319	???
X320	???
X738	???
YK28	Yakovlev Yak-28
ZULU	Bul Zùlù

Table 16: ICAO *type-of-aircraft* codes that are no longer needed

4.2.3 Taxi times

The taxi-in and taxi-out times that are used by the AEM have been calculated differently this year. See Section 3.5.4.4 above.

4.2.4 Calculations

The mass of NMVOCs emitted is now calculated simply by multiplying the mass of UHCs emitted by 1.15.

The values in the AEM.VOCTOG_CONSTANTS.txt file have been updated, as indicated in the following table:

Multiplier	Old value	New value	Change
HC_to_VOC_Multiplier	0.99	1.15	↑
VOC_Acetaldehyde	0.04	0.04315	↑
VOC_Acrolein	0.02	0.02473	↑
VOC_POM_16_PAH	0.00006829	0.00006829	=
VOC_POM_7_PAH	0.000007234	0.000007234	=
VOC_Styrene	0.0037	0.00312	↓
VOC_to_TOG_Multiplier	0.3	1.00870	↑
TOG_Butadiene	0.01	0.01687	↑
TOG_Benzene	0.01	0.01681	↑
TOG_Ethylbenzene	0.0015	0.00174	↑
TOG_Formaldehyde	0.14	0.12310	↓
TOG_Propionaldehyde	0.009	0.00727	↓
TOG_Toluene	0.0049	0.00642	↑
TOG_Xylene	0.0044	0.00448	↑

Table 17: The old and new values in the AEM.VOCTOG_CONSTANTS.txt file.

4.3 Modifications that were made to the FEIS procedure in 2016

In 2016, the estimates of the masses of jet fuel and avgas burnt and certain species emitted during 2015 were produced. This section lists the changes in the real world in 2015 or to the FEIS procedure used in 2016.

4.3.1 Geographic scope.

There was no change to the geographic scope in 2015.

4.3.2 Types of aircraft

Some of the PRISME types of airframe (as designated by ICAO *type-of-aircraft* codes) of the aircraft that made relevant flights in 2015 had not been seen during the previous years (2005 to 2014 inclusive). These previously-unseen PRISME types of airframe (ICAO types of aircraft) are listed in the table below:

ICAO *type-of-aircraft* code	Type of aircraft
A158	Antonov An-158
ATL	Robin ATL
B412	Agusta AB-412 Griffon
B58T	Beech Pressurized Baron
BN2T	Britten-Norman Turbine Islander
BT36	Beech Bonanza
C337	Cessna 337 Super Skymaster
C55B	Cessna Citation Bravo
CL35	Bombardier Challenger 350

ICAO *type-of-aircraft* code	Type of aircraft
CVLP	Convair CV-240 Convairliner
DC93	Douglas DC-9-30
DHC5	De Havilland Canada DHC-5 Buffalo
DLTA	Verhees Delta
E45X	Embraer ERJ-145XR
E550	Embraer EMB-550 Legacy 500
EH10	Agusta Westland EH-101 Merlin
ERCO	Erco 415 Ercoupe
F260	Aermacchi F-260F
JS1	Handley Page Jetstream 1
LJ70	Learjet 70
N262	Nord 262 Frégate
P28S	Piper Turbo Arrow
PC6T	Pilatus Turbo-Porter
RF4	Fournier RF-4
S330	Schweizer 330
SH33	Short Sherpa
T206	Cessna Turbo Stationair 6
T210	Cessna Turbo Centurion
T37	Cessna T-37
TB30	Socata TB-30 Epsilon
TBM9	Socata TM-900
TWEN	Tecnam Twenty-Ten
UH1	Bell Iroquois
W3	PZL-Swidnik W-3 Gluszec

Table 18: New ICAO *type-of-aircraft* codes for 2015.

In previous years, entries for these previously-unseen ICAO type-of-aircraft designators would have had to be added to the ***ACT_PRF.aircraft_engine.txt*** file. See Section 4.3.4 below to see how these new types were treated this year.

4.3.3 Taxi times

The average taxi-in and taxi-out times in 2015 for those airports with more than 100 movements (i.e. more than 100 arrivals and/or 100 departures) in 2015, as determined by EUROCONTROL's CODA, were added.

Another change made this year concerns all the airports for which an annual average taxi-out or taxi-in time for a particular year is not available from CODA. Previously, the ICAO default taxi-out time (1,140 seconds) or taxi-in time (420 seconds) was used instead. This year, estimations were made of the average taxi-out and taxi-in times for so-called "minor" European airports.

For the purposes of this document, a minor airport is an airport that has less than 1,000 departures and/or arrivals in a year.

A European airport is one whose ICAO code begins with:

- **BK** (for airports in Kosovo),

- **E** (except for **EGYP**, which is the code for RAF Mount Pleasant in the Falkland Islands), or
- **L** (except for **LFVM** and **LFVP**, which are the codes for Miquelon Airport and Saint-Pierre Airport respectively).

The annual average taxi-out and taxi-in times for those European airports with between 101 and 1,000 departures and/or arrivals per year are available in CODA. By plotting the annual average taxi-out and taxi-in times of these European airports, it was possible to obtain an estimate of the annual average taxi-in and taxi-out times for European airports with less than 100 departures and/or arrivals per year. The default taxi-out time for minor European airports is estimated to be 490 seconds and the default taxi-in time is estimated to be 304 seconds.

4.3.4 Calculations

There was one major change and several minor changes to the calculations in the FEIS procedure.

The biggest difference between the FEIS procedure that was used in 2015 (for 2005-2014 data) and that used in 2016 (for 2005-2015 data) is that now it is not just the PRISME type of airframe of an aircraft that made a flight that is used to select the fuel burn and emissions data that is used by AEM but the {PRISME type of airframe, PRISME type of engine} combination that is used.

Every {PRISME type of airframe, PRISME type of engine} combination is converted into an equivalent FEIS type of aircraft, which itself is equivalent to a {PRISME type of airframe, DB type of engine} combination. The FEIS *type-of-aircraft* code, rather than the ICAO *type-of-aircraft* code, is now used as the key in the ***ACT_PRF.aircraft_engine.txt*** file to select the DB type of engine, number of engines, and BADA type of aircraft. As some PRISME type of airframes can be associated with as many as 12 different DB types of engine, the number of entries in the ***ACT_PRF.aircraft_engine.txt*** file has greatly increased.

The following minor changes were made to the FEIS procedure.

The method for calculating the mass of methane emitted has been changed. See Section 3.5.6.1 for details of the new method.

The method for calculating the mass of nitrous oxide emitted has been changed. See Section 3.5.6.1 for details of the new method.

The default taxi times for minor European airports (those with 100 or fewer arrivals and/or departures during a year for which CODA does not determine an annual average taxi-in or taxi-out time) is no longer set to the ICAO default taxi times.

4.4 Modifications that were made to the FEIS procedure in 2015

In 2015, the estimates of the masses of jet fuel and avgas burnt and certain species emitted during 2014 were produced. This section lists the changes in the real world in 2014 or to the EUROCONTROL FEIS procedure used in 2015.

4.4.1 Geographic scope

Mayotte was classified by the EU as an outermost region of the EU on 1 January, 2014 and, as such, on that date, it became a part of the territory of the EU.

4.4.2 Types of aircraft

Some of the PRISME types of airframe (as designated by ICAO *type-of-aircraft* codes) of the aircraft that made relevant flights in 2014 had not been seen during the previous years (2005 to 2013 inclusive). Consequently, it was necessary to add entries for aircraft with such types of airframe in the ***ACT_PRF.aircraft_engine.txt*** file. The new types of airframe are listed in the table below:

ICAO *type-of-aircraft* code	Type of aircraft
A189	Agusta Westland AW189
B789	Boeing 787 Dreamliner Series 9
C162	Cessna 162 Skycatcher
G12T	Grob G 120TP
LJ75	Learjet 75
M346	Alenia Aermacchi M-346 Master
P28U	Piper PA-28RT-201T Turbo Arrow 4
PA47	Piper PA-47 PiperJet
PO60	Potez 60 – Sauterelle
S22T	Cirrus SR22 Turbo
SHRK	Shark.Aero Shark
TB21	Socata TB-21 Trinidad

Table 19: New actual types of aircraft added to the *ACT_PRF.aircraft_engine.txt* file.

