SECTOR

Simple aircraft Emission CalculaTOR

Version 1.0

Program Manual

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Contents

1. Introduction

In course of the EU project RAPTOR,[1] investigations on aircraft particulate matter (PM) emissions were carried out. Among them, different data sets and methodologies for estimating emission indices (EIs) of non-volatile particulate matter (nvPM) were applied in emission calculations.

The idea came up to implement these methodologies in a small program that could serve as a reference e.g. when comparing different implementations. This simple program then extend to the automatic reading of original databanks, the calculation of LTO emissions for specified engines, and the ability to use as input various definitions of aircraft traffic, including regulated and some non-regulated engine types.

This effort resulted in the JAVA program SECTOR, the Simple aircraft Emission CalculTOR, an open source program which can be used for airport-related LTO emission calculations and for testing the effect of applying different nvPM calculation methods. As the program is provided free of charge and including source code (within the JAR file), it may also serve as a reference.

In course of the project, desirable extension of SECTOR were already seen, like the calculation of start emissions and cruise emissions and the estimation of effective emissions of volatile PM. These features could not be realized within the project but may be subject to future extensions of SECTOR.

SECTOR is free software under the GNU General Public License. It can be redistributed and modified under the terms of this licence. The program is distributed in the hope that it will be useful, but without any warranty.

2. Program features

2.1. Directories and files

SECTOR is a text oriented program. The user-defined input data are specified in a text file. The file name must start with `sector-` followed by an identification, the file extension must be `.txt`. The results are stored as text file with location and name of the input file but with the file extension `.log`. Data tables in input and output files are in CSV format with a semicolon as separator and a marker before each section.

Default settings are provided in a settings file (file `Sector.settings` in subdirectory `jar`). The settings file may not be modified, the program checks the CRC code of the file at start.

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[1] Research of Aviation PM Technologies, mOdelling and Regulation, grant agreement No 863969, November 2019 to April 2022.

The program reads the original Excel data files of the

- ICAO Engine Emission Databank (ICAO EEDB)
- FOCA piston Emission Databank (FOCA EEDB)
- FOI turboprop Emission Databank (FOI EEDB)

These files must be located in subdirectory `jar\data`,[2] the default file names are defined in the settings file and can be changed in the user input file. While the ICAO and FOCA EEDB are provided freely in the web, the FOI EEDB is not public and must be requested at the FOI (Swedish Defence Research Agency). The FOI EEDB is therefore not provided in the SECTOR package.

The core program is `Sector.jar` located in subdirectory `jar`. A simple graphical user interface (GUI) is provided that allows reading and editing of input files, execution of SECTOR, and inspecting the output file. The program is `SectorGUI.jar` and is also located in subdirectory `jar`. The JAR files require some additional libraries which are located in subdirectory `jar\lib`.

The JAVA programs of SECTOR were developed with JAVA 1.8. JAR files are archive files and can be inspected e.g. with the free program 7-Zip. The provided JAR files contain also the source codes of the programs.

Execution of JAR files requires a JAVA Runtime Environment (JRE). JREs are provided in the web free of charge for Windows, Linux, and Mac systems. The JRE can be a local one (local directory without any changes to the system) or an installed version on the computer. The distribution of SECTOR contains a local JRE (from Oracle, version 1.8) for Windows 11 in subdirectory `jre` and the program `SectorGUI.exe` which calls the GUI using the local JRE in subdirectory `jre`.

The directory structure is as follows:

`.`	root directory of SECTOR
`.\doc`	documentation
`.\jar`	data and programs
`.\jar\data`	engine data files
`.\jar\lib`	JAVA libraries
`.\jre`	local JRE (Windows)
`.\test`	examples

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[2] In this document, Windows path separators are used.

2.2. Data and units

The EEDBs contain engine-specific fuel flows and emission indices for the 4 thrust settings of the certification LTO. All other data are provided in the settings file.

The settings file contains fuel flows and emission indices for generalized aircraft groups. These can be applied if no specific information on aircraft engines is available. The settings file contains also a list of aircraft types and associated default engine UIDs. This list is applied if the user input contains aircraft types, but not the engine UIDs. The settings file contains also some additional engine definitions and the APU emissions according to ICAO document 9889, second edition [1].

All group emissions, aircraft type settings, engine definitions, and APU emissions can be modified and extended in the user input file. The program reads the EEDB data, then the settings file, then the user input file. Multiple parameter values are overwritten in this order.

In several data sections, the required and expected units are explicitly stated. The program applies SI units. Emissions are listed in the output file either as Mg (mega grams or metric tons), MOU (mega odor units), or as number (particle number).

The input files should be provided as plain text files using standard (ANSI) encoding. They should not use the encoding UTF. The output files are provided in ANSI encoding.

2.3. Aircraft groups and APU

Beside specific combinations of aircraft types (specified by the ICAO code) and engine (specified by the UID according to the data bases), the program allows to use generalized aircraft groups (motivated by the groups applied in the program system LASPORT [2]) and APU groups (motivated by the APU groups of ICAO document 9889). The groups are as follows:

Name	Description
Large	jets with MTOW typically > 300t (A340,B747, DC85,MD11,...)
Medium	jets with MTOW typically > 120t (A310,A330,B760,...)
Small	jets with MTOW typically > 50t (A319,A320,B730,MD81,...)
Regional	jets with MTOW typically < 50t (B731,DC9,E145,...)
Business	jets with MTOW typically < 34t C25A,E50P,GLF2,...)
Turboprop	turboprops (DHC8,D328,JS31,...)
Piston	pistons (PA28,C150,...)
HeliLarge	helicopters with MTOW > 5t (B4121,KA25,...)
HeliSmall	helicopters with MTOW < 5t (A109,EC55,...)
A991	APU for business jets (seats < 100)
A992	APU for regional jets (seats < 100)
A993	APU for smaller (100 <= seats < 200), older types
A994	APU for smaller (100 <= seats < 200), newer types
A995	APU for mid-range (200 <= seats < 300), all types
A996	APU for larger (300 <= seats), older types
A997	APU for larger (300 <= seats), newer types

2.4. PM methodologies

SECTOR calculates mass emissions of PM10 according to ICAO document 9889 2nd edition [1]. The mass consists of 3 parts:

1. Non-volatile PM (mainly black carbon, BC); if the EEDB contains a measured value, it is used, otherwise it is estimated from the smoke number according to the method FOA4.
2. Effective volatile PM due to the sulphur content of the fuel.
3. Effective volatile PM due to organics in the exhaust.

The latter contributions are named effective because these particles are not emitted but formed during the atmospheric transport after engine exit.

For completeness, SECTOR provides also a mass emission of PM25. It is set identical to the mass of PM10 because basically all particles emitted by the aircraft engines have an aerodynamic diameter smaller than 1 micrometer.

In addition to PM10 and PM25, SECTOR allows to calculate mass and emission indices for nvPM using different methodologies:

FOA4 This is the method provided in ICAO document 9889 2nd edition [1] which

	specifies the calculation of the mass EI and from that (assuming mode-specific mean diameters) the number EI.
FOA3N	This is the mass calculation method of ICAO document 9889 1st edition [3] plus a method to derive from that the number EI (the latter similar to FOA4 but with different diameters).
FOA4USR	This is the same method as FOA4, but with user-provided, mode-specific mean diameters (GMD) and standard deviations (GSD).
FOA4GC	This is the same method as FOA4, but with mean diameters derived from engine parameters according to the publication on which FOA4 is based [4].
FOA4DF	This is the same method as FOA4GC, but with the effective density and correction factors calculated from a fractal aggregate model [5].

Most methods contain corrections that account for line losses. By default, these corrections are made (loss-corrected values). The default method is FOA4, it can be changed by the user.

The methods are applied to engines of the ICAO EEDB, FOA EEDB and the engines listed in the CSV EEDB. In the engine record, they are stored as separate values under parameter names that encode the method (see the extended engine listing in the examples). The EIs for nvPM (mass) and nvPN (number) are set to the value of the default method only if they are not defined or negative. Hence, measured values (ICAO EEDB) or user-defined values (CSV EEDB) are not overwritten.

2.5. Further details

- Data sets in the ICAO EEDB

  The ICAO EEDB contains a sheet with fuel flows and EIs for the gaseous substances (sheet 1) and a sheet with measured EIs for nvPM together with according fuel flows (sheet 2). This implies that the nvPM EIs must be used in combination with these fuel flows while the EIs of the gaseous substances must be used with the fuel flows stated in the other sheet. Although the differences are small, this can hamper a simple application of the data.

  Therefore SECTOR scales on reading the ICAO EEDB the nvPM EIs with the fuel flow ratio sheet 2 over sheet 1. Then the resulting EIs can be used in combination with the fuel flows of sheet 1; the fuel flows of sheet 2 are not used further within SECTOR. Likewise, all other engine parameters (like the bypass ratio) are taken from sheet 1.

3. Program call

3.1. With GUI

The graphical user interface (GUI) can be called under Windows simply by a double-click on `SectorGUI.exe` in the root directory of SECTOR. The program calls `SectorGUI.jar` in subdirectory `jar` using the local JRE in subdirectory `jre`. Alternatively, the GUI is opened by a double-click on `SectorGUI.jar`, but this requires an installed JRE.

