Introduction to the ICAO Engine Emissions Databank

1 Background

International standards limiting the emissions of smoke, unburnt hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x) and non-volatile Particulate Matter (nvPM) from turbojet and turbofan aircraft engines are contained in Annex 16 Volume II (Fourth Edition, July 2017, plus amendments) [Reference 1] to the Convention on International Civil Aviation. The Annex also contains approved test and measurement procedures.

With respect to subsonic engines, the provisions of the Standards for **smoke** apply to engines whose date of manufacture is on or after 1 January 1983. For the **gaseous emissions**, the Standards apply only to engines whose rated output is greater than 26.7 kN. For hydrocarbons and carbon monoxide, they apply to engines whose date of manufacture is on or after 1 January 1986. For oxides of nitrogen, the Standards have several levels of stringency depending on the date of manufacture of the engine. For **non-volatile PM emissions** standards apply to all in-production engines as of 1 January 2020, while additional provisions for nvPM will apply to engines from 1 January 2023. These Standards are summarised hereafter.

Since ICAO Annex16 Volume II (Fourth Edition, July 2017, equivalent to Amendment 9) it is required that all in production engines with a rated thrust of 26.7 kN or more shall comply with the CAEP/10 mass concentration Standard as described in Chapter 4 of the Annex. Reporting of nvPM emissions for mass and number in accordance with Appendix 7 of the Annex are required and the maximum nvPM mass concentration shall comply with the limit set in Chapter 4 (paragraph 4.2) [Reference 1]. Amendment 10 of ICAO Annex 16 Volume II provides further standards and requires that engines from 1 January 2023 comply with LTO cycle limitations for nvPM mass and number emissions as mentioned in paragraph 4.2.2 of the Annex. nvPM mass and number are already included in the databank. However compliance to the nvPM mass and number emissions standard data may not yet be certified at this point in time.

The ICAO Engine Emissions Databank contains information on exhaust emissions of only those engines that have entered production, irrespective of the numbers actually produced. It has been compiled mainly from information supplied for newly certified engines. However, for some engines, the data has been revised to reflect evidence from subsequent engine tests. For a very few numbes of engines emissions data from reseach measurements are included. It also includes data on older engines which did not have to comply with the emissions standards and some data from a very limited number of in-service engines measured before or after overhaul. The original version was published as a printed document [Reference 2]. All subsequent updates have been electronic.

With the release of the Revision 28 in December 2020 the ICAO Engine Emissions Databank contains two main spreadsheets of datasets. One sheet contains the data for gaseous and Smoke emissions (as in previous versions) and the other sheet contains nvPM emissions data. For engines with nvPM information available, both spreadsheets are interrelated by a common unique identifier (UID No.).

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2 Revision of data

The electronic version of the databank is updated at periodic intervals, pending the availability of new or revised data. Engine manufacturers are advised to use the latest data templates to submit the data, which are available from the EASA Website.

New data are included for:

a) engines certificated since the last issue of the data bank;
b) engines that had to comply with a new standard;
c) engines already certificated for which data were not previously available; or
d) engines already certificated and listed in the Databank for which:
   i) emissions data have been recalculated as a result of a better definition of engine performance characteristics with continuing production of an engine type;
   ii) component design changes have been introduced which affect the emissions levels,e.g. new combustor design; or
   iii) improvements in emissions measurement techniques have resulted in changes to the emissions data.

Data will not be removed from the databank. Where data is superseded the row is marked to indicate that this data should not be used, and the newer data to be used instead is specified. Data is also marked where an engine is no longer in service, and where an engine is no longer in production. The Record of Changes documents the history of revisions, and the date of latest review.

3 Use of the Databank

The user of the Databank should note the limitations in the emissions data; i.e.:

a) The Dp/Foo values are based on an idealized Landing/Take-Off (LTO) cycle in International Standard Atmosphere (ISA) conditions. In assessing, for example, total aircraft emissions at a specific airport, consideration must be given to the appropriateness of the prescribed thrusts, the times in mode and the reference conditions.
b) The LTO cycle only assesses the emissions below 915 m (3000 ft) and therefore may not be a good guide for comparing the emissions of different engines in other flight modes, e.g. cruise.
c) The reported fuel flows are presented for each phase of the LTO cycle. The data is based on sea level static information at fixed power settings with no customer engine bleeds or power off-takes. These fuel flows cannot necessarily be related to fuel efficiency at different power settings, higher forward speeds, and at altitudes above sea level. As a consequence the reported fuel flows and other information in the ICAO emissions databank should not be used for comparing the fuel efficiency of different engines.
d) The fuel flows between the gaseous and nvPM data sets may differ slightly depending on whether the data has been measured/computed and evaluated at the same time. Any assessments of nvPM emissions should ideally use the data contained in the nvPM data sheet and vice versa for gaseous and smoke.