Data for 3 existing actual types of aircraft were changed in the ***ACT_PRF.aircraft_engine.txt*** file as indicated in the table below:

ICAO code	Change made
A119	Engine ID changed from 1PW011 to AEM_FAA10
A119	Number of engines changed from 4 to 1
A119	BADA type changed from A124 to TRIN
B788	Engine ID changed from 11RR048 to 12RR055
PUP	Number of engines changed from 2 to 1
PUP	BADA type changed from PA31 to P28A

Table 20: Changes to the *ACT_PRF.aircraft_engine.txt* file for 3 existing types of aircraft.

Finally, the DB type of engine associated with a number of the existing actual types of aircraft that are powered by turboprop engines was changed as indicated in the table below:

ICAO *type-of-aircraft* code	Old *type-of-engine* code	New *type-of-engine* code
AN26	1RR018	AI24VT
AT72	PW127F	PW124B
B190	1AS002	PT6A67
B350	AEM_FAA19	PT6A60
BE20	AEM_FAA19	PT6A42
C130	AEM_FAA23	T56A15
DH8A	4PW072	PW120A
DH8C	4PW072	PW123B
DH8D	4PW072	PW150A
D328	4PW072	PW119B
E110	1AS002	PT6A34
E120	4PW072	PW118
F27	1RR018	PW127B
F50	4PW072	PW125B
JS31	1AS002	TPE11U
JS41	1AS002	TPE14
L410	1AS002	PT6A34
SB20	8AL025	PW123B
SF34	AEM_FAA5	CT79B
SH36	AEM_FAA19	PT667R
SW4	1AS002	TP10UA

Table 21: Changes to the DB **type of engine associated with some actual types of aircraft powered by turboprop engines in the *ACT_PRF.aircraft_engine.txt* file**

A change to the DB type of engine associated with an actual type of aircraft can only result in changes to the results of the calculations for the LTO cycle. Consequently, only the LTO part of the calculations had to be redone for the flights in the years 2005-2013 inclusive.

No change was made to either the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** or the ***ACT_PRF.BADA_FUEL_BURN.txt*** files.

4.4.3 Taxi times

The average taxi-in and taxi-out times in 2014 for those airports with more than 100 movements in 2014, as determined by EUROCONTROL's CODA, were added.

4.4.4 Calculations

A few small changes have been made to the calculations in the FEIS procedure.

Firstly, a few flights that would have been classed as relevant flights in previous years have been removed as it has been realised that these were just duplicates of other flights.

Secondly, concerning the types of PM; only the masses of $PM_{non\text{-}vol}$, $PM_{vol\text{-}org}$, and $PM_{vol\text{-}sul}$ are now estimated by the AEM. The masses of the other types of PM, specifically PM_{total}, $PM_{0.1}$ and $PM_{2.5}$, are derived from these values.

Lastly, in previous years, the calculation of the mass of nitrous oxide emitted during the cruise stage of a flight was over-estimated by a factor of 1,000. This has now been corrected.

5. References

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A The parties

Each of the 33 states that are members of the EEA has sovereignty over a certain territory or group of territories. The table below indicates the territories over which each of these 33 states has sovereignty and also shows which of these territories are considered to be included in (✓) or excluded from (x) the territory of:

- the EU, when the EU as a single entity is party to
  - both the UNFCCC and the CLRTAP – this territory is called EU-28 in the table;
  - the 2nd commitment period for the Kyoto Protocol (**2KP**)) – this territory is called EU-2KP in the table,
- the state, when the state is party to
  - the UNFCCC,
  - the 2KP, and
  - the CLRTAP.

So, for example, the only part of the territory of the Kingdom of Denmark that is considered to be in EU-28 is Denmark itself. But when the Kingdom of Denmark is a party to the UNFCCC or the CLRTAP, the territory of the Kingdom of Denmark is considered to include Denmark, Greenland, and the Faroe Islands.

Nothing is reported for those territories in the table below that have a light orange background. Thus, for example, that part of the territory of the *de jure* Republic of Cyprus that is currently the territory of the *de facto* Turkish Republic of Northern Cyprus, which itself is a party to neither the UNFCCC nor the CLRTAP, is not considered to be a part of the EU-28. Such territories are included in this table just for the sake of completeness.

As of 1 January, 2015, when the Republic of Estonia joined EUROCONTROL, all the 28 states that are members of the EU-28 are also members of EUROCONTROL.

Party	Territory	Territory is included in…		Territory is included when party is party to…		
		EU-28	EU-2KP	UNFCCC	2KP	CLRTAP
European Union	EU-28	N/A	N/A	✓	x	✓
European Union	EU-2KP	N/A	N/A	x	✓	x
Republic of Austria	Austria	✓	✓	✓	✓	✓
Kingdom of Belgium	Belgium	✓	✓	✓	✓	✓
Republic of Bulgaria	Bulgaria	✓	✓	✓	✓	✓
Republic of Croatia	Croatia	✓	✓	✓	✓	✓
De jure Republic of Cyprus	*De facto* Republic of Cyprus	✓	✓	✓	✓	✓
	UN Buffer Zone	x	x	x	x	x
	De facto Turkish Republic of Northern Cyprus	x	x	x	x	x
Czech Republic	Czech Republic	✓	✓	✓	✓	✓
Kingdom of Denmark	Denmark	✓	✓	✓	✓	✓
	Faroe Islands	x	x	✓	x	✓
	Greenland	x	x	✓	x	✓
Republic of Estonia	Estonia	✓	✓	✓	✓	✓
Republic of Finland	Finland	✓	✓	✓	✓	✓
	Åland Islands	✓	✓	✓	✓	✓

Party	Territory	Territory is included in…		Territory is included when party is party to…		
		EU-28	EU-2KP	UNFCCC	2KP	CLRTAP
French Republic	France	✓	✓	✓	✓	✓
	Guadeloupe	✓	✓	✓	✓	✓
	Martinique	✓	✓	✓	✓	✓
	French Guiana	✓	✓	✓	✓	✓
	Reunion	✓	✓	✓	✓	✓
	Mayotte	✓	✓	✓	✓	✓
	New Caledonia	x	x	✓	x	✓
	Wallis and Futuna	x	x	✓	x	✓
	French Polynesia	x	x	✓	x	✓
	Saint-Pierre and Miquelon	x	x	✓	x	✓
	Saint Martin	✓	✓	✓	✓	✓
	Saint Barthélemy	✓	✓	✓	✓	✓
Federal Republic of Germany	Germany	✓	✓	✓	✓	✓
	Büsingen am Hochrhein	✓	✓	✓	✓	✓
	Helgoland	✓	✓	✓	✓	✓
United Kingdom of Great Britain and Northern Ireland	England	✓	✓	✓	✓	✓
	Scotland	✓	✓	✓	✓	✓
	Wales	✓	✓	✓	✓	✓
	Northern Ireland	✓	✓	✓	✓	✓
	Anguilla	x	x	x	x	x
	Bermuda	x	x	✓	x	x
	British Antarctic Territory	x	x	x	x	x
	British Indian Ocean Territory	x	x	x	x	x
	British Virgin Islands	x	x	x	x	x
	Cayman Islands	x	✓	✓	✓	✓
	Falkland Islands	x	✓	✓	✓	✓
	Gibraltar	✓	✓	✓	✓	✓
	Montserrat	x	x	x	x	x
	Pitcairn Islands	x	x	x	x	x
	Saint Helena, Ascension, and Tristan da Cunha	x	x	x	x	x
	South Georgia and the South Sandwich Islands	x	x	x	x	x
	Turks and Caicos Islands	x	x	x	x	x
	Jersey	x	✓	✓	✓	✓
	Guernsey [41]	x	✓	✓	✓	✓
	Isle of Man	x	✓	✓	✓	✓
	Akrotiri [42]	x	x	x	x	✓
	Dhekelia [37]	x	x	x	x	✓
Hellenic Republic	Greece	✓	✓	✓	✓	✓
	Mount Athos	✓	✓	✓	✓	✓
Hungary	Hungary	✓	✓	✓	✓	✓
Republic of Iceland	Iceland	x	✓	✓	✓	✓
Ireland	Ireland	✓	✓	✓	✓	✓
Italian Republic	Italy	✓	✓	✓	✓	✓
	Campione d'Italia	✓	✓	✓	✓	✓
	Livigno	✓	✓	✓	✓	✓
Republic of Latvia	Latvia	✓	✓	✓	✓	✓
Principality of Liechtenstein	Liechtenstein	x	x	✓	✓	✓
Republic of Lithuania	Lithuania	✓	✓	✓	✓	✓

[41] Including Alderney.
[42] The Sovereign Base Areas of Akrotiri and Dhekelia is a British Overseas Territory on the island of Cyprus.