The GUI can be called also from a command shell (DOS shell under Windows), e.g. using the local JRE. From the SECTOR root directory, the call is (here with Windows path separators):

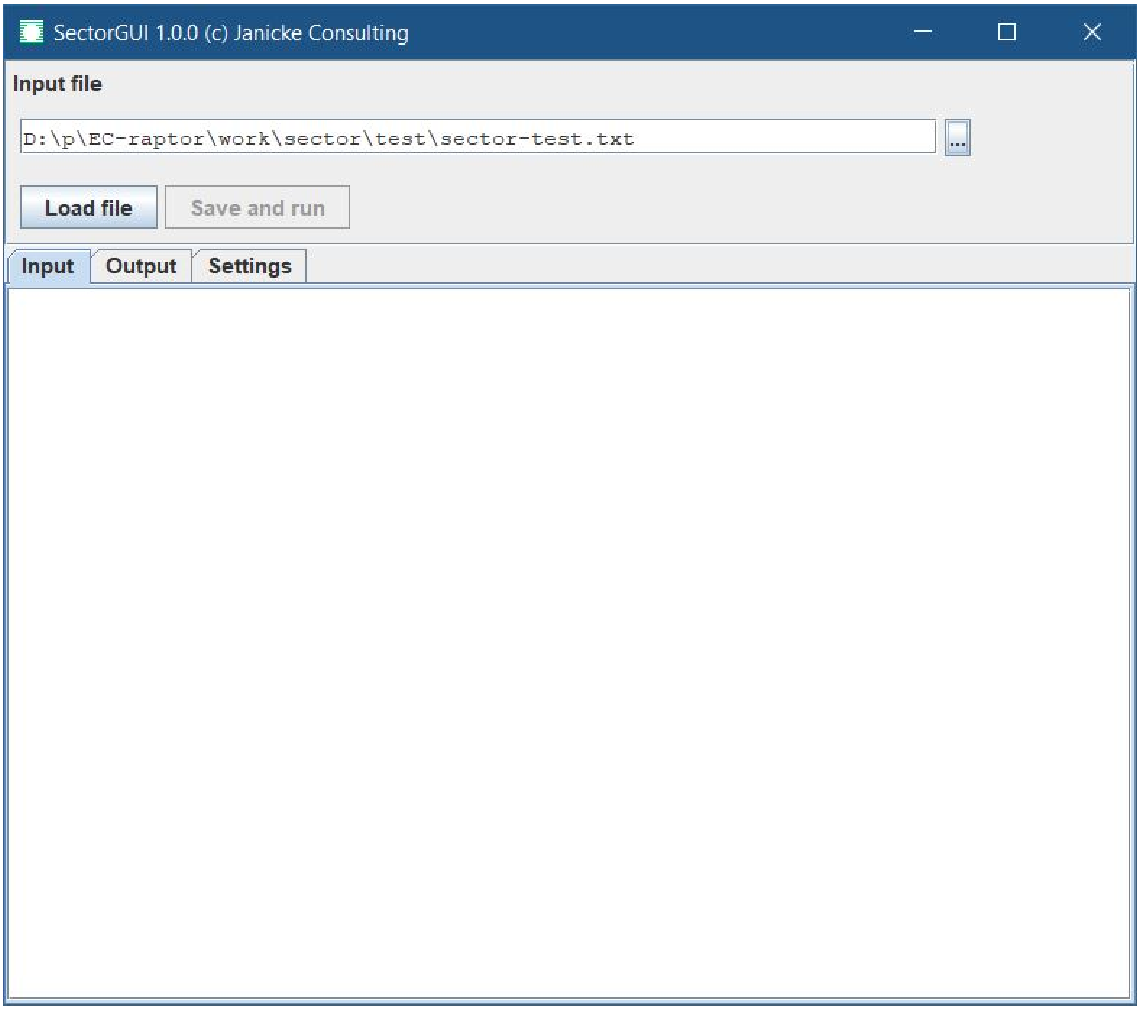
```
jre\bin\java -jar jar\SectorGUI.jar
```

The GUI is very simple and shown in the following figure. The input file is specified in the text field at the top. A file can be also selected by pressing button [...]. Note that all SECTOR input files must start with `sector-` and end with `.txt`. The file selection box only lists those files.

The file is read and displayed by pressing button [Load file]. The file identification (text in the file name after `sector-`) is displayed in the title of the sheets Input and Output. Sheet Input lists the input file and allows to edit its contents. If a result file is available (same directory and name as the input file, but with extension `.log`), its contents are shown in sheet Output.

Sheet Settings lists for information the contents of the settings file. Sheets Output and Settings cannot be edited and are shown with yellow background. The character size of all sheets be changed by pressing Ctrl]-[+] and Ctrl]-[-].

With button [Save and run] the current contents of sheet Input is saved, the calculation with program `Sector.jar` is carried out (the small logo of the GUI window turns into red), and after the calculation the contents of the output file is displayed in sheet Output.



Input file

D:\p\EC-raptor\work\sector\test\sector-test.txt

3.2. Without GUI

The program can be executed without GUI in a command shell, preferably from the root directory of SECTOR. The program call using the local JRE is

```
jre\bin\java -jar jar\SectorGUI.jar path id
```

where *path* is the path (relative or absolute) to the input file and *id* is the identifier of the input file which must have the name `sector-`*id*`.txt`. The result is written to file `sector-`*id*`.log` under the same path as the input file.

Example:

```
jre\bin\java -jar jar\SectorGUI.jar test example-1
```

4. Input and output data

Parameters are specified in the input file in form of sections. Each section starts with a section marker which has the form `[PARAMETER.SETTINGS]` for parameter assignments and `[TABLE.`*marker*`]` for tabular data.

Parameter assignments have the form

name ; *value(s)*

where *name* is the name of the parameter and *value(s)* is one or several (separated by a semicolon) values.

Table assignments start with a column header with the names of the columns separated by a semicolon. The column names are usually not case-sensitive and do not require a specific order except for the first column. Then follow the table rows with one value for each column, separated by a semicolon.

A parameter or table section ends with the definition of a new section or the end of the file. A table also ends if a row with a number of values is encountered that deviates from the number of columns in the column header.

Lines that start with `//` are interpreted as comment lines and skipped. Values and column separators can be combined with any number of blanks.

Example:

```
// Example input file
[PARAMETER.SETTINGS]
Listing; MOV

[TABLE.MOVEMENTS]
ACT  ;   LTO
A20N ;   155
B748 ;    90
```

All sections of the settings file can be overwritten by the input file,[3] either completely or only for certain parameter assignments, table rows, or table columns.

The input files should be provided as plain text files using standard (ANSI) encoding. They should not use the encoding UTF. The output files are provided in ANSI encoding.

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[3] The only substantial exception is section `TABLE.UID.MAPPING` which is used to internally map UID aliases. In addition, section `TABLE.DESCRIPTIONS` is only provided for information and not further evaluated.

5. Examples

The following provides some examples for input and output files. More information on the applied parameters is provided in Section 6 with the format specifications.

5.1. Example 1

The input file `sector-example-1.txt` reads:

```
[TABLE.MOVEMENTS]
ACG   ;     LTO
Large ;    1000
Medium;    1000
Small ;    1000
Regional;  1000
```