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e) Total LTO cycle emissions can be calculated where missing. E.g NOx emissions per LTO cyle = SUM of [EI(NOx) x fuel flow x time in mode] for each of the four thrust settings.

4 Definitions

By-pass ratio: The ratio of the air mass flow through the by-pass ducts of a gas turbine engine to the air mass flow through the engine core, calculated at maximum thrust when the engine is stationary in an international standard atmosphere at sea level.

Characteristic level: The characteristic level of a gaseous pollutant or smoke is the mean D_p/F_{oo} or SN value of a species, for all the engines tested, measured and corrected to the reference standard engine and reference atmospheric conditions, divided by a coefficient corresponding to the number of engines tested. The procedure and coefficients are given in Annex 16, Volume II. This is in recognition that at the certification stage there are usually not many engines to production standard available for testing, so the manufacturer is allowed to select any number of engines, including a single engine if so desired, for testing. Statistically derived coefficients, corresponding to the number of engines tested, are then applied to ensure a high confidence that the mean of the anticipated total engine production will not exceed the regulatory level. The procedure and coefficients are given in Annex 16 Volume II, Appendix 6.

Data Status: This has been grouped into three categories:

1. Pre-regulation: Data obtained on engines generally prior to the promulgation of the Standards of Annex 16, Volume II, and for which the manufacturer was not required to apply for emissions certification.
2. Certification: Data which have been submitted for certification approval after the applicability dates or which have been obtained at an earlier date, generally after the promulgation of the Standards of Annex 16. Volume II, with the intention of gaining approval.
3. Revised: Existing data which have been modified, as noted in paragraph d) under REVISION OF DATA above, and may not require the engine to be re-certificated.

Dp/Foo: The mass, in grams (Dp), of any pollutant emitted during the reference landing and take-off (LTO) cycle, divided by the rated output (Foo) of the engine.

Emissions index (EI): The mass of pollutant (CO, HC, NO_x, nvPM mass or nvPM number), in grams, divided by the mass of fuel used in kilograms.

Fuel: The fuel used is aviation kerosene as specified in Annex 16, Volume II, Appendix 4.

Hydrocarbons (HC): The total of hydrocarbon compounds of all classes and molecular weights contained in a gas sample, calculated as if they were in the form of methane.

International Standard Atmosphere (ISA): The atmosphere defined in the Manual of the ICAO Standard Atmosphere (Doc 7488). These are the atmospheric conditions to which all engine performance data should be corrected.

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LTO cycle: The reference emissions LTO cycle defines the thrust settings to be used when making emissions and smoke measurements and the time to be used for each mode in the subsequent calculations of Dp. These thrust settings and times are listed in Annex 16, Volume II, Part III, Chapter 2 (engines for subsonic propulsion).

Non-volatile particulate matter (nvPM): Emitted particles that exist at a gas turbine engine exhaust nozzle exit plane that do not volatilize when heated to a temperature of 350 °C.

Oxides of nitrogen (NO_x): The sum of the amounts of the nitric oxide and nitrogen dioxide contained in a gas sample calculated as if the nitric oxide were in the form of nitrogen dioxide.

Particle mass concentration (nvPM Mass Concentration): The mass of particles per unit of volume sample (expessed in microgram per cubic meter).

Pressure ratio (π_{oo}): The ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane when the engine is developing take-off thrust rating in ISA sea level static conditions.

Rated output (F_{oo}): The maximum thrust available for take-off under normal operating conditions at ISA sea level static conditions without the use of water injection as approved by the certificating authority. Thrust is expressed in kilonewtons.

Reference Atmospheric Conditions: The atmospheric conditions to which all emissions results should be corrected. The reference atmospheric conditions are ISA at sea level except that the reference absolute humidity shall be 0.00634 kg water/kg dry air.

Regulatory Level: The level below which the characteristic Dp/Foo or Smoke Number value for a pollutant species must fall in order to obtain certification approval. The regulatory levels reproduced from Annex 16, Volume II, Part III, Chapters 2 (subsonic engines) are given below in Section 7.