Party	Territory	Territory is included in…		Territory is included when party is party to…		
		EU-28	EU-2KP	UNFCCC	2KP	CLRTAP
Grand Duchy of Luxembourg	Luxembourg	✓	✓	✓	✓	✓
Republic of Malta	Malta	✓	✓	✓	✓	✓
Kingdom of the Netherlands	Netherlands	✓	✓	✓	✓	✓
	Aruba	x	x	x	x	x
	Curaçao	x	x	x	x	x
	Sint Maarten	x	x	x	x	x
	Bonaire	x	x	x	x	x
	Sint Eustatius	x	x	x	x	x
	Saba	x	x	x	x	x
Kingdom of Norway	Norway	x	x	✓	✓	✓
	Svalbard	x	x	✓	✓	✓
	Jan Mayen	x	x	✓	✓	✓
Republic of Poland	Poland	✓	✓	✓	✓	✓
Portuguese Republic	Portugal	✓	✓	✓	✓	✓
	Azores	✓	✓	✓	✓	✓
	Madeira	✓	✓	✓	✓	✓
Romania	Romania	✓	✓	✓	✓	✓
Slovak Republic	Slovakia	✓	✓	✓	✓	✓
Republic of Slovenia	Slovenia	✓	✓	✓	✓	✓
Kingdom of Spain	Spain	✓	✓	✓	✓	✓
	Canary Islands	✓	✓	✓	✓	✓
	Ceuta	✓	✓	✓	✓	✓
	Melilla	✓	✓	✓	✓	✓
	Plazas de soberanía	✓	✓	✓	✓	✓
Kingdom of Sweden	Sweden	✓	✓	✓	✓	✓
Swiss Confederation	Switzerland	x	x	✓	✓	✓
Republic of Turkey	Turkey	x	x	✓	✓	✓

Table 22: Territories of the 33 states that are members of the EEA in 2018.

B Airports in the territories of the 33 member states of the EEA

Each of the 33 member states of the EEA has sovereignty over a particular territory or set of territories. The table below indicates the territories over which each of these 33 states has sovereignty and also shows which of these territories are considered to be included in the territory of the EU (EU-28).

The table also indicates the 4-character ICAO codes of the airports that are considered to be located in each of these territories as well as, where necessary, the ICAO codes of any airports that are considered to be located outside each of these territories. An ICAO code such as **LOxx** refers to any airport whose ICAO code begins with **LO**.

For any territory, a code in **green** in the "included" column indicates that all the airports whose code matches that code are considered to be located in the territory. A code in **blue** in the "Included" column indicates that only some airports whose code matches that code are considered to be located in the territory; the code of any airport that is considered to be located outside the territory will be listed in **red** in the "Except for" column.

So, for example, the only part of the Kingdom of Denmark that is considered to be included in the territory of the EU is Denmark itself. Now airports that are located in Denmark and the Faroe Islands have the ICAO code **EKxx**. Airports that are located in Greenland have the ICAO code **BGxx**. Thus, to include all the airports in Denmark, you have to include all the airports whose ICAO code begins with **EK** (**EKxx**) except for the airports that have the following ICAO codes (all of which are in the Faroe Islands): **EKFA**, **EKKV**, **EKMS**, **EKSO**, **EKSR**, **EKSY**, **EKTB**, and **EKVG**. It is not necessary to implicitly exclude the airports that are located in Greenland because their ICAO codes all begin with "BG" (**BGxx**).

Note that there are no airports with an ICAO code in some territories (for example the Pitcairn Islands). And those territories that are not involved in reporting to the UNFCCC or CLRTAP have a light orange background in the table below.

State	Territory	Part of the EU	Airports	
			Included	Except for
Republic of Austria	Austria	✓	**LOxx**	
Kingdom of Belgium	Belgium	✓	**EBxx**	
Republic of Bulgaria	Bulgaria	✓	**LBxx**	
Republic of Croatia	Croatia	✓	**LDxx**	
De jure Republic of Cyprus	*De facto* Republic of Cyprus	✓	**LCxx**	**LCRA** **LCEN** **LCGK**
	UN Buffer Zone	✓		
	De facto Turkish Republic of Northern Cyprus	**x**	**LCEN** **LCGK**	
Czech Republic	Czech Republic	✓	**LKxx**	

State	Territory	Part of the EU	Airports	
			Included	Except for
Kingdom of Denmark	Denmark	✓	EKxx	EKFA EKKV EKMS EKSO EKSR EKSY EKTB EKVG
	Faroe Islands	x	EKFA EKKV EKMS EKSO EKSR EKSY EKTB EKVG	
	Greenland	x	BGxx	
Republic of Estonia	Estonia	✓	EExx	
Republic of Finland	Finland	✓	EFxx	
	Åland Islands	✓		
French Republic	France	✓	LFxx	LFVM LFVP
	Guadeloupe	✓	TFxx	TFFG TFFJ
	Martinique	✓		
	French Guiana	✓	SOxx	
	Reunion	✓	FMEE FMEP	
	Mayotte	✓	FMCZ	
	New Caledonia	x	NWxx	
	Wallis and Futuna	x	NLxx	
	French Polynesia	x	NTxx	
	Saint-Pierre and Miquelon	x	LFVM LFVP	
	Saint Martin	x	TFFG	
	Saint Barthélemy	x	TFFJ	
Federal Republic of Germany	Germany	✓	EDxx	
	Büsingen am Hochrhein	✓		
	Helgoland	✓		
United Kingdom of Great Britain and Northern Ireland	England	✓	EGxx	EGAH EGAR EGJA EGJB EGJJ EGNS EGYP
	Scotland	✓		
	Wales	✓		
	Northern Ireland	✓		
	Anguilla	x	TQxx	
	Bermuda	x	TXxx	

State	Territory	Part of the EU	Airports	
			Included	Except for
United Kingdom of Great Britain and Northern Ireland (continued)	British Antarctic Territory	x	EGAH EGAR	
	British Indian Ocean Territory		FJxx	
	British Virgin Islands	x	TUxx	
	Cayman Islands	x	MWxx	
	Falkland Islands	x	EGYP	
	Gibraltar	✓	LXxx	
	Montserrat	x	TRxx	
	Pitcairn Islands	x		
	Saint Helena, Ascension, and Tristan da Cunha	x	FHxx	
	South Georgia and the South Sandwich Islands	x		
	Turks and Caicos Islands	x	MBxx	
	Jersey	x	EGJJ	
	Guernsey	x	EGJA EGJB	
	Isle of Man	x	EGNS	
	Akrotiri	x	LCRA	
	Dhekelia	x	-	
Hellenic Republic	Greece	✓	LGxx	
	Mount Athos	✓		
Hungary	Hungary	✓	LHxx	
Republic of Iceland	Iceland	x	BIxx	
Ireland	Ireland	✓	EIxx	
Italian Republic	Italy	✓	LIxx	
	Campione d'Italia	✓		
	Livigno	✓		
Republic of Latvia	Latvia	✓	EVxx	
Principality of Liechtenstein	Liechtenstein	x	LSXB	
Republic of Lithuania	Lithuania	✓	EYxx	
Grand Duchy of Luxembourg	Luxembourg	✓	ELxx	
Republic of Malta	Malta	✓	LMxx	
Kingdom of the Netherlands	Netherlands	✓	EHxx	
	Aruba	x	TNxx	
	Curaçao	x		
	Sint Maarten	x		
	Bonaire	x		
	Sint Eustatius	x		
	Saba	x		