It defines the number of LTOs for 4 aircraft groups. The output file `sector-example-1.log` reads (some information is skipped):

```
2022-04-19T09:01:11+0100, JAVA 1.8.0_321
SECTOR 1.0.0 (c) 2022 Janicke Consulting, Germany

USE_CERT_LTO        : 1
PM_Method           : FOA4
ENG EEDB            : 815 engines from edb-emissions-databank_v28c_web.xlsx
ENG FOCA            : 22 engines from FOCA_Aircraft_Piston_Engine_Database.xlsx
ENG FOI             : 117 engines from All TPengs FOI 2006.xlsx
ENG CSV             : 4/0 engines added/modified from default settings
ACG CSV             : 9/0 aircraft groups (EEDB) added/modified from default settings
APU CSV             : 7 APU added from default settings
TIM CSV             : 9 aircraft groups (TIM) added from default settings
EI/PM               : emission indices and PM methods inserted
ACT                 : 825/0/0 aircraft types added/modified/removed from default settings
MOV                 : 4 effective movements with 4000.0 arr, 4000.0 dep, 4000.0 LTO

[TABLE.LTO.SECONDS]
ACG         ;       TO;       CO;       AP;       ID; APU   ;       SS;       HL;       NR
Large       ;     42.0;    132.0;    240.0;   1560.0; A997  ;    360.0;    140.0;   2400.0
Medium      ;     42.0;    132.0;    240.0;   1560.0; A995  ;    360.0;     35.0;   2400.0
Small       ;     42.0;    132.0;    240.0;   1560.0; A994  ;    360.0;     35.0;   2400.0
Regional    ;     42.0;    132.0;    240.0;   1560.0; A992  ;    360.0;     35.0;   2400.0
Business    ;     42.0;    132.0;    240.0;   1560.0; A991  ;    360.0;     35.0;   2400.0
Turboprop   ;     42.0;    132.0;    240.0;   1560.0;       ;      0.0;      0.0;      0.0
Piston      ;     42.0;    132.0;    240.0;   1560.0;       ;      0.0;      0.0;      0.0
HeliLarge   ;     42.0;    132.0;    240.0;   1560.0;       ;      0.0;      0.0;      0.0
HeliSmall   ;     42.0;    132.0;    240.0;   1560.0;       ;      0.0;      0.0;      0.0

[TABLE.MOVEMENTS.SUMMARY]
Name        ;   Arrivals; Departures;        LTO;    Percent
Large       ;     1000.0;     1000.0;     1000.0;       25.0
Medium      ;     1000.0;     1000.0;     1000.0;       25.0
Small       ;     1000.0;     1000.0;     1000.0;       25.0
Regional    ;     1000.0;     1000.0;     1000.0;       25.0
Business    ;        0.0;        0.0;        0.0;        0.0
Turboprop   ;        0.0;        0.0;        0.0;        0.0
Piston      ;        0.0;        0.0;        0.0;        0.0
HeliLarge   ;        0.0;        0.0;        0.0;        0.0
HeliSmall   ;        0.0;        0.0;        0.0;        0.0
TOTAL       ;     4000.0;     4000.0;     4000.0;      100.0

[TABLE.MASS.AC.TO]
Name        ;           FB;          NOX;           CO;           HC;          CO2;          SOX;         NVPM;         NVPN;         PM10;         PM25
Unit        ;           Mg;           Mg;           Mg;           Mg;           Mg;           Mg;           Mg;            1;           Mg;           Mg
Large       ; 2.59980e+02; 9.59326e+00; 1.61968e-01; 2.19163e-03; 8.20237e+02; 2.07984e-01; 8.73533e-02; 5.51158e+20; 1.00352e-01; 1.00352e-01
Medium      ; 2.83920e+02; 1.15839e+01; 4.94021e-02; 8.71634e-03; 8.95768e+02; 2.27136e-01; 8.48921e-03; 5.33770e+19; 2.33666e-02; 2.33666e-02
Small       ; 9.24000e+01; 2.16216e+00; 7.82628e-02; 9.00900e-03; 2.91522e+02; 7.39200e-02; 5.04504e-03; 3.17856e+19; 1.06260e-02; 1.06260e-02
Regional    ; 7.14000e+01; 1.33518e+00; 5.45496e-02; 7.28280e-03; 2.25267e+02; 5.71200e-02; 9.85320e-03; 6.19038e+19; 1.41372e-02; 1.41372e-02
Business    ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Turboprop   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Piston      ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliLarge   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
```

```
HeliSmall   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
TOTAL       ; 7.07700e+02; 2.46745e+01; 3.44182e-01; 2.71998e-02; 2.23279e+03; 5.66160e-01; 1.10741e-01; 6.98224e+20; 1.48482e-01; 1.48482e-01

[TABLE.MASS.AC.CO]
Name        ;          FB;         NOX;          CO;          HC;         CO2;         SOX;        NVPM;        NVPN;        PM10;        PM25
Unit        ;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;           1;          Mg;          Mg
Large       ; 6.83760e+02; 1.94872e+01; 3.50085e-01; 6.07179e-03; 2.15726e+03; 5.47008e-01; 2.11966e-01; 1.34017e+21; 2.46154e-01; 2.46154e-01
Medium      ; 7.11480e+02; 2.09887e+01; 2.12021e-01; 1.84273e-02; 2.24472e+03; 5.69184e-01; 2.30520e-02; 1.45142e+20; 5.92663e-02; 5.92663e-02
Small       ; 2.38920e+02; 4.34834e+00; 3.94218e-01; 2.81926e-02; 7.53793e+02; 1.91136e-01; 1.41202e-02; 8.91172e+19; 2.79536e-02; 2.79536e-02
Regional    ; 1.21044e+02; 1.81566e+00; 1.19228e-01; 1.90039e-02; 3.81894e+02; 9.68352e-02; 2.02143e-02; 1.27096e+20; 2.74770e-02; 2.74770e-02
Business    ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Turboprop   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Piston      ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliLarge   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliSmall   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
TOTAL       ; 1.75520e+03; 4.66398e+01; 1.07555e+00; 7.16956e-02; 5.53767e+03; 1.40416e+00; 2.69352e-01; 1.70152e+21; 3.60851e-01; 3.60851e-01

[TABLE.MASS.AC.AP]
Name        ;          FB;         NOX;          CO;          HC;         CO2;         SOX;        NVPM;        NVPN;        PM10;        PM25
Unit        ;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;           1;          Mg;          Mg
Large       ; 4.58400e+02; 5.08824e+00; 6.69264e-01; 1.65024e-02; 1.44625e+03; 3.66720e-01; 1.48980e-02; 7.51776e+20; 3.82306e-02; 3.82306e-02
Medium      ; 4.12800e+02; 5.20128e+00; 7.10016e-01; 2.53872e-02; 1.30238e+03; 3.30240e-01; 7.59552e-03; 3.81840e+20; 2.92262e-02; 2.92262e-02
Small       ; 1.51440e+02; 1.30238e+00; 1.69613e+00; 2.43818e-01; 4.77793e+02; 1.21152e-01; 7.25398e-03; 3.64970e+20; 2.83193e-02; 2.83193e-02
Regional    ; 9.40800e+01; 6.85843e-01; 5.17440e-01; 4.33709e-02; 2.96822e+02; 7.52640e-02; 3.28339e-03; 1.64640e+20; 1.03488e-02; 1.03488e-02
Business    ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Turboprop   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Piston      ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliLarge   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliSmall   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
TOTAL       ; 1.11672e+03; 1.22777e+01; 3.59285e+00; 3.29079e-01; 3.52325e+03; 8.93376e-01; 3.30309e-02; 1.66323e+21; 1.06125e-01; 1.06125e-01

[TABLE.MASS.AC.ID]
Name        ;          FB;         NOX;          CO;          HC;         CO2;         SOX;        NVPM;        NVPN;        PM10;        PM25
Unit        ;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;           1;          Mg;          Mg
Large       ; 9.98400e+02; 4.65254e+00; 2.87539e+01; 3.81389e+00; 3.14995e+03; 7.98720e-01; 4.35302e-02; 2.19648e+21; 1.15814e-01; 1.15814e-01
Medium      ; 8.84520e+02; 4.26339e+00; 2.48550e+01; 2.63587e+00; 2.79066e+03; 7.07616e-01; 1.24717e-02; 6.28894e+20; 7.19999e-02; 7.19999e-02
Small       ; 3.38520e+02; 1.45564e+00; 1.00202e+01; 9.27545e-01; 1.06803e+03; 2.70816e-01; 1.20175e-02; 6.05951e+20; 3.41905e-02; 3.41905e-02
Regional    ; 2.44920e+02; 7.81295e-01; 9.69883e+00; 1.34951e+00; 7.72723e+02; 1.95936e-01; 7.05370e-03; 3.37990e+20; 2.74310e-02; 2.74310e-02
Business    ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Turboprop   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Piston      ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliLarge   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliSmall   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
TOTAL       ; 2.46636e+03; 1.11529e+01; 7.33280e+01; 8.72681e+00; 7.78137e+03; 1.97309e+00; 7.50731e-02; 3.76931e+21; 2.49436e-01; 2.49436e-01

[TABLE.MASS.AC]
Name        ;          FB;         NOX;          CO;          HC;         CO2;         SOX;        NVPM;        NVPN;        PM10;        PM25
Unit        ;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;           1;          Mg;          Mg
Large       ; 2.40054e+03; 3.88212e+01; 2.99352e+01; 3.83865e+00; 7.57370e+03; 1.92043e+00; 3.57747e-01; 4.83958e+21; 5.00551e-01; 5.00551e-01
Medium      ; 2.29272e+03; 4.20373e+01; 2.58265e+01; 2.68840e+00; 7.23353e+03; 1.83418e+00; 5.16084e-02; 1.20925e+21; 1.83859e-01; 1.83859e-01
Small       ; 8.21280e+02; 9.26852e+00; 1.21888e+01; 1.20856e+00; 2.59114e+03; 6.57024e-01; 3.84366e-02; 1.09182e+21; 1.01089e-01; 1.01089e-01
Regional    ; 5.31444e+02; 4.61798e+00; 1.03900e+01; 1.41917e+00; 1.67671e+03; 4.25155e-01; 4.04046e-02; 6.91630e+20; 7.93940e-02; 7.93940e-02
Business    ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Turboprop   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Piston      ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliLarge   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliSmall   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
TOTAL       ; 6.04598e+03; 9.47450e+01; 7.83405e+01; 9.15479e+00; 1.90751e+04; 4.83679e+00; 4.88197e-01; 7.83229e+21; 8.64893e-01; 8.64893e-01

[TABLE.MASS.APU]
Name        ;          FB;         NOX;          CO;          HC;         CO2;         SOX;        NVPM;        NVPN;        PM10;        PM25
Unit        ;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;           1;          Mg;          Mg
Large       ; 1.83456e+02; 2.20637e+00; 2.42961e-01; 3.11333e-02; 5.78802e+02; 1.46764e-01; 1.97611e-02; 1.44997e+20; 1.97611e-02; 1.97611e-02
Medium      ; 1.21990e+02; 1.14330e+00; 2.99586e-01; 2.29944e-02; 3.84879e+02; 9.75922e-02; 2.88319e-02; 2.64524e+20; 2.88319e-02; 2.88319e-02
Small       ; 8.22972e+01; 5.17367e-01; 5.57412e-01; 1.05307e-01; 2.59648e+02; 6.58378e-02; 2.05708e-02; 6.79583e+19; 2.05708e-02; 2.05708e-02
Regional    ; 7.52028e+01; 5.01008e-01; 7.50868e-01; 1.21076e-01; 2.37265e+02; 6.01622e-02; 2.99834e-02; 1.36765e+20; 2.99834e-02; 2.99834e-02
Business    ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Turboprop   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
Piston      ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliLarge   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
HeliSmall   ; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00; 0.00000e+00
TOTAL       ; 4.62946e+02; 4.36804e+00; 1.85083e+00; 2.80511e-01; 1.46059e+03; 3.70357e-01; 9.91472e-02; 6.14243e+20; 9.91472e-02; 9.91472e-02

[TABLE.MASS.TOTAL]
Name        ;          FB;         NOX;          CO;          HC;         CO2;         SOX;        NVPM;        NVPN;        PM10;        PM25
Unit        ;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;          Mg;           1;          Mg;          Mg
TOTAL       ; 6.50893e+03; 9.91130e+01; 8.01914e+01; 9.43530e+00; 2.05357e+04; 5.20714e+00; 5.87344e-01; 8.44653e+21; 9.64041e-01; 9.64041e-01
```

5.2. Example 2

The input file contains information on specific aircraft types and requests to list more detailed movement information in the output:

```
[PARAMETER.SETTINGS]
Listing; MOV

[TABLE.MOVEMENTS]
ACT  ;   LTO
A20N ;   155
B748 ;    90
```

The output file contains, among other, the sections:

```
[TABLE.MOVEMENTS]
ACG         ; ACT       ; UID           ;   NEN; APU  ; A/D/L;        OPS
Large       ; B748      ; 01P17GE215    ;     4; A997 ; L    ;       90.0
Small       ; A20N      ; 01P20CM128    ;     2; A994 ; L    ;      155.0

[TABLE.MOVEMENTS.SUMMARY]
Name        ;   Arrivals; Departures;        LTO;    Percent
Large       ;       90.0;       90.0;       90.0;       36.7
Medium      ;        0.0;        0.0;        0.0;        0.0
Small       ;      155.0;      155.0;      155.0;       63.3
Regional    ;        0.0;        0.0;        0.0;        0.0
Business    ;        0.0;        0.0;        0.0;        0.0
Turboprop   ;        0.0;        0.0;        0.0;        0.0
Piston      ;        0.0;        0.0;        0.0;        0.0
HeliLarge   ;        0.0;        0.0;        0.0;        0.0
HeliSmall   ;        0.0;        0.0;        0.0;        0.0
TOTAL       ;      245.0;      245.0;      245.0;      100.0
```

5.3. Example 3

The input file modifies the default EI of CO_2 and requests a listing of engine parameters for 2 engines with different levels of detail:

```
[PARAMETER.SETTINGS]
EI_CO2(g/kg) ; 3160
Listing      ; 18PW122-1; 01P17GE215-4
```