Smoke Number (SN): The dimensionless term quantifying smoke emissions. Smoke Number is calculated from the reflectance of a filter paper measured before and after the passage of a known volume of a smoke-bearing sample.

Superseded data: If a manufacturer has supplied new data replacing previous data from the emissions databank, the previous dataset is marked as superseded by the new dataset. This would apply for example to data corrections, results of additional engine testing etc. The revised data superseding a previous dataset would typically apply to the same engine (in terms of hardware)[1]. The superseded data should no longer be used for any assessment.

[1] Note that new build standards of an engine type replacing a previous production standard (different hardware) would be listed as separate entries in the emissions databank, and the older dataset would not be marked as superseded.

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5 Regulatory Standards

The applicability requirements and regulatory levels are those found in Annex 16, Volume II, Part III, Chapter 2 (for smoke and gaseous emissions of subsonic engines) and Chapter 4 (for nvPM emissions), and are described in this document for reference purposes only.

5.1 Smoke

Applicability: The regulatory levels for smoke are applicable to engines whose date of manufacture is on or after 1 January 1983.

Regulatory smoke number: The characteristic level of the smoke number at any thrust setting, measured in accordance with Annex 16, Volume II, must not exceed 83.6 $(F_{oo})^{-0.274}$ or a value of 50, whichever is lower.

5.2 Gaseous emissions

Applicability: The regulatory levels for gaseous emissions apply to engines whose rated output is greater than 26.7kN and whose date of manufacture is on or after 1 January 1986 and as further specified for oxides of nitrogen.

Regulatory levels: The characteristic levels of the gaseous emissions measured over the LTO cycle in accordance with Annex 16, Volume II, must not exceed the following regulatory levels [g/kN]:

- Hydrocarbons (HC): $D_p/F_{oo} = 19.6$
- Carbon monoxide (CO): $D_p/F_{oo} = 118$
- Oxides of nitrogen (NOx):

a) for engines of a type or model of which the date of manufacture of the first individual production model was before 1 January 1996 and for which the date of manufacture of the individual engine was before 1 January 2000: $D_p/F_{oo} = 40 + 2\pi_{oo}$ *(original NO_x standard)*

b) for engines of a type or model of which the date of manufacture of the first individual production model was on or after 1 January 1996 or for which the date of manufacture of the individual engine was on or after 1 January 2000: $D_p/F_{oo} = 32 + 1.6\pi_{oo}$ *(CAEP/2 NO_x standard)*

c) for engines of a type or model of which the date of manufacture of the first individual production model was on or after 1 January 2004: *(CAEP/4 NO_x standard)*

1. for engines with a pressure ratio of 30 or less:

i. for engines with a maximum rated thrust of more than 89.0 kN:
$D_p/F_{oo} = 19 + 1.6\pi_{oo}$

ii. for engines with a maximum rated thrust of more than 26.7 kN but not

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more than 89.0 kN:

$$D_p/F_{oo} = 37.572 + 1.6\pi_{oo} - 0.2087F_{oo}$$

2. for engines with a pressure ratio of more than 30 but less than 62.5:

i. for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = 7 + 2.0\pi_{oo}$$

ii. for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 42.71 + 1.4286\pi_{oo} - 0.4013F_{oo} + 0.00642\pi_{oo} \times F_{oo}$$

3. for engines with a pressure ratio of 62.5 or more:

$$D_p/F_{oo} = 32 + 1.6\pi_{oo}$$

d) for engines of a type or model of which the date of manufacture of the first individual production model was on or after 1 January 2008 or for which the date of manufacture of the individual engine was on or after 1 January 2013: *(CAEP/6 NO_x standard)*

1. for engines with a pressure ratio of 30 or less:

i. for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = 16.72 + 1.4080\pi_{oo}$$

ii. for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 38.5486 + 1.6823\pi_{oo} - 0.2453F_{oo} - 0.00308\ \pi_{oo} \times F_{oo}$$

2. for engines with a pressure ratio of more than 30 but less than 82.6:

i. for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = -1.04 + 2.0\pi_{oo}$$

ii. for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 46.1600 + 1.4286\pi_{oo} - 0.5303F_{oo} + 0.00642\pi_{oo} \times F_{oo}$$

3. for engines with a pressure ratio of 82.6 or more:

$$D_p/F_{oo} = 32 + 1.6\pi_{oo}$$

e) for engines of a type or model of which the date of manufacture of the first individual production model was after 1st January 2014 and for which an application for a Type Certificate was submitted before 1 January 2023: *(CAEP/8 NO_x standard)*