State	Territory	Part of the EU	Airports	
			Included	Except for
Kingdom of Norway	Norway	x	ENxx	ENAS ENJA ENSA ENSB
	Svalbard	x	ENAS ENSA ENSB	
	Jan Mayen	x	ENJA	
Republic of Poland	Poland	✓	EPxx	
Portuguese Republic	Portugal	✓	LPxx	
	Azores	✓		
	Madeira	✓		
Romania	Romania	✓	LRxx	
Slovak Republic	Slovakia	✓	LZxx	
Republic of Slovenia	Slovenia	✓	LJxx	
Kingdom of Spain	Spain	✓	LExx	
	Canary Islands	✓	GCxx	
	Ceuta	✓	GExx	
	Melilla	✓		
Kingdom of Sweden	Sweden	✓	ESxx	
Swiss Confederation	Switzerland	x	LSxx	LSXB
Republic of Turkey	Turkey	x	LTxx	

Table 23: Airports in the EU and in the territories of the 33 members of the EEA in 2018.

C Real associations between PRISME types, FEIS types, and BADA types

In Table 24 below there are some real examples of the associations that were made in the FEIS procedure in 2017.

In this table, and in the examples below, a type designator in **green** indicates that the type is the same as the PRISME type, a type designator in **orange** indicates that the type could be the same as the PRISME type, and a type designator in **red** indicates that the type is not the same as the PRISME type. A PRISME type of engine name in **blue** indicates that that type of engine is a DB type of engine.

Example	PRISME type of…		FEIS type of…			BADA type of…	
	airframe	engine	aircraft	airframe	engine	aircraft	engine
1	**A310**	**CF6-80C2A2**	**A310-A**	**A310**	**CF6-80C2A2**	**A310**	**CF6_80C2A2**
2	**A310**	**???**	**A310-A**	**A310**	**CF6-80C2A2**	**A310**	**CF6_80C2A2**
3	**A310**	**CF6-80C2A8**	**A310-B**	**A310**	**CF6-80C2A8**	**A310**	**CF6_80C2A2**
4	**A124**	**D-18T**	**A124-A**	**A124**	**CF6-50C2B**	**A124**	**D-18T**
5	**C425**	**PT6A-112**	**C425-A**	**C425**	**PT6A-112**	**BE9L**	**PT6A**
6	**C425**	**???**	**C425-A**	**C425**	**PT6A-112**	**BE9L**	**PT6A**

Table 24: Some examples of real associations that were made in the FEIS procedure.

In the first example, the PRISME *type of aircraft* is specified by {**A310**, **CF6-80C2A2**}. It is assumed that this correctly identifies the type of the actual aircraft. Because the PRISME type of engine is a DB type of engine, this type of aircraft can, and indeed does, have an FEIS *type-of-aircraft* code associated with it (specifically **A310-A**). The BADA type of aircraft that matches up with the PRISME type of airframe uses the same type of engine as the PRISME type of engine. This is the ideal case where the PRISME type of aircraft is the same as the FEIS type of aircraft and both of these are the same as the BADA type of aircraft, all three using the same DB type of engine. So:

- the PRISME type of aircraft is specified by{**A310**, **CF6-80C2A2**},
- the FEIS type of aircraft (designated by **A310-A**) is specified by {**A310**, **CF6-80C2A2**},
- the BADA type of aircraft is specified by {**A310**, **CF6-80C2A2**}, and
- the DB type of engine is specified by **CF6-80C2A2**.

In the second example, no type of engine is specified for the PRISME type of aircraft. Consequently, this PRISME type of aircraft is represented by the most common [43] FEIS type of aircraft of which the type of airframe is the same as the PRISME type of airframe. So:

- the PRISME type of aircraft is specified by{**A310**, **???**},
- the FEIS type of aircraft (designated by **A310-A**) is specified by {**A310**, **CF6-80C2A2**},
- the BADA type of aircraft is specified by {**A310**, **CF6-80C2A2**}, and
- the DB type of engine is specified by **CF6-80C2A2**.

In the third example, the PRISME *type of aircraft* is specified by {**A310**, **CF6-80C2A8**}. It is assumed that this correctly identifies the type of the actual aircraft. Because the PRISME type of engine is a DB type of engine, this type of aircraft can, and indeed does, have an FEIS

[43] That is to say the FEIS type of aircraft for which there are the most associated flights.

type-of-aircraft designator associated with it (specifically **A310-B**). The BADA type of aircraft that matches up with the PRISME type of airframe uses a different type of engine to the PRISME type of engine. So:

- the PRISME type of aircraft is specified by {**A310**, **CF6-80C2A8**},
- the FEIS type of aircraft(designated by **A310-B**) is specified by {**A310**, **CF6-80C2A8**},
- the BADA type of aircraft is specified by {**A310**, **CF6-80C2A2**}, and
- the DB type of engine is specified by **CF6-80C2A8**.

In the fourth example, the PRISME *type of aircraft* is specified by {**A124**, **D-18T**}. It is assumed that this correctly identifies the type of the actual aircraft. This type of aircraft does not have an FEIS *type-of-aircraft* designator associated with it because the PRISME type of engine is not a DB type of engine. Consequently, this PRISME type of aircraft is represented by the most common FEIS type of aircraft (specifically **A124-A**) of which the type of airframe is the same as the PRISME type of airframe. As this FEIS type of aircraft must be associated with a DB type of engine (specifically the **CF6-50C2B** type of engine, which has a similar power to the **D-18T** type of engine), it does not represent an actual type of aircraft.

The BADA type of aircraft that matches up with the PRISME type of airframe uses the same type of engine as the PRISME type of engine. So:

- the PRISME type of aircraft is specified by{**A124**, **D-18T**},
- the FEIS type of aircraft (designated by **A124-A**) is specified by {**A124**, **CF6-50C2B**},
- the BADA type of aircraft Is specified by {**A124**, **D-18T**}, and
- the DB type of engine is specified by **CF6-50C2B**.

In the fifth example, the PRISME *type of aircraft* is specified by {**C425**, **PT6A-112**}. It is assumed that this identifies the type of the actual aircraft. Because the PRISME type of engine is a DB type of engine, this type of aircraft can, and indeed does, have an FEIS *type-of-aircraft* designator associated with it (specifically **C425-A**). There is no BADA type of aircraft that matches up with the PRISME type of airframe and so an equivalent BADA type of aircraft is associated with this PRISME type of aircraft. So:

- the PRISME type of aircraft is specified by{**C425**, **PT6A-112**},
- the FEIS type of aircraft (designated by **C425-A**) is specified by {**C425**, **PT6A-112**},
- the BADA type of aircraft is specified by {**BE9L**, **PT6A**}, and
- the DB type of engine is specified by **PT6A-112**.

Lastly, in the sixth example, no type of engine is specified for the PRISME type of aircraft. Consequently, this PRISME type of aircraft is represented by the most common FEIS type of aircraft of which the type of airframe is the same as the PRISME type of airframe. There is no BADA type of aircraft that matches up with the PRISME type of airframe and so an equivalent BADA type of aircraft is associated with this PRISME type of aircraft. So:

- the PRISME type of aircraft is specified by{**C425**, **???**},
- the FEIS type of aircraft (designated by **C425-A**) is specified by {**C425**, **PT6A-112**},
- the BADA type of aircraft is specified by {**BE9L**, **PT6A**}, and
- the DB type of engine is specified by **PT6A-112**.