The output file contains, among other, the sections:

```
[PARAMETER.ENGINE.18PW122]
UID; 18PW122
ENG; PW1127G-JM
SRC; EEDB
ETP; TF
CMB; TALON X
BYP; 12.28
PRR; 31.66
ROP; 120.43
SNM; 13.40
FTD; 2014-03-14
SSB; true
SSU; 01P18PW153
SRG;
PMM; FOA4

[TABLE.ENGINE.18PW122]
```

```
Name            ; Unit ;        Takeoff;       Climbout;       Approach;           Idle;            LTO
FF              ; kg/s ;        0.80000;        0.67000;        0.23220;        0.08000;      302.56800
NOX             ; g/kg ;       18.82000;       15.30000;        9.07000;        4.84000;     3094.96896
CO              ; g/kg ;        0.22000;        0.30000;        5.36000;       27.93000;     3818.29008
HC              ; g/kg ;        0.02000;        0.04000;        0.02000;        0.43000;       58.98816
FB              ; g/kg ;     1000.00000;     1000.00000;     1000.00000;     1000.00000;   302568.00000
CO2             ; g/kg ;     3160.00000;     3160.00000;     3160.00000;     3160.00000;   956114.88000
SOX             ; g/kg ;        0.80000;        0.80000;        0.80000;        0.80000;      242.05440
NVPM            ; g/kg ;        0.07747;        0.07052;        0.00419;        0.01037;       10.36668
NVPN            ; 1/kg ;    4.88389e+14;    4.44552e+14;    2.11117e+14;    5.22740e+14;    1.32729e+17
PM10            ; g/kg ;        0.12873;        0.12252;        0.05427;        0.06198;       25.92061
PM25            ; g/kg ;        0.12873;        0.12252;        0.05427;        0.06198;       25.92061

[PARAMETER.ENGINE.01P17GE215]
UID; 01P17GE215
ENG; GEnx-2B67/P
SRC; EEDB
ETP; TF
CMB; TAPS
BYP; 8.03
PRR; 43.55
ROP; 299.81
SNM; 0.58
FTD; 2012-06-21
SSB; false
SSU;
SRG;
PMM; MEASURED

[TABLE.ENGINE.01P17GE215]
Name            ; Unit ;        Takeoff;       Climbout;       Approach;           Idle;            LTO
FF              ; kg/s ;        2.45300;        2.00900;        0.64200;        0.21900;      863.93400
NOX             ; g/kg ;       34.21000;       21.10000;       11.11000;        4.92000;    12512.68386
CO              ; g/kg ;        0.07000;        0.17000;        1.78000;       14.28000;     5205.17538
HC              ; g/kg ;        0.02000;        0.02000;        0.04000;        0.41000;      153.59988
BNZ             ; g/kg ;        0.00040;        0.00040;        0.00080;        0.00820;        3.07200
ODOR            ; OU/kg;    6.20000e+02;    6.20000e+02;    1.24000e+03;    1.27100e+04;    4.76160e+06
FB              ; g/kg ;     1000.00000;     1000.00000;     1000.00000;     1000.00000;   863934.00000
CO2             ; g/kg ;     3160.00000;     3160.00000;     3160.00000;     3160.00000;  2730031.44000
SOX             ; g/kg ;        0.80000;        0.80000;        0.80000;        0.80000;      691.14720
SN              ; 1    ;        0.47000;        0.47000;        0.54000;        0.54000;
NVPM            ; g/kg ;        0.00235;        0.00221;        0.00484;        0.00282;        2.53827
NVPN            ; 1/kg ;    1.05173e+11;    1.08975e+11;    4.36069e+14;    6.65823e+13;    8.99764e+16
PM10_NV         ; g/kg ;        0.00235;        0.00221;        0.00484;        0.00282;        2.53827
PM10_VS         ; g/kg ;        0.04896;        0.04896;        0.04896;        0.04896;       42.29821
PM10_VH         ; g/kg ;        0.00230;        0.00152;        0.00225;        0.00253;        1.85165
PM10            ; g/kg ;        0.05361;        0.05269;        0.05605;        0.05431;       46.68814
PM25            ; g/kg ;        0.05361;        0.05269;        0.05605;        0.05431;       46.68814
GMD_FOA3N       ; nm   ;       40.00000;       30.00000;       20.00000;       15.00000;
GMD_FOA4        ; nm   ;       40.00000;       40.00000;       20.00000;       20.00000;
GMD_FOA4USR     ; nm   ;       40.00000;       40.00000;       20.00000;       20.00000;
GMD_FOA4GC      ; nm   ;       16.14833;       15.98224;       14.42392;       12.15609;
GMD_FOA4DF      ; nm   ;       16.14833;       15.98224;       14.42392;       12.15609;
CEE_FOA3N       ; g/m3 ;    2.73356e-05;    2.73356e-05;    3.24439e-05;    3.24439e-05;
CEE_FOA4        ; g/m3 ;    6.22737e-05;    6.22737e-05;    6.67256e-05;    6.67256e-05;
CEE_FOA4USR     ; g/m3 ;    6.22737e-05;    6.22737e-05;    6.67256e-05;    6.67256e-05;
CEE_FOA4GC      ; g/m3 ;    6.22737e-05;    6.22737e-05;    6.67256e-05;    6.67256e-05;
CEE_FOA4DF      ; g/m3 ;    6.22737e-05;    6.22737e-05;    6.67256e-05;    6.67256e-05;
NVPM_FOA3N      ; g/kg ;        0.00098;        0.00111;        0.00212;        0.00270;        1.64188
NVPM_FOA4       ; g/kg ;        0.00223;        0.00252;        0.00435;        0.00555;        3.46227
NVPM_FOA4USR    ; g/kg ;        0.00223;        0.00252;        0.00435;        0.00555;        3.46227
NVPM_FOA4GC     ; g/kg ;        0.00223;        0.00252;        0.00435;        0.00555;        3.46227
NVPM_FOA4DF     ; g/kg ;        0.00223;        0.00252;        0.00435;        0.00555;        3.46227
NVPN_FOA3N      ; 1/kg ;    8.22478e+12;    2.20315e+13;    1.42425e+14;    4.29895e+14;    1.75504e+17
NVPN_FOA4       ; 1/kg ;    1.40274e+13;    1.58576e+13;    2.19600e+14;    2.79737e+14;    1.35056e+17
NVPN_FOA4USR    ; 1/kg ;    1.40274e+13;    1.58576e+13;    2.19600e+14;    2.79737e+14;    1.35056e+17
NVPN_FOA4GC     ; 1/kg ;    2.13194e+14;    2.48602e+14;    5.85425e+14;    1.24583e+15;    6.03718e+17
NVPN_FOA4DF     ; 1/kg ;    1.42566e+14;    1.65992e+14;    3.85063e+14;    7.99177e+14;    3.91069e+17
```

```
NVPM_UC         ; g/kg ;        0.00174;        0.00165;        0.00346;        0.00228;        1.93043
NVPN_UC         ; 1/kg ;    7.60892e+10;    7.89154e+10;    8.28203e+13;    1.99975e+13;    1.96217e+16
GMD_UC_FOA3N    ; nm   ;       40.00000;       30.00000;       20.00000;       15.00000;
GMD_UC_FOA4     ; nm   ;       40.00000;       40.00000;       20.00000;       20.00000;
GMD_UC_FOA4USR  ; nm   ;       40.00000;       40.00000;       20.00000;       20.00000;
GMD_UC_FOA4GC   ; nm   ;       14.65213;       14.50143;       13.10884;       11.04777;
GMD_UC_FOA4DF   ; nm   ;       14.65213;       14.50143;       13.10884;       11.04777;
CEE_UC_FOA3N    ; g/m3 ;    2.73356e-05;    2.73356e-05;    3.24439e-05;    3.24439e-05;
CEE_UC_FOA4     ; g/m3 ;    3.68173e-05;    3.68173e-05;    3.97982e-05;    3.97982e-05;
CEE_UC_FOA4USR  ; g/m3 ;    3.68173e-05;    3.68173e-05;    3.97982e-05;    3.97982e-05;
CEE_UC_FOA4GC   ; g/m3 ;    3.68173e-05;    3.68173e-05;    3.97982e-05;    3.97982e-05;
CEE_UC_FOA4DF   ; g/m3 ;    3.68173e-05;    3.68173e-05;    3.97982e-05;    3.97982e-05;
NVPM_UC_FOA3N   ; g/kg ;        0.00098;        0.00111;        0.00212;        0.00270;        1.64188
NVPM_UC_FOA4    ; g/kg ;        0.00132;        0.00149;        0.00260;        0.00331;        2.06037
NVPM_UC_FOA4USR ; g/kg ;        0.00132;        0.00149;        0.00260;        0.00331;        2.06037
NVPM_UC_FOA4GC  ; g/kg ;        0.00132;        0.00149;        0.00260;        0.00331;        2.06037
NVPM_UC_FOA4DF  ; g/kg ;        0.00132;        0.00149;        0.00260;        0.00331;        2.06037
NVPN_UC_FOA3N   ; 1/kg ;    8.22478e+12;    2.20315e+13;    1.42425e+14;    4.29895e+14;    1.75504e+17
NVPN_UC_FOA4    ; 1/kg ;    8.29324e+12;    9.37527e+12;    1.30979e+14;    1.66848e+14;    8.05240e+16
NVPN_UC_FOA4USR ; 1/kg ;    8.29324e+12;    9.37527e+12;    1.30979e+14;    1.66848e+14;    8.05240e+16
NVPN_UC_FOA4GC  ; 1/kg ;    1.68734e+14;    1.96757e+14;    4.65158e+14;    9.89891e+14;    4.79420e+17
NVPN_UC_FOA4DF  ; 1/kg ;    1.11240e+14;    1.29519e+14;    3.01705e+14;    6.26172e+14;    3.06220e+17
```

5.4. Example 4

The input file contains a flight-by-flight journal with several 10 000 movements (only the first lines are shown) and requests a listing of movement statistics and average group values derived from the journal:

```
[PARAMETER.SETTINGS]
Listing; MOV; ACG

[TABLE.MOVEMENTS]
     FID ; A/D ;   ACT ;                AZB ;                UID ;   APU
 16524253 ;   A ;  B788 ;               S6.1 ;            12RR056 ;  A995
 16524249 ;   A ;  A332 ;               S6.1 ;             9PW095 ;  A995
 16524259 ;   A ;  A346 ;               S6.3 ;            avRR045 ;  A997
 16524266 ;   A ;  A388 ;                 S8 ;             8RR046 ;  A997
...
```