1. for engines with a pressure ratio of 30 or less:

i. for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = 7.88 + 1.4080\pi_{oo}$$

ii. for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018\ \pi_{oo} \times F_{oo}$$

2. for engines with a pressure ratio of more than 30 but less than 104.7:

i. for engines with a maximum rated thrust of more than 89.0 kN:

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$$D_p/F_{oo} = -9.88 + 2.0\pi_{oo}$$

ii. for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo} \times F_{oo}$$

3. for engines with a pressure ratio of 104.7 or more:

$$D_p/F_{oo} = 32 + 1.6\pi_{oo}$$

As of 1 January 2023 the reference date for applicability of the NO_x requirement will change from "date of manufacture of the individual engine" to "date of application for a Type Certificate for a type or model" (Reference 8), whereas the limits for D_p/F_{00} remain those shown in section e) above.

5.3 nvPM emissions

5.3.1 nvPM Mass Concentration (CAEP/10 nvPM standard)

Applicability: The regulatory levels for nvPM mass concentration apply to turbofan and turbojet engines whose rated output is greater than 26.7kN and whose date of manufacture is on or after 1 January 2020.

Regulatory levels: The characteristic level of the maximum nvPM mass concentration shall not exceed the limit: $10 \exp(3+2.9\ F_{oo}^{-0.274})$

In addition, reporting requirements are in place for the fuel flows at each LTO thrust setting, nvPM EImass and nvPM EInumber at each LTO thrust setting and for the maximum EImass and maximum EInumber.

5.3.2 nvPM LTO mass and number (CAEP/11 nvPM standard)

nvPM mass:

For all inproduction engines (turbofan and turbojet, F_{oo} > 26.7 kN) manufactured after 1 January 2023:

Regulatory limit: $LTO_{mass}/F_{oo} = 347.5$ for engines with a rated thrust of more than 200 kN;
$LTO_{mass}/F_{oo} = 4646.9 - 21.497F_{oo}$ for engines with a rated thrust of 26.7kN<F_{oo}<200 kN

For engines for which an application for a Type Certificate was submitted after 1 January 2023:

Regulatory limit: $LTO_{mass}/F_{oo} = 214.0$ for engines with a rated thrust of more than 150 kN;
$LTO_{mass}/F_{oo} = 1251.1 - 6.914F_{oo}$ for engines with a rated thrust of 26.7kN<F_{00}< 150 kN.

nvPM number:

For all inproduction engines (turbofan and turbojet, Foo > 26.7 kN) manufactured after 1 January 2023:

Regulatory limit: $LTO_{num}/F_{oo} = 4.170 \times 10^{15}$ for engines with a rated thrust of more than 200 kN;
$LTO_{num}/F_{oo} = 2.669 \times 10^{16} - 1.126 \times 10^{14} F_{oo}$ for engines with a rated thrust of 26.7kN<F< 200 kN.

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For engines for which an application for a Type Certificate was submitted after 1 January 2023:

Regulatory limit: $LTO_{num}/F_{oo} = 2.780 \text{ x } 10^{15}$ for engines with a rated thrust of more than 150 kN;
$LTO_{num}/F_{oo} = 1.490 \text{ x } 10^{16} - 8.080 \text{ x } 10^{13} F_{oo}$ for engines with a rated thrust of 26.7kN<F< 150 kN.

In addition, maximum EImass and maximum EInumber remain to be reported.

6 Known Issues

6.1 Data Gaps

- For some databank entries information in some data fields may be missing, as it has not been reported by the manufacturer. In some of these cases (e.g. for total LTO cycle emissions) there is a possibility to calculate the missing information, as was described in section 3.

6.2 Inconsistencies

- Deviations of up to 2% between some of the data (e.g. total LTO cycle emissions) and results of recalculations of the respective information from information in other data fields (e.g. from fuel flows and emission indices) may be observed for some entries in the databank. Most likely reason are rounding issues in the fuel flows or emission indices when the data was reported for inclusion into the databank.

7 References

1. ICAO Annex 16 "International standards and recommended practices, Environmental protection", Volume II "Aircraft engine emissions", 4th Edition, Amendment 9, 2017 plus further amendments:
   - Amendment 10, 1 January 2021

2. ICAO Engine Exhaust Emissions Databank, First Edition 1995, ICAO, Doc 9646- AN/943.

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