D Gaseous species and types of particulate matter treated by the AEM

The table below indicates the species of interest. $\mathbf{S_i}$ is the i[th] species. A tick (✓ or ✔) in the VOC column indicates that the species is a VOC. The species marked as VOC with a green tick (✓) were included when calculating the mass of NMVOCs emitted (see Section 3.5.6.3) prior to 2017.

Species or type of particulate matter	S_i	Treated by the AEM	Required for UNFCCC	Required for CLRTAP	Is a VOC
Acetaldehyde	$\mathbf{S_1}$	✓			✓
Acrolein	$\mathbf{S_2}$	✓			✓
Benzene	$\mathbf{S_3}$	✓			✓
Buta-1,3-diene	$\mathbf{S_4}$	✓			✓
Carbon dioxide	$\mathbf{S_5}$	✓	✓		
Carbon monoxide	$\mathbf{S_6}$	✓	✓	✓	
Ethylbenzene	$\mathbf{S_7}$	✓			✓
Formaldehyde	$\mathbf{S_8}$	✓			✓
UHCs	$\mathbf{S_9}$	✓			
Methane	$\mathbf{S_{10}}$	x	✓		✔
Nitrous oxide	$\mathbf{S_{11}}$	x	✓		
NMVOCs	$\mathbf{S_{12}}$	x	✓	✓	✔
NO_X	$\mathbf{S_{13}}$	✓	✓	✓	
SO_X	$\mathbf{S_{14}}$	✓	✓	✓	
Water	$\mathbf{S_{15}}$	✓			
$PM_{2.5}$	$\mathbf{S_{16}}$	x		✓	
PM_{10}	$\mathbf{S_{17}}$	x		✓	
$PM_{non\ vol}$	$\mathbf{S_{18}}$	✓			
PM_{total}	$\mathbf{S_{19}}$	x			
$PM_{vol\text{-}org}$	$\mathbf{S_{20}}$	✓			
$PM_{vol\text{-}sul}$	$\mathbf{S_{21}}$	✓			
4-PAH	$\mathbf{S_{22}}$	x		✓	✔
7-PAH	$\mathbf{S_{23}}$	✓			✔
16-PAH	$\mathbf{S_{24}}$	✓			✓
Propionaldehyde	$\mathbf{S_{25}}$	✓			✓
Styrene	$\mathbf{S_{26}}$	✓			✓
Toluene	$\mathbf{S_{27}}$	✓			✓
Xylene	$\mathbf{S_{28}}$	✓			✓

Table 25: The species of interest.

E The calculation

The way the AEM produces estimates of the masses of fuel burnt and certain species emitted for that part of the trajectory where there aircraft is below a height of 3,000 feet is different from how it does it for that part of the trajectory where the aircraft is above a height of 3,000 feet. Table 6 above provides a summary of the methods used by the AEM for calculating the fuel burnt and emissions above and below 3,000 feet.

In fact, the AEM only calculates the mass of fuel burnt and the emitted masses of:

- carbon monoxide,
- NO_X,
- $PM_{non\text{-}vol}$,
- $PM_{vol\text{-}org}$,
- $PM_{vol\text{-}sul}$, and
- UHCs.

The masses of carbon dioxide, SO_X, and water vapour emitted are determined by multiplying the mass of fuel burnt by the relevant constants that are found in the ***AEM.CONSTANT_PARAMS.txt*** file. The masses of the VOCs emitted are determined by multiplying the mass of UHC emitted by the relevant constants that are found in the ***AEM.VOCTOG_CONSTANTS.txt*** file.

E.1 Some terminology

In what follows, the following terms are used.

- *spc* is a gaseous species or a type of PM and can have one of the following values: **carbon monoxide** | **NO_X** | **$PM_{non\text{-}vol}$** | **$PM_{vol\text{-}org}$** | **$PM_{vol\text{-}sul}$** | **UHCs**
- *p* is one phase of, or one stage of, or the whole of, the LTO cycle [44] and can have one of the following values: **Taxi out** | **Take off** | **Climb out** | **Approach** | **Landing** | **Taxi in** | **ARR** (for the whole landing stage) | **DEP** (for the whole take-off stage) | **LTO** (for the whole LTO cycle);
- *apt* is an airport;
- t(*p*, *apt*) is the duration [in seconds] of Phase *p* at Airport *apt*;
- *eng* is the identifier of the type of engine fitted to the aircraft;
- *n* is the number of engines fitted to the aircraft;
- *thr* is the thrust setting of an engine and can have a value between 0% and 100%. The default ICAO thrust settings are **7%**, **30%**, **85%**, and **100%**.
- rfb(*eng*, *thr*) is the rate at which fuel is burnt [in kilograms per second] (which is equivalent to the fuel flow) by an engine of type *eng* when the thrust is set to *thr*;
- mse(*spc*, *eng*, *p*, *apt*) is the mass [in kilograms] of *spc* emitted by an engine of type *eng* during Phase *p* at Airport *apt*;
- m(*spc*) is the mass [in kilograms] of *spc* emitted.
- rse(*spc*, *eng*, *thr*) is the rate at which *spc* is emitted [in kilograms per second] by an engine of type *eng* when the thrust is set to *thr*.
- ei(*spc*, *eng*, *thr*) is the mass [in grams] of *spc* emitted per kilogram of fuel burnt by an engine of type *eng* when the thrust is set to *thr*.

[44] In the text below, “phase” is to be understood to mean “phase/stage/LTO cycle”.

E.2 Below 3,000 feet – the take-off and landing stages

Because information about flight trajectories below 3,000 feet is often not sufficiently accurate, the estimation of the mass of fuel burnt during the LTO cycle is based on the durations of the various phases of the ICAO LTO cycle with the rate of fuel burn for the particular type of engine associated with the aircraft being provided by the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** file.

A "standard" LTO cycle lasts for a total of 32 minutes and 54 seconds and for 26 of these minutes the engines are in idle mode while the aircraft is taxiing out and in (19 minutes and 7 minutes respectively). But for many airports in Europe, the time spent with the engine thrust set on idle is different from the 26 minutes of the ICAO LTO cycle.

As indicated in Table 3 above, the LTO cycle consists of six phases, two of which, namely Phase 7 and Phase 8, are grouped together. Each of these phases and groups of phases is associated with a specific thrust setting and a time in mode.

mse(*spc*, *eng*, **ARR**, *apt*), the total mass of *spc* emitted by an engine of type *eng* at Airport *apt* during the landing stage of the LTO cycle, is given by:

$$\mathrm{mse}(spc, eng, \mathbf{ARR}, apt) = \mathrm{mse}(spc, eng, \mathbf{Approach}, apt) + \mathrm{mse}(spc, eng, \mathbf{Landing}, apt) + \mathrm{mse}(spc, eng, \mathbf{Taxi\ in}, apt)$$

and mse(*spc*, *eng*, **DEP**, *apt*), the total mass of *spc* emitted by an engine of type *eng* at Airport *apt* during the take-off stage of the LTO cycle, is given by:

$$\mathrm{mse}(spc, eng, \mathbf{DEP}, apt) = \mathrm{mse}(spc, eng, \mathbf{Taxi\ out}, apt) + \mathrm{mse}(spc, eng, \mathbf{Take\ off}, apt) + \mathrm{mse}(spc, eng, \mathbf{Climb\ out}, apt)$$

where

$$\mathrm{mse}(spc, eng, \mathbf{Taxi\ out}, apt) = \mathrm{rse}(spc, eng, \mathbf{7\%}) \times \mathrm{t}(\mathbf{Taxi\ out}, apt) \times n$$
$$\mathrm{mse}(spc, eng, \mathbf{Take\ off}, apt) = \mathrm{rse}(spc, eng, \mathbf{100\%}) \times \mathrm{t}(\mathbf{Take\ off}, apt) \times n$$
$$\mathrm{mse}(spc, eng, \mathbf{Climb\ out}, apt) = \mathrm{rse}(spc, eng, \mathbf{85\%}) \times \mathrm{t}(\mathbf{Climb\ out}, apt) \times n$$
$$\mathrm{mse}(spc, eng, \mathbf{Approach}, apt) = \mathrm{rse}(spc, eng, \mathbf{30\%}) \times \mathrm{t}(\mathbf{Approach}, apt) \times n$$
$$\mathrm{mse}(spc, eng, \mathbf{Landing}, apt) = \mathrm{rse}(spc, eng, \mathbf{30\%}) \times \mathrm{t}(\mathbf{Landing}, apt) \times n$$
$$\mathrm{mse}(spc, eng, \mathbf{Taxi\ in}, apt) = \mathrm{rse}(spc, eng, \mathbf{7\%}) \times \mathrm{t}(\mathbf{Taxi\ in}, apt) \times n$$

and

t(**Taxi out**, *apt*) is either:

- the specific measured average taxi-out time at Airport *apt*, or
- the calculated average taxi-out time for an airport located in a member state of the EEA, or
- the default ICAO taxi-out time, which is **1,140** seconds (i.e. **19** minutes) for all other airports;

t(**Take off**, *apt*) is the default ICAO take-off time, which is **42** seconds for all airports;
t(**Climb out**, *apt*) is the default ICAO climb-out time, which is **132** seconds for all airports;
t(**Approach**, *apt*) is the default ICAO final approach time, which is **198** [45] seconds for all airports;

[45] In ICAO documents, the duration of the approach and landing phases together is **240** seconds.

t(**Landing**, *apt*) is the default ICAO landing time, which is **42** seconds for all airports, and
t(**Taxi in**, *apt*) is either:

- the specific measured average taxi-in time at *apt*, or
- the calculated average taxi-in time for an airport located in a member state of the EEA, or
- the default ICAO taxi-in time, which is **420** seconds (i.e. **7** minutes) for all other airports

Thus, to determine the mass of Species *spc* that is emitted by an aircraft with *n* engines of type *eng* during the landing and take-off stages at Airport *apt*, it is necessary to know the rate of emission of Species *spc* from an engine of type *eng* for the four engine thrust settings of **7%**, **30%**, **85%**, and **100%** and, optionally, the measured average taxi-out and taxi-in times for Airport *apt*. If the taxi-out and taxi-in times are not known, the calculated value for EEA airports or the default ICAO values is used.

The rse(*spc*, *eng*, *thr*) values are read from the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** file, and the default ICAO values:

- t(**Taxi out**, *apt*),
- t(**Take off**, *apt*),
- t(**Climb out**, *apt*),
- t(**Approach**, *apt*),
- t(**Landing**, *apt*), and
- t(**Taxi in**, *apt*)

are read from the ***AEM.CONSTANT_PARAMS.txt*** file.

E.3 Above 3,000 feet – the cruise stage

Above 3,000 feet, the AEM uses the segments (defined by two consecutive points) of the flight trajectory to calculate the mass of fuel burnt. See Figure 5 above.

If the trajectory information does not contain the actual rate of fuel burn or the actual weight of the aircraft, these data cannot be provided to the AEM as an input. Therefore the rate of fuel burn is provided by the BADA.

The BADA provides altitude- and attitude-dependent performance and fuel burn data for more than 150 aircraft types. So as to be able to use the BADA, the aircraft types that are present in the AEM input file have to be associated with the aircraft types that the BADA knows about. In the AEM, the associations between the input (ICAO) aircraft types and the BADA aircraft types are stored in the ***ACT_PRF.aircraft_engine.txt*** file. If a flight is associated with a type of aircraft that is not in the BADA database, expert judgement can be used to select the "nearest" match to the unknown type of aircraft from the database and the type of aircraft of the flight can be changed manually to this type (by updating the ***ACT_PRF.aircraft_engine.txt*** file).

The BADA performance table provides the necessary information about the rate at which fuel is burnt for a particular type of aircraft at a particular flight level in a particular flight attitude (climb, cruise, descent). This information is stored in the AEM BADA reference table data file, ***ACT_PRF.BADA_FUEL_BURN.txt***.

Emission calculations are based on the values found in the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** file but the emission factors and rate of fuel burn are adapted to the atmospheric conditions at altitude by using the BFFM2. The assumption is made that a plot of the logarithm of the emission index against the logarithm of the fuel flow gives a bilinear graph.

As the emission indices at 85% and 100% thrust are generally two orders of magnitude smaller than the emission indices at 7% and 30% thrust, the average of the emission indices at 85% and 100% thrust are used for all thrust settings from 100% down to the thrust setting where the value intersects the fit of the 7% and 30% thrust settings.

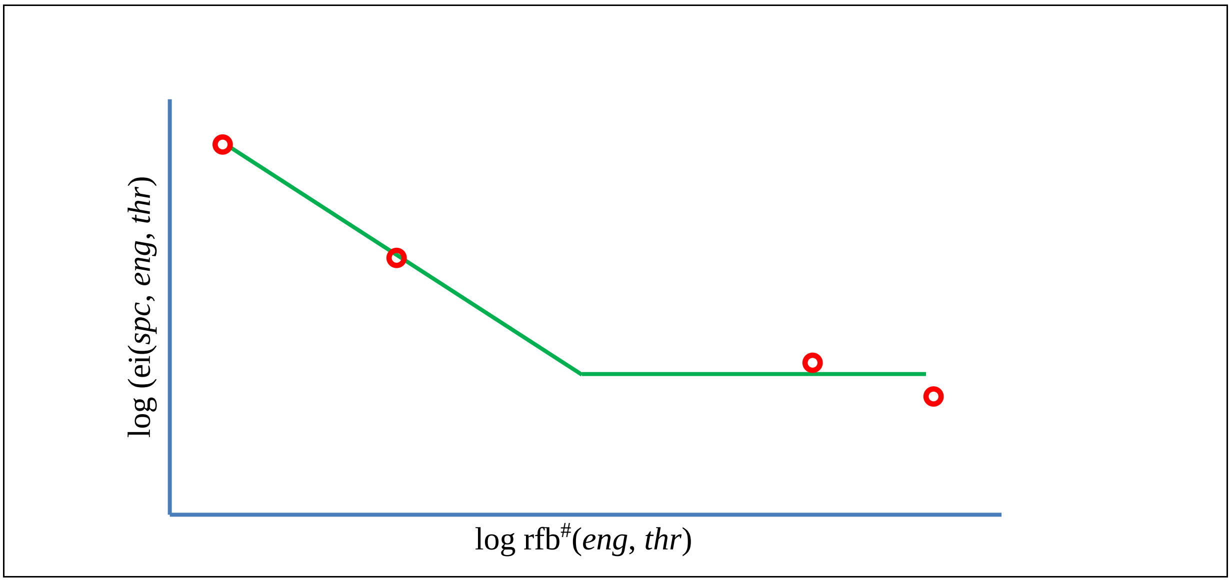

Figure 13 : Logarithm of the emission index as a function of the logarithm of the rate of fuel burn.

The four points plotted on the graph are the emission indices at standard atmospheric conditions (a pressure of 1 013.25 kPa and a temperature of 15°C (288.15K) at sea level) at the corrected (see below) fuel flow values corresponding to 7%, 30%, 85%, and 100% of maximum thrust.

In fact, there are three forms of the graph to take account of, and these are shown in **Figure 14** below.