The output file contains, among other, sections with the movements statistics and average group emissions (fuel flows and EIs):

```
[TABLE.MOVEMENTS]
ACG         ; ACT        ; UID             ;   NEN; APU  ; A/D/L;        OPS
Business    ; C25A       ; BJET12          ;     2; A991 ; L    ;        3.0
Business    ; C25B       ; BJET12          ;     2; A991 ; L    ;        3.0
Business    ; C25C       ; BJET12          ;     2; A991 ; L    ;        8.0
Business    ; E50P       ; BJET12          ;     2; A991 ; L    ;        5.0
Business    ; E55P       ; BJET12          ;     2; A991 ; L    ;        3.0
Large       ; A343       ; 1CM010          ;     4; A997 ; L    ;        1.0
Large       ; A343       ; 1CM011          ;     4; A997 ; L    ;        1.0
Large       ; A343       ; 2CM015          ;     4; A997 ; L    ;      186.0
...

[TABLE.EMISSIONS.AC]
Name        ; Tracer  ; Unit    ;           TO;           CO;           AP;           ID
Large       ; FF      ; kg/s    ;  9.39774e+00;  7.62804e+00;  2.49004e+00;  8.94599e-01
```

```
Medium      ; FF      ; kg/s    ;  6.74045e+00;  5.38054e+00;  1.73632e+00;  5.73877e-01
Small       ; FF      ; kg/s    ;  2.28610e+00;  1.87258e+00;  6.45128e-01;  2.25199e-01
Regional    ; FF      ; kg/s    ;  1.49547e+00;  1.23453e+00;  4.23917e-01;  1.60922e-01
...
Large       ; NOX     ; g/kg    ;  4.50226e+01;  3.19981e+01;  1.10578e+01;  4.94235e+00
Medium      ; NOX     ; g/kg    ;  4.35032e+01;  3.22635e+01;  1.30085e+01;  4.83466e+00
Small       ; NOX     ; g/kg    ;  2.65733e+01;  2.12332e+01;  9.42903e+00;  4.45168e+00
Regional    ; NOX     ; g/kg    ;  1.95528e+01;  1.62391e+01;  7.86613e+00;  3.49539e+00
...

[TABLE.EMISSIONS.APU]
Name        ; Tracer  ; Unit    ;           SS;           HL;           NR
Large       ; FF      ; kg/h    ;  1.42654e+02;  2.57904e+02;  2.34968e+02
Medium      ; FF      ; kg/h    ;  1.07185e+02;  1.89350e+02;  1.62567e+02
Small       ; FF      ; kg/h    ;  7.69989e+01;  1.30000e+02;  1.10002e+02
Regional    ; FF      ; kg/h    ;  6.80938e+01;  1.11876e+02;  1.02970e+02
...
```

5.5. Example 5

The input file overwrites some of the default group values and requests emission output only for the basic substances of the ICAO EEDB:

```
[PARAMETER.SETTINGS]
Listing          ; EMIS-0
USE_CERT_LTO     ; 0

[TABLE.LTO.SECONDS]
ACG   ;  TO
Medium;  40

[TABLE.EEDB.ACG]
ACG         ;        FF-TO
Unit        ;         kg/s
Medium      ;          6.0

[TABLE.MOVEMENTS]
ACG   ; LTO
Medium; 100
```

The output file contains, among other, the following sections:

```
[TABLE.LTO.SECONDS]
ACG         ;       TO;       CO;       AP;       ID; APU   ;       SS;       HL;       NR
Large       ;     42.0;    132.0;    240.0;   1560.0; A997  ;    360.0;    140.0;   2400.0
Medium      ;     40.0;    132.0;    240.0;   1560.0; A995  ;    360.0;     35.0;   2400.0
Small       ;     42.0;    132.0;    240.0;   1560.0; A994  ;    360.0;     35.0;   2400.0
Regional    ;     42.0;    132.0;    240.0;   1560.0; A992  ;    360.0;     35.0;   2400.0
Business    ;     42.0;    132.0;    240.0;   1560.0; A991  ;    360.0;     35.0;   2400.0
Turboprop   ;     42.0;    132.0;    240.0;   1560.0;       ;      0.0;      0.0;      0.0
Piston      ;     42.0;    132.0;    240.0;   1560.0;       ;      0.0;      0.0;      0.0
HeliLarge   ;      0.0;    180.0;    400.0;    600.0;       ;      0.0;      0.0;      0.0
HeliSmall   ;      0.0;    180.0;    400.0;    600.0;       ;      0.0;      0.0;      0.0

[TABLE.MOVEMENTS.SUMMARY]
Name        ;   Arrivals; Departures;        LTO;    Percent
Large       ;        0.0;        0.0;        0.0;        0.0
Medium      ;      100.0;      100.0;      100.0;      100.0
Small       ;        0.0;        0.0;        0.0;        0.0
```

```
Regional    ;        0.0;        0.0;        0.0;        0.0
Business    ;        0.0;        0.0;        0.0;        0.0
Turboprop   ;        0.0;        0.0;        0.0;        0.0
Piston      ;        0.0;        0.0;        0.0;        0.0
HeliLarge   ;        0.0;        0.0;        0.0;        0.0
HeliSmall   ;        0.0;        0.0;        0.0;        0.0
TOTAL       ;      100.0;      100.0;      100.0;      100.0

[TABLE.MASS.AC.TO]
Name        ;           FB;          NOX;           CO;           HC
Unit        ;           Mg;           Mg;           Mg;           Mg
Large       ;  0.00000e+00;  0.00000e+00;  0.00000e+00;  0.00000e+00
Medium      ;  2.40000e+01;  9.79200e-01;  4.17600e-03;  7.36800e-04
Small       ;  0.00000e+00;  0.00000e+00;  0.00000e+00;  0.00000e+00
Regional    ;  0.00000e+00;  0.00000e+00;  0.00000e+00;  0.00000e+00
Business    ;  0.00000e+00;  0.00000e+00;  0.00000e+00;  0.00000e+00
Turboprop   ;  0.00000e+00;  0.00000e+00;  0.00000e+00;  0.00000e+00
Piston      ;  0.00000e+00;  0.00000e+00;  0.00000e+00;  0.00000e+00
HeliLarge   ;  0.00000e+00;  0.00000e+00;  0.00000e+00;  0.00000e+00
HeliSmall   ;  0.00000e+00;  0.00000e+00;  0.00000e+00;  0.00000e+00
TOTAL       ;  2.40000e+01;  9.79200e-01;  4.17600e-03;  7.36800e-04
```

6. Format specifications

The following sections contain the format specifications of the parameter and table sections of the input and output files.

6.1. Input sections

`[TABLE.MOVEMENTS]`

List of movements for which the emissions are calculated; this is the only section that must be provided by the user.

Column	Description
`ACG`	*(string)* name of the aircraft group; allowed names are `Large`, `Medium`, `Small`, `Regional`, `Business`, `Turboprop`, `Piston`, `HeliSmall`, `HeliLarge`
`ACT`	*(string)* name of the aircraft type (as alternative to the aircraft group); allowed names are the ICAO codes listed in section `TABLE.AIRCRAFT.TYPES` in the settings file and/or in the input file
`UID`	*(string)* engine UID (in combination with aircraft type); allowed names are the UIDs of the applied EEDBs and/or the ones listed in section `TABLE.EEDB.OTHER` in the settings file and/or in the input file; if not specified, the default UID of the given aircraft type is used
`NEN`	*(int)* number of engines; if not specified the default number of the given aircraft type is used
`APU`	*(string)* APU name; if not specified the default number of the given aircraft type is used
`LTO`	*(float)* number of LTOs
`A/D`	*(char)* `A` for arrivals, `D` for departures (in combination with `OPS` alternative to `LTO`)
`A/D/L`	*(char)* `A` for arrivals, `D` for departures, `L` for LTO (in combination with `OPS` alternative to `LTO`)
`OPS`	*(float)* number of operations (arrivals, departures, or LTOs)

[PARAMETER.SETTINGS]

Various parameter settings.

Parameter	Description
`Filename_EEDB`	*(string)* file name of the ICAO EEDB XLS file
`Filename_FOCA`	*(string)* file name of the FOCA EEDB XLS file
`Filename_FOI`	*(string)* file name of the FOI EEDB XLS file
`EI_CO2(g/kg)`	*(float)* emission index for CO_2 in g/kg
`EI_SOX(g/kg)`	*(float)* emission index for SO_x in g/kg
`EI_FB(g/kg)`	*(float)* emission index for fuel burn in g/kg
`BNZ_IN_HC(g/g)`	*(float)* mass fraction of benzene in HC, used to estimate the emission index of benzene
`ODOR_IN_HC(OU/g)`	*(float)* emitted odor units per emitted gram HC, used to estimate odor emission
`PM25_IN_PM10(g/g)`	*(float)* mass fraction of PM2.5 in PM10, used to estimate the emission index of PM2.5
`USE_CERT_LTO`	*(int)* if not equal to 0, the times-in-mode of the certification LTO are applied independent of other specified settings
`PM_Method`	*(string)* applied method to estimate the nvPM indices; allowed names are `FOA4`, `FOA3N`, `FOA4GC`, `FOA4DF`
`PM_FOA4USR`	*(float[8])* GMDs and GSDs used for PM method `FOA4USR` in the order TO, CO, AP, ID
`Listing`	*(string[])* key words separated by a semicolon that specify additional output tables beside the overall emissions; the key word can be followed by a `-` and a verbose level which specifies the level of output detail in some cases (e.g. `EMIS-2`); possible key words are: `EMIS` emissions with specified level of detail; levels: `0` ICAO substances `1` plus derived ones (e.g. SOX) `2` plus PM parameters and BNZ and ODOR `3` plus all PM parameters `4` plus uncorrected PM values (marker `_UC`) `MOV` aircraft/engine statistics `ACT` aircraft type statistics `EEDB` extended EEDB with all applied UIDs and tracers `APU` average APU fuel flows and emission indices `ACG` average fuel flows and emission indices `ACGX` average fuel flows and emission indices per aircraft group with extended LTO segmentation *uid* information on engine with UID *uid*, including fuel flows and emission indices

`[TABLE.LTO.SECONDS]`

Times-in-mode and APU running times for the different aircraft groups.

Column	Description
`ACG`	*(string)* name of the aircraft group; allowed names are `Large`, `Medium`, `Small`, `Regional`, `Business`, `Turboprop`, `Piston`, `HeliSmall`, `HeliLarge`
`TO`	*(float)* time-in-mode (in s) for LTO segment take-off
`CO`	*(float)* time-in-mode (in s) for LTO segment climb
`AP`	*(float)* time-in-mode (in s) for LTO segment approach
`ID`	*(float)* time-in-mode (in s) for LTO segment idle
`APU`	name of the default APU; allowed names are `A997`, `A996`, `A995`, `A994`, `A993`, `A992`, `A991`
`SS`	*(float)* APU operating time (in s) for start and stabilization (APU start)
`HL`	*(float)* APU operating time (in s) for high load (main engine start)
`NR`	*(float)* APU operating time (in s) for normal running (dependent on the stand position)

`[TABLE.AIRCRAFT.TYPES]`

Aircraft type list.

Column	Description
`ACT`	*(string)* aircaft type name (ICAO code)
`MOD`	*(string)* aircraft model (only for information)
`ACG`	*(string)* name of the aircraft group, to which this aircraft type belongs; allowed names are `Large`, `Medium`, `Small`, `Regional`, `Business`, `Turboprop`, `Piston`, `HeliSmall`, `HeliLarge`
`UID`	*(string)* default engine UID of this aircraft type (must be available in the database)
`NEN`	*(int)* default number of engines of this aircraft type
`APU`	*(string)* default APU name of this aircraft type; allowed names are `A997`, `A996`, `A995`, `A994`, `A993`, `A992`, `A991`

`[TABLE.EEDB.OTHER]`

Engine emission data; this extends or modifies the engine data that are read from the external EEDBs.

The first table row (after the column header) must contain in column `UID` the entry `Unit` and contains the units; the unit of fuel flows must be kg/s, the unit of ordinary tracers must be g/kg, the unit of tracers ending with `PN` must be 1/kg (number of particles per kg), the unit of tracers containing `ODOR` must be OU/kg; the program checks the units.

Column	Description
`UID`	*(string)* engine UID
`ENG`	*(string)* engine name (for information only)
`SRC`	*(string)* data source (for information only)
`CMB`	*(string)* combustor type (for information only)
`ETP`	*(string)* engine type, must be empty, `TF` or `MTF`, required by PM methodologies to account for bypass
`BYP`	*(float)* bypass ratio, required by PM methodologies
`PRR`	*(float)* pressure ratio
`ROP`	*(float)* rated output power
`TYR`	*(string)* final test date
`FF-`*mode*	*(float)* fuel flows in kg/s per engine for the LTO modes `TO`, `CO`, `AP`, `ID`
tracer-mode	*(float)* emission indices in g/kg, 1/kg, or OU/kg for the trace substance *tracer* and the LTO modes `TO`, `CO`, `AP`, `ID`

[TABLE.EEDB.ACG]

Average fuel flows and EIs of the aircraft groups. These values are applied if the movements are defined based on aircraft groups.

The first table row (after the column header) must contain in column `ACG` the entry `Unit` and contains the units; the unit of fuel flows must be kg/s, the unit of ordinary tracers must be g/kg, the unit of tracers ending with `PN` must be 1/kg (number of particles per kg), the unit of tracers containing `ODOR` must be OU/kg; the program checks the units.

Column	Description
`ACG`	*(string)* name of the aircraft group; allowed names are `Large`, `Medium`, `Small`, `Regional`, `Business`, `Turboprop`, `Piston`, `HeliSmall`, `HeliLarge`
`FF-`*mode*	*(float)* fuel flows in kg/s per aircraft for the LTO modes `TO`, `CO`, `AP`, `ID`
tracer-mode	*(float)* emission indices in g/kg, 1/kg, or OU/kg for the trace substance *tracer* and the LTO modes `TO`, `CO`, `AP`, `ID`

[TABLE.EEDB.APU]

Fuel flows and EIs for the APU groups.

Column	Description
`Name`	*(string)* name of the APU group; allowed names are `A997`, `A996`, `A995`, `A994`, `A993`, `A992`, `A991`
`Tracer`	*(string)* `FF` for the fuel flow, tracer name otherwise
`Unit`	*(string)* unit in which the emission is specified; must be kg/h for the fuel flow and g/kg, 1/kg, or OU/kg for the trace substances
`SS`	*(float)* emission value for start and stabilization
`HL`	*(float)* emission value for high load
`NR`	*(float)* emission value for normal running

6.2. Output sections

The following lists the most important output sections.

`[TABLE.MASS.AC.`*mode*`]`, `[TABLE.MASS.AC]`

Total emissions from aircraft main engines, by LTO segment and summed over the LTO.

The first table row (after the column header) states in column `Name` the entry `Unit` and contains the units; the unit is Mg or 1 or MOU.

Column	Description
`Name`	*(string)* name of the aircraft group
tracer	*(string)* tracer name, `FB` for fuel burn

`[TABLE.MASS.APU]`

Total emissions from APU.

The first table row (after the column header) states in column `Name` the entry `Unit` and contains the units; the unit is Mg or 1 or MOU.

Column	Description
`Name`	*(string)* name of the aircraft group
tracer	*(string)* tracer name, `FB` for fuel burn

`[TABLE.MASS.TOTAL]`

Total emissions from aircraft and APU.

The first table row (after the column header) states in column `Name` the entry `Unit` and contains the units; the unit is Mg or 1 or MOU.

Column	Description
`Name`	*(string)* name of the aircraft group
tracer	*(string)* tracer name, `FB` for fuel burn

`[TABLE.MOVEMENTS.SUMMARY]`

Summary of the applied movements; always written.

Column	Description
`Name`	*(string)* name of the APU group
`Arrivals`	*(float)* number of arrivals
`Departures`	*(float)* number of departures
`LTO`	*(float)* number of LTOs
`Percent`	*(float)* percentage of total movements

`[TABLE.MOVEMENTS]`

Aircraft/engine statistics.

Column	Description
`ACG`	*(string)* name of the aircraft group
`ACT`	*(string)* name of the aircraft type
`UID`	*(string)* engine UID
`NEN`	*(int)* number of engines
`APU`	*(string)* APU group
`A/D/L`	*(char)* type of operation
`OPS`	*(float)* number of operations

7. PM calculation

This section describes the implemented methods for the calculation of nvPM emission indices. In short, the methods are:

FOA3N	Method of ICAO document 9889 1st edition [3] plus a method to derive from that the number EI (similar to FOA4 but with different diameters).
FOA4	Method of ICAO document 9889 2nd edition [1] which specifies the calculation of the mass EI and from this (assuming mode-specific mean diameters) the number EI.
FOA4GC	FOA4 with mean diameters derived from engine parameters according to [4].
FOA4DF	FOA4GC with effective density and correction factors calculated from a fractal aggregate model [6, 5].

The calculation proceeds in the following steps:

1. Calculation of the mass concentration
2. Calculation of the geometric mean diameter and standard deviation
3. Calculation of the effective density
4. Calculation of the mass EI
5. Calculation of the number EI

7.1. Mass concentration

The mass concentration is calculated from the smoke number S. If no S is provided, it is calculated by the Calvert method [1] from the maximum smoke number. If no maximum smoke number is provided, the maximum smoke number is estimated as 10 (this applies to all FOI turboprop data).

The nvPM mass concentration at instrument level c_i has been measured for various engines and a fit was proposed (SCOPE11) to estimate it from the actual smoke number [4]. The concentration at engine exit c_e is then set in an approximate form equal to c_i or derived by an estimate of the system line-losses that occured between engine exit and instrument level. In the following $c_0 = 1\ \mathrm{g/m^3}$.

FOA3N

$$c_\mathrm{i} = c_0 10^{-3} \begin{cases} 0.0694 S^{1.234} & S \leq 30 \\ 0.0297 S^2 - 1.802 S + 31.94 & S > 30 \end{cases} \tag{1}$$

$$c_\mathrm{e} = c_\mathrm{i} \tag{2}$$

FOA4, FOA4GC, FOA4DF

$$c_\mathrm{i} = c_0 10^{-6} \frac{648.4 \exp(0.0766 S)}{1 + \exp[-1.098(S - 3.064)]} \tag{3}$$

$$k = \ln\left[\frac{3.219 \cdot 10^6 c_\mathrm{i}(1+\beta) + 312.5}{10^6 c_\mathrm{i}(1+\beta) + 42.6}\right] \tag{4}$$

$$c_\mathrm{e} = k c_\mathrm{i} \tag{5}$$

with the bypass ratio β. Here and in subsequent sections, $\beta = 0$ for all engines that are not mixed turbofans (code MTF in the EEDB).

7.2. Calculation of the geometric mean diameter and standard deviation

The geometric mean diameter D_g and the geometric standard deviation σ_g define a lognormal diameter distribution. They are either set to a mode-specific fixed value or calculated from the concentration. With $D_0 = 1$ nm the settings are:

FOA3N

$$\sigma_\mathrm{g} = 1.7 \tag{6}$$

$$D_\mathrm{g} = D_0 \begin{cases} 40 & \text{take-off} \\ 30 & \text{climb} \\ 20 & \text{approach} \\ 15 & \text{idle} \end{cases} \tag{7}$$

FOA4N

$$\sigma_\mathrm{g} = 1.8 \tag{8}$$

$$D_\mathrm{g} = D_0 \begin{cases} 40 & \text{take-off} \\ 40 & \text{climb} \\ 20 & \text{approach} \\ 20 & \text{idle} \end{cases} \tag{9}$$

FOA4GC, FOA4DF

$$\sigma_\mathrm{g} = 1.8 \tag{10}$$

For the calculation of D_g, the mass concentration of nvPM (more specifically, BC) at combustor exit c_c is required. It is estimated from the concentration at engine exit as

$$c_\mathrm{c} = c_\mathrm{e}(1+\beta)\frac{\rho_4}{\rho_\mathrm{a}} \tag{11}$$

with the exhaust density ρ_4 at stage 4 (combustor exit) and the density of ambient air ρ_a. With the definition of the density

$$\rho = \frac{p}{RT} \tag{12}$$

with pressure p, temperature T, and gas constant R (set to the one of dry air, $R = 8.314472/0.02896546\,\mathrm{J/mol\,K}$). For the ambient conditions, $T_\mathrm{a} = 283.15\,\mathrm{K}$ and $p_\mathrm{a} = 101325\,\mathrm{Pa}$ are assumed.

The temperature and pressure at stage 4 is derived starting at stage 1 with ambient conditions in front of the engine, via stage 2 at the compressor inlet, and stage 3 at the combustor inlet.

$$p_1 = p_\mathrm{a} \tag{13}$$

$$T_1 = T_\mathrm{a} \tag{14}$$

$$p_2 = p_1\left(1+\frac{\gamma-1}{2}M^2\right)^{\gamma/(\gamma-1)} \tag{15}$$

$$T_2 = T_1\left(1+\frac{\gamma-1}{2}M^2\right) \tag{16}$$

$$p_3 = p_2\left[1+(r_\mathrm{p}-1)r_\mathrm{t}\right] \tag{17}$$

$$T_3 = T_2\left(\frac{p_3}{p_2}\right)^{(\gamma-1)/(\gamma\eta)} \tag{18}$$

$$p_4 = p_3 \tag{19}$$

$$T_4 = \frac{r_\mathrm{af}c_\mathrm{p}T_3 + l_\mathrm{f}}{c_\mathrm{e}(1+r_\mathrm{af})} \tag{20}$$

with

- Mach number M (set to 0.1 for take-off, 0.2 for climb, 0.1 for approach, 0 for idle),
- ratio of specific heats $\gamma = 1.4$,
- pressure ratio r_p (set to 1.0 if not defined),

- thrust ratio with respect to maximum thrust r_t (set to 1.00 for take-off, 0.85 for climb, 0.30 for approach, 0.07 for idle),
- compressor polytropic efficiency $\eta = 0.9$,
- air-to-fuel ratio r_{af} (set to 45 kg/kg for take-off, 51 kg/kg for climb, 83 kg/kg for approach, 106 kg/kg for idle),
- specific heat at constant pressure $c_p = 1005\,\mathrm{J/kg\,K}$,
- lower calorific fuel value $l_f = 43.2 \cdot 10^6\,\mathrm{J/kg}$,
- heat capacity for combustion $c_e = 1250\,\mathrm{J/kg\,K}$

Then the geometric mean diameter is estimated as

$$D_g = D_0\, a \left(\frac{c_c}{10^{-6} c_0} \right)^b \tag{21}$$

with the fitting constants $a = 5.08$ and $b = 0.185$.