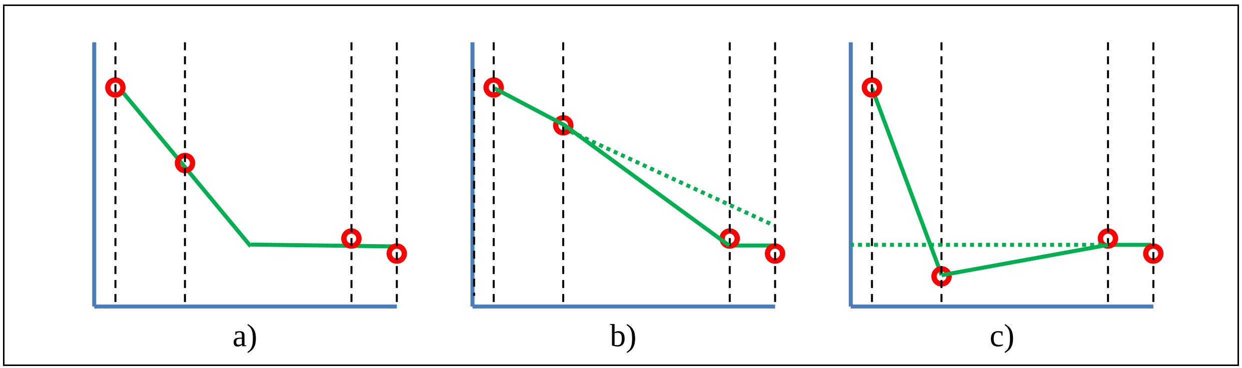

Figure 14 : Possible forms of the graph of the logarithm of the emission index as a function of the logarithm of the rate of fuel burn.

Figure 14a) shows the case shown in Figure 13.

Figure 14b) shows the case where the intersection between the two lines occurs at a fuel flow value greater than the 85% one. In this case, another line is added between the 30% emission index and the average of the 85% and 100% emission indices at the 85% rate of fuel burnt value.

Figure 14c) shows the case where the emission index at 30% thrust is lower than the average of the 85% and 100% thrust emission indices. In this case, another line is also added between the 30% emission index and the average of the 85% and 100% emission indices at the 85% rate of fuel burnt value.

The amount of one of the species emitted by a particular type of aircraft flying a segment in the cruise stage is determined as follows.

1. Get the relevant *eng* and *n* from the ***ACT_PRF.aircraft_engine.txt*** file.
2. Get
   a. all the rfb(*eng*, *thr*) values (for *thr* equal to **7%**, **30%**, **85%**, and **100%**) and
   b. all the rse(*spc*, *eng*, *thr*) values (for *spc* equal to:
      i. **carbon monoxide**,
      ii. $\mathbf{NO_X}$,
      iii. $\mathbf{PM_{vol\text{-}org}}$,
      iv. $\mathbf{PM_{vol\text{-}sul}}$,
      v. $\mathbf{PM_{non\text{-}vol}}$, and
      vi. **UHCs**

      and *thr* equal to **7%**, **30%**, **85%**, and **100%**) from the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** file.
3. Determine the emission indices:

   ei(*spc*, *eng*, *thr*) = rse(*spc*, *eng*, *thr*) × 1000 / rfb(*eng*, *thr*)
4. Adjust the fuel flows, rfb(*eng*, *thr*), to take account of the effects resulting from the fact that the engine is/engines are installed on an airframe. The four fuel flow values have to be multiplied by the following factors (as suggested by Boeing), giving the adjusted fuel flows $rfb^{\#}$(*eng*, **7%**), $rfb^{\#}$(*eng*, **30%**), $rfb^{\#}$(*eng*, **85%**), and $rfb^{\#}$(*eng*, **100%**).

	Take-off	Climb out	Approach	Taxi / Idle
Thrust setting	100%	85%	30%	7%
Factor	1.010	1.013	1.020	1.100

Table 26: Correction factors for the ICAO fuel flow values.

   The emission indices that correspond to these adjusted fuel flows are ei(*spc*, *eng*, **7%**), ei(*spc*, *eng*, **30%**), ei(*spc*, *eng*, **85%**), and ei(*spc*, *eng*, **100%**).
5. Determine rfb^(*eng*, **BADA**), the actual fuel flow, for the current segment, using the BADA. If the aircraft is climbing or descending, take the average value of the fuel flow at each end of the segment.
6. Correct rfb^(*eng*, **BADA**) to take account of the atmospheric conditions at the altitude the aircraft is flying to give rfb(*eng*, **BADA**), the reference fuel flow at standard atmospheric conditions:

   $$rfb(eng, \mathbf{BADA}) = rfb\hat{}(eng, \mathbf{BADA}) \times (\theta_{amb})^{3.8} \times \exp(0.2 \times M^2) / \delta_{amb}$$

   with

$\delta_{amb} = P_{amb} / 101.3$

and

$\theta_{amb} = T_{amb} / 288.15$

where

P_{amb} = the ambient pressure at altitude (in kPa)
T_{amb} = the ambient temperature at altitude (in K)
M = the Mach number (which is fixed at 0.84 for the AEM)

7. Determine ei(*spc*, *eng*, **BADA**), the emission index at the reference fuel flow rfb(*eng*, **BADA**) as follows:
   a. If rfb(*eng*, **BADA**) is greater than $rfb^{\#}$(*eng*, **85%**), then
      i. ei(*spc*, *eng*, **BADA**) = (ei(*spc*, *eng*, **85%**) + ei(*spc*, *eng*, **100%**)) / 2
      ii. Continue from Step 8.
   b. Else if rfb(*eng*, **BADA**) is greater than $rfb^{\#}$(*eng*, **30%**) then
      i. Determine the equation of the straight line (on the log-log graph) that passes through the points

         {rfb#(*eng*, **7%**), ei(*spc*, *eng*, **7%**)}

         and

         {rfb#(*eng*, **30%**), ei(*spc*, *eng*, **30%**)}
      ii. Determine ei(*spc*, *eng*, **avg**) from

         ei(*spc*, *eng*, **avg**) = (ei(*spc*, *eng*, **85%**) + ei(*spc*, *eng*, **100%**)) / 2
      iii. Determine rfb(*eng*, **X**), the fuel flow value at which the straight line (on the log-log graph) that passes through the points

         {rfb#(*eng*, **7%**), ei(*spc*, *eng*, **7%**)}

         and

         {rfb#(*eng*, **30%**), ei(*spc*, *eng*, **30%**)}

         crosses the horizontal line at ei(*spc*, *eng*, **avg**).
      iv. If $rfb^{\#}$(*eng*, **30%**) is less than or equal to rfb(*eng*, **X**) and rfb(*eng*, **X**) is less than or equal to $rfb^{\#}$(*eng*, **85%**) (Case a above) then
         1. If rfb(*eng*, **BADA**) is greater than or equal to rfb(*eng*, **X**) then
            a. ei(*spc*, *eng*, **BADA**) = ei(*spc*, *eng*, **avg**)
            b. Go to Step 8.
         2. Else
            a. Determine ei(*spc*, *eng*, **BADA**) corresponding to a fuel flow rfb(*eng*, **BADA**) from the equation of the straight line (on the log-log graph) that passes through the points

               {rfb#(*eng*, **7%**), ei(*spc*, *eng*, **7%**)}

               and

               {rfb#(*eng*, **30%**), ei(*spc*, *eng*, **30%**)}

b. Go to Step 8.

v. Else (Case b or Case c above)

1. Determine ei(*spc*, *eng*, **BADA**) corresponding to a fuel flow rfb(*eng*, **BADA**) from the equation of the straight line (on the log-log graph) that passes through the points

{rfb#(*eng*, **30%**), ei(*spc*, *eng*, **30%**)}

and

{rfb#(*eng*, **85%**), ei(*spc*, *eng*, **avg**)}

c. Else if rfb(*eng*, **BADA**) is greater than $rfb^{\#}$(*eng*, **7%**) then

i. Determine ei(*spc*, *eng*, **BADA**) corresponding to a fuel flow rfb(*eng*, **BADA**) from the equation of the straight line (on the log-log graph) that passes through the points

{rfb#(*eng*, **7%**), ei(*spc*, *eng*, **7%**)}

and

{rfb#(*eng*, **30%**), ei(*spc*, *eng*, **30%**)}

ii. Go to Step 8.

d. Else ei(*spc*, *eng*, **BADA**) = ei(*spc*, *eng*, **7%**).