7.3. Calculation of the effective density

The nvPM particles are not solid spheres but an aggregate of smaller sub-particles. The effective density of a nvPM particle is estimated as follows.

FOA3N, FOA4, FOA4GC

$$\rho = 1 \cdot 10^6\,\mathrm{g/m^3} \tag{22}$$

FOA4DF (from Equations (6) and (11) in [6])

$$\rho = \rho_0 k_a \left[k_{tem} \left(\frac{D_g}{D_1} \right)^{D_{tem}-1} \right]^{3-D_{fm}} \tag{23}$$

with $D_1 = 1\,\mathrm{m}$, $\rho_0 = 1.77 \cdot 10^6\,\mathrm{g/m^3}$,m, $k_a = 1$, $k_{tem} = 1.621 \cdot 10^{-5}$, $D_{tem} = 0.39$, $D_{fm} = 2.76$.

7.4. Calculation of the mass EI

The mass emission index M is calculated from the mass concentration at engine exit c_e (mass per volume) and the volumetric flow rate q (volume per mass fuel burned).

FOA3N

$$q = q_0[0.776 r_\mathrm{af}(1+\beta) + 0.877] \tag{24}$$

$$M = c_\mathrm{e} q \tag{25}$$

FOA4, FOA4GC, FOA4DF

$$q = q_0[0.777 r_\mathrm{af}(1+\beta) + 0.767] \tag{26}$$

$$M = c_\mathrm{e} q \tag{27}$$

For all methods, $q_0 = 1\,\mathrm{m}^3/\mathrm{kg}$ and the air-to-fuel ratio r_af is set to 45 kg/kg for take-off, 51 kg/kg for climb, 83 kg/kg for approach, 106 kg/kg for idle.

7.5. Calculation of the number EI

The number emission index N is calculated from the mass emission index M, the geometric mean diameter D_g, the geometric standard deviation σ_g and the effective density ρ as follows. This relation can be used as well to calculate number emission or number concentration from mass emission or mass concentration.

FOA3N, FOA4, FOA4GC

$$N = \frac{M}{(\pi/6)\rho D_\mathrm{g}^3 \exp\left[(9/2)\ln^2\sigma_\mathrm{g}\right]} \tag{28}$$

FOA4DF

$$N = \frac{M}{(\pi/6)\rho D_\mathrm{g}^3 \exp\left[(9/2)\ln^2\sigma_\mathrm{g}\right]} \exp\left(\frac{9-\varphi^2}{2}\ln^2\sigma_\mathrm{g}\right) \tag{29}$$

with $\varphi = 3D_\mathrm{tem} + (1 - D_\mathrm{tem})D_\mathrm{fm}$, $D_\mathrm{tem} = 0.39$, $D_\mathrm{fm} = 2.76$.

References

[1] ICAO: *ICAO document 9889: Airport Air Quality Manual, Second Edition*, 2020. International Civil Aviation Organisation.

[2] Janicke, U., Fleuti, E., and Fuller, I.: *LASPORT – a model system for airport-related source systems based on a Lagrangian particle model.* In *Proceedings of the 11th International Conference on Harmonization within Atmospheric Dispersion Modeling for Regulatory Purposes, Cambridge, Great Britain*, 2007.

[3] ICAO: *ICAO document 9889: Airport Air Quality Manual, First Edition*, 2011. International Civil Aviation Organisation.

[4] Agarwal, A., Speth, R.L., Fritz, T.M., Jacob, S.D., Rindlisbacher, T., Iovinelli, R., Owen, B., Miake-Lye, R., Sabnis, J.S., and Barrett, S.R.H.: *SCOPE11 method for estimating aircraft black carbon mass and particle number emissions.* Environ. Sci. Technol., 53:1364–1373, 2019.

[5] Teoh, R., Schumann, U., Majumdar, A., and Stettler, M.E.J.: *Mitigating the climate forcing of aircraft contrails by small-scale divisions and technology adoption.* Environ. Sci. Technol., 54:2941–2950, 2020.

[6] Teoh, R., Stettler, M.E.J., Majumdar, A., Schumann, U., Graves, B., and Boles, A.M.: *A methodology to relate black carbon particle number and mass emissions.* J. Aerosol Sci., 132:44–59, 2019.

A. Comparisons of measured and modelled nvPM EIs

Figure 1 shows a comparison of measured (ICAO EEDB v28c) and modelled mass EIs for the 4 thrust modes of the certification LTO[4] and Figure 2 the according number EIs. The data were produced with SECTOR and the setting

```
Listing; EEDB-4
```

which provides all relevant information in the extended EEDB that is written to the output file.

The colour encodes the thrust mode (red: TO, magenta: CO, blue: AP, green: ID), the symbol the engine type (circle: turbofan TF, diamond: mixed turbofan MTF). The dashed lines denote a factor 2 difference between measured and modelled values. Also indicated in the figures are the correlation coefficient r, the root mean square error (RMSE) σ and the fit factor b.[5]

For nvPM mass (Figure 1), there is some tendency for the EIs to be higher at higher thrusts (green and blue symbols versus magenta and red symbols), more pronounced for the modelled values than for the measured values. For nvPM number (Figure 2), EIs populate similar value ranges over all LTO modes.

Multiplication of the EI with fuel flow and time-in-mode yields the emission over a segment of the certification LTO, and the sum over all segments ID, AP, CO, TO gives the LTO emission. Figures 3 and 4 show a comparison of modelled and measured LTO emissions. In the Figures, the colours indicate some of the combustor types:

---

[4] The measured nvPM EIs are listed in the EEDB Excel table in a separate sheet. They must be applied in combination with the fuel flows listed in that sheet. These fuel flows are slightly different from the ones in the sheet for the gaseous substances, differences are smaller than 10% and in most cases below 5%. To facilitate the use of the data, the nvPM EIs listed here were scaled by the fuel flow ratios (fuel flow for nvPM divided by fuel flow for gases) such that the nvPM EIs can be used in combination with the usual fuel flows listed for the gaseous substances. The scaling factors are close to unity and not of relevance for this discussion.

[5] Given n modelled values y_i and n measured values x_i, the correlation coefficient r (or Pearson's r) was applied as

$$r = \frac{\sum_i (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_i (x_i - \overline{x})^2}\,\sqrt{\sum_i (y_i - \overline{y})^2}} \tag{30}$$

with the arithmetic means $\overline{x} = (\sum_i x_i)/n$ and $\overline{y} = (\sum_i y_i)/n$. The root mean square error is defined as

$$\sigma = \sqrt{\frac{1}{n}\sum_i (x_i - y_i)^2} \tag{31}$$

and the factor b of a least square fit for the linear regression $y_i = b x_i$

$$b = \frac{\sum_i x_i y_i}{\sum_i x_i^2} \tag{32}$$

where $b < 1$ implies that the model tends to under-estimate.

red	PHASE (Rolls-Royce)
magenta	LEC (General Electric Company)
gray	TAPS (General Electric Company)
green	TECH Insertion (CFM International)
yellow	TALON (Pratt & Whitney)
cyan	Other

The dark blue symbols denote the arithmetic averages over all TF and MTF engines, respectively.

Deviations between modelled and measured LTO emissions do not give a direct indication on the relevance for local air quality (LAQ). For example, a higher modelled emission for climb-out (CO) may be compensated by a lower modelled emission for taxiing (ID). But for near-ground concentrations, taxiing emissions are much more relevant than climb emission. Thus, even if modelled and measured LTO emissions are the same, differences between the LTO segment emissions may exist and may be of relevance in view of LAQ.

Figures 5 and 6 show a comparison of the LTO segment emissions. Here, the colours refer again to the LTO segment. There is a tendency that the highest mass emissions are due to the LTO segments TO and CO and the highest number emissions due to the LTO segment ID. However, there is a large spread in the values.