8. Determine m(*spc*, *eng*, *n*) the mass [in kilograms] of *spc* emitted by *n* engines of type *eng* adjusted for altitude.

$$m(spc, eng, n) = ei(spc, eng, BADA) \times \theta^{3.3} \times rfb(eng, BADA) \times n / \delta^{1.02} / 1000$$

9. To get the total mass of *spc* emitted during the cruise stage, add up the emitted masses for all the segments flown.

F Determining the aircraft engine particulate matter emission data

The source of much of the engine data that is used by the AEM is the ICAO AEED. For each type of engine *eng* in this database, the following information, amongst others, is potentially available:

- whether the engine is of type Turbofan (**TF**) or Mixed turbofan (**MTF**),
- BPR(*eng*), the engine bypass ratio,
- ei(*spc*, *eng*, *thr*), the emission indices [in grams per kilogram of fuel burnt] for Species *spc*, (where *spc* is **carbon monoxide**, **UHCs**, or **NO_X**) when the thrust is set to *thr* (where *thr* is **7%**, **30%**, **85%**, or **100%** of the maximum thrust),
- SN(*eng*, *thr*), the smoke number when the thrust is set to *thr*, and
- SN_{max}(*eng*), the maximum smoke number.

The procedure for determining the particulate matter emission indices for a type of engine, as found in Attachment D to Appendix 1 of ICAO Doc 9889 [**15**], consists of the following six steps:

1. Classify the type of engine.
2. Determine the smoke number values.
3. Determine the emission indices for non-volatile particulate matter.
4. Determine the emission indices for volatile sulphate particulate matter.
5. Determine the emission indices for volatile organic aerosols.
6. Calculate the total emission indices.

F.1 Classify the type of engine

Determine the *class* of the type of engine by examining the following table:

class	Reason
Aviadvigatel	The engine was manufactured by Aviadvigatel [46].
Textron Lycoming	The engine was manufactured by Textron Lycoming [47].
GE CF34	The engine is a GE [48] CF34 engine.
GE/CFM DAC	The engine is a GE or CFM [49] double annular combustor (**DAC**) engine.
Other non-DAC	The engine is any other (non-DAC) engine.

Table 27: The classes of the types of engine.

F.2 Determine the smoke number values

Get SN(*eng*, *thr*), the smoke number when the thrust is set to *thr* (where *thr* is one of the 4 ICAO standard engine power settings).

[46] Aviadvigatel is a Russian aircraft engine manufacturer.
[47] Textron Lycoming is an American aircraft engine manufacturer.
[48] GE is the abbreviation for "General Electric".
[49] CFM International is a joint venture between GE Aviation and SNECMA.

If the smoke number corresponding to a particular thrust setting is not given for a particular type of engine then make an estimation of it as follows:

$$SN(eng, thr) = SF(class, thr) \times SN_{max}(eng)$$

where the scaling factor, SF(*class*, *thr*), at the various thrust settings for the various engine categories is given in the following table.

class		SF(*class*, *thr*)			
	LTO mode	Take off	Climb out	Approach	Idle
	thr	100%	85%	30%	7%
Aviadvigatel		1.0	1.0	0.8	0.3
Textron Lycoming		1.0	1.0	0.6	0.3
GE CF34		1.0	0.4	0.3	0.3
GE/CFM DAC		0.3	0.3	0.3	1.0
Other non-DAC		1.0	0.9	0.3	0.3

Table 28: Scaling factors for the various classes of type of engine

If a given smoke number value is preceded by a “less than” sign (<), just use the value itself.

F.3 Determine the emission index for non-volatile particulate matter

If SN(*eng*, *thr*) is less than or equal to 30 then calculate CI(*eng*, *thr*), the carbon index [in milligrams per cubic metre], from

$$CI(eng, thr) = 0.0694 \times SN(eng, thr)^{1.234}$$

otherwise calculate the carbon index from

$$CI(eng, thr) = 0.0297 \times SN(eng, thr)^2 - (1.803 \times SN(eng, thr)) + 31.94$$

Determine the air-fuel ratio, AFR(*thr*), when the thrust is set to *thr*, from the following table:

LTO mode	*thr*	AFR(*thr*)
Idle	7%	106
Approach	30%	83
Climb out	85%	51
Take off	100%	45

Table 29: Air-fuel ratios.

If the engine of type **TF**, calculate $Q_{core}(eng, thr)$, the exhaust volumetric flow rate [in cubic metres per kilogram of fuel burnt] at standard temperature and pressure (**STP**) of the engine core, from

$$Q_{core}(eng, thr) = (0.776 \times AFR(thr)) + 0.877$$

If the engine is of type **MTF**, calculate $Q_{mixed}(eng, thr)$, the exhaust volumetric flow rate [in cubic metres per kilogram of fuel burnt] at STP of the engine core and bypass, from

$$Q_{mixed}(eng, thr) = (0.7769 \times AFR(thr) \times (1 + BPR(eng)) + 0.877$$

where BPR(*eng*) is the engine bypass ratio.

Finally calculate ei($\mathbf{PM_{non\text{-}vol}}$, *eng*, *thr*), the emission index [in milligrams per kilogram of fuel burnt] for non-volatile particulate matter using $Q_{core}(eng, thr)$ or $Q_{mixed}(eng, thr)$ as relevant from

$$ei(\mathbf{PM_{non\text{-}vol}}, eng, thr) = CI(eng, thr) \times Q_{core}(eng, thr)$$

or

$$ei(\mathbf{PM_{non\text{-}vol}}, eng, thr) = CI(eng, thr) \times Q_{mixed}(eng, thr)$$

F.4 Determine the emission index for volatile sulphur particulate matter

Assuming a fuel sulphur content of 0.068 weight per cent and a S(IV) to S(VI) conversion rate of 2.4 weight per cent, ei($\mathbf{PM_{vol\text{-}sul}}$, *eng*, *thr*), the modal independent emission index [in milligrams per kilogram of fuel burnt] for volatile sulphur particulate matter is given by:

$$ei(\mathbf{PM_{vol\text{-}sul}}, eng, thr) = 10^6 \times 0.00068 \times 0.024 \times MW_{out} / MW_{sulphur}$$

where

$$MW_{out} = 96$$

and

$$MW_{sulphur} = 32$$

F.5 Determine the emission index for volatile organic aerosols

ei($\mathbf{PM_{vol\text{-}org}}$, *eng*, *thr*), the emission index [in milligrams per kilogram of fuel burnt] for volatile organic aerosols is given by:

$$ei(\mathbf{PM_{vol\text{-}org}}, eng, thr) = \delta(thr) \times ei(\mathbf{UHCs}, eng, thr)$$

where $\delta(thr)$ is given in the following table

LTO mode	*thr*	$\delta(thr)$
Idle	7%	6.17
Approach	30%	56.25
Climb-out	85%	76
Take-off	100%	115

Table 30: δ values.

F.6 Calculate the total emission index

Calculate ei($\mathbf{PM_{total}}$, *eng*, *thr*), the emission index for all particulate matter from:

$$ei(\mathbf{PM_{total}}, eng, thr) \quad = \quad ei(\mathbf{PM_{non\text{-}vol}}, eng, thr) \; +$$

ei($\mathbf{PM}_{\mathbf{vol\text{-}org}}$, *eng*, *thr*) +
ei($\mathbf{PM}_{\mathbf{vol\text{-}sul}}$, *eng*, *thr*)

F.7 Calculate the emission index for PM_{10} and $PM_{2.5}$

All the particulate matter emitted by aircraft engines has an aerodynamic diameter that is less than 0.1 µm. Consequently,

$$\mathrm{ei}(\mathbf{PM}_{\mathbf{10}}, \mathit{eng}, \mathit{thr}) = \mathrm{ei}(\mathbf{PM}_{\mathbf{total}}, \mathit{eng}, \mathit{thr})$$

and

$$\mathrm{ei}(\mathbf{PM}_{\mathbf{2.5}}, \mathit{eng}, \mathit{thr}) = \mathrm{ei}(\mathbf{PM}_{\mathbf{total}}, \mathit{eng}, \mathit{thr})$$

Once the various PM emission indices have been calculated, they can be modified (as indicated in Section 3.4.1.3.3) and stored in the ***ACT_PRF.ENGINE_LTO_VALUES.txt*** file that is read in by the AEM.