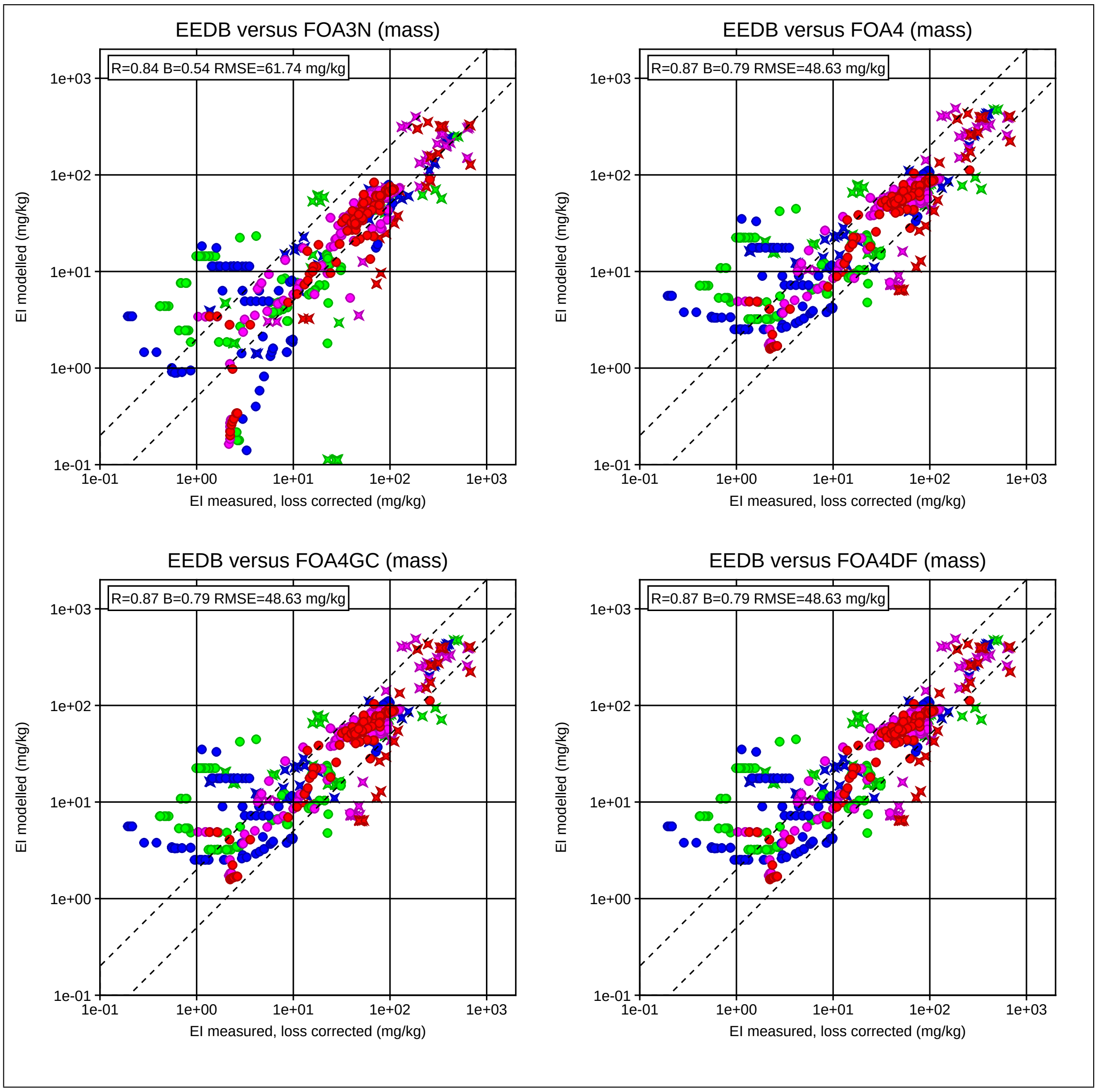

Figure 1: Comparison of measured and modelled nvPM mass emission indices. Red: TO, magenta: CO, blue: AP, green: ID, circles: TF, diamonds: MTF.

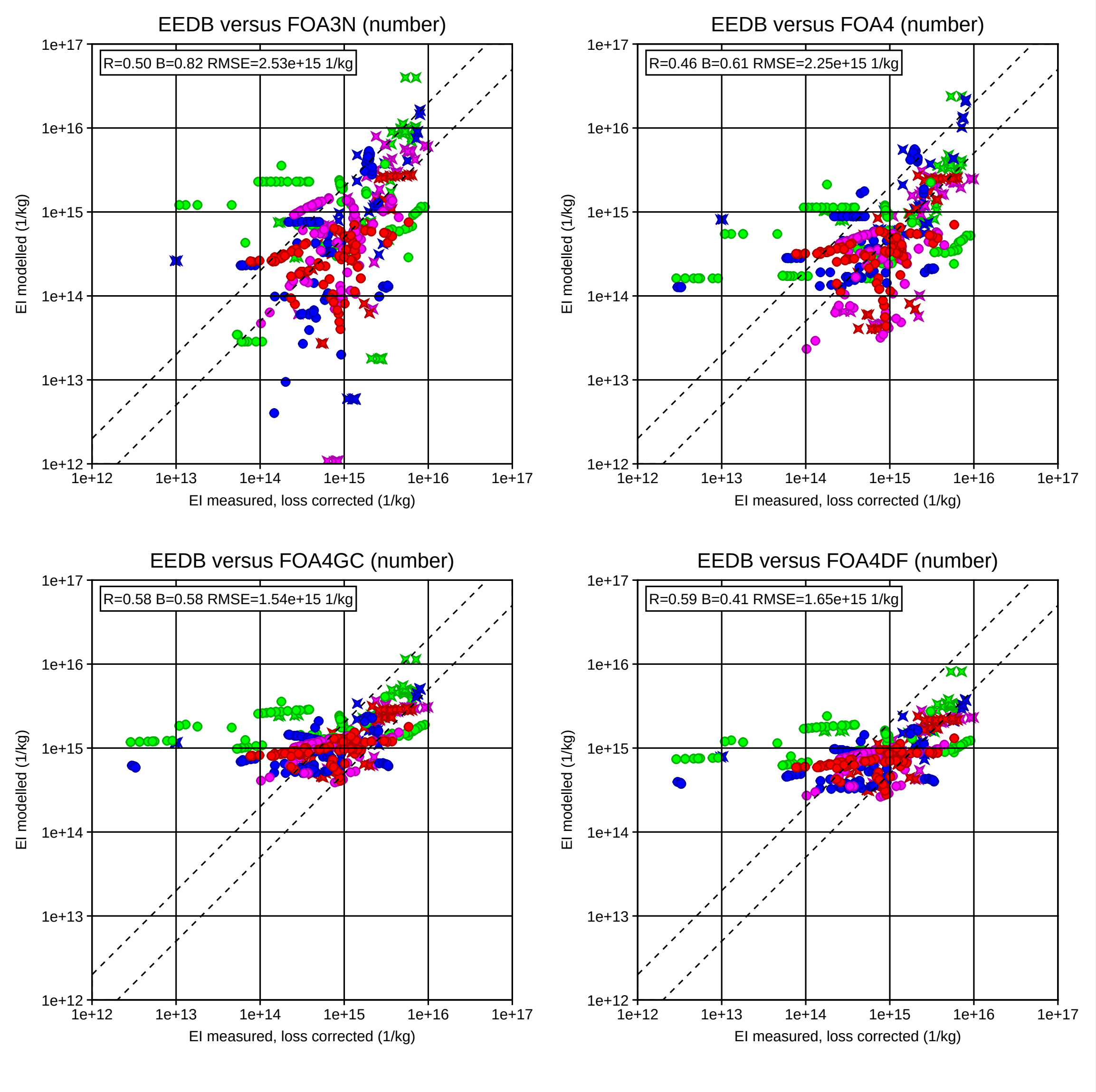

FIGURE 2: Comparison of measured and modelled nvPM number emission indices. Red: TO, magenta: CO, blue: AP, green: ID, circles: TF, diamonds: MTF.

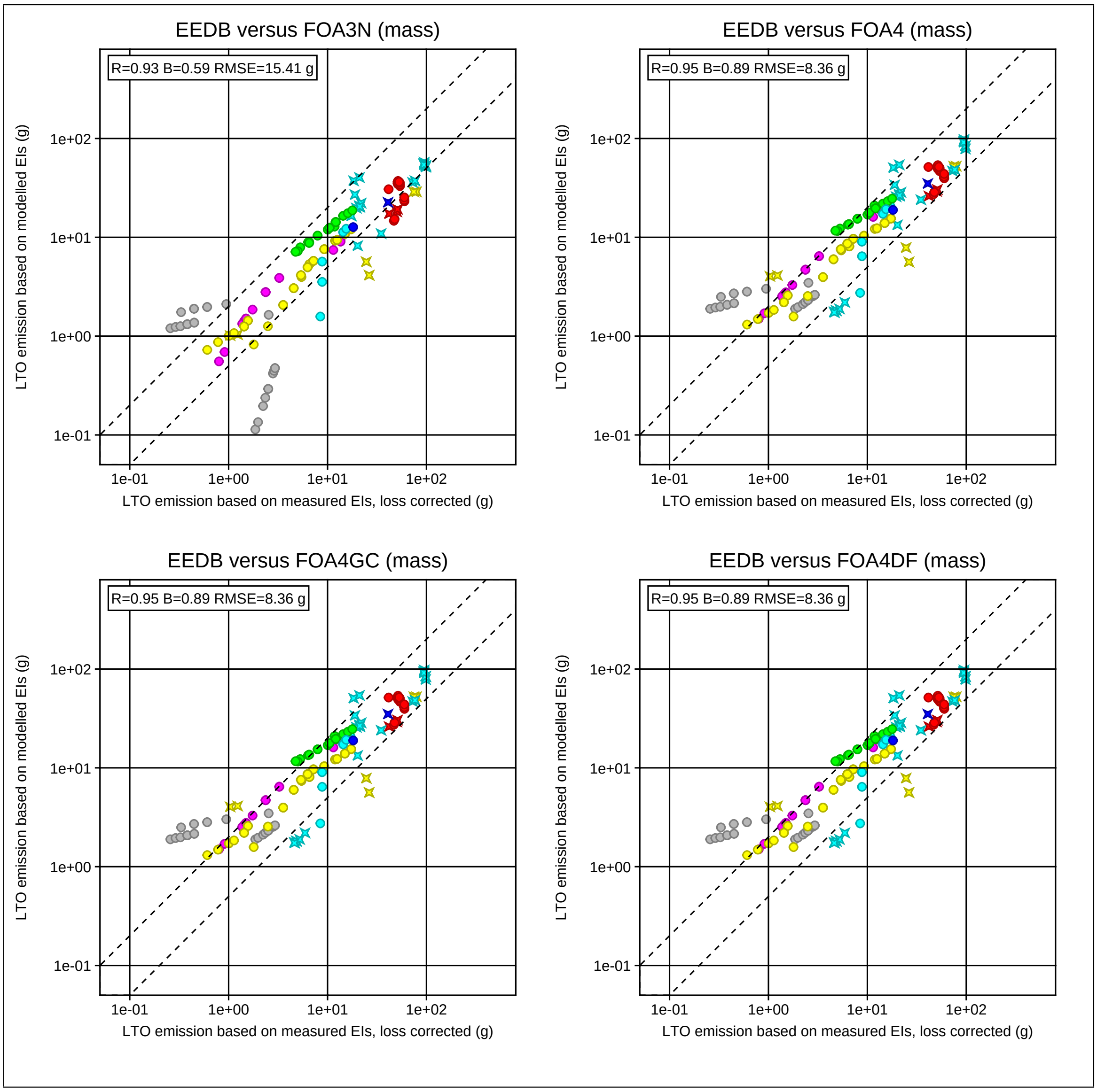

FIGURE 3: Comparison of measured and modelled nvPM mass emission over the certification LTO. Circles: TF, diamonds: MTF. The colours indicate the combustor type (red: PHASE, magenta: LEC, gray: TAPS, green: TECH, yellow: TALON, cyan: other) and the dark blue symbols the arithmetic averages over all TF and MTF engines, respectively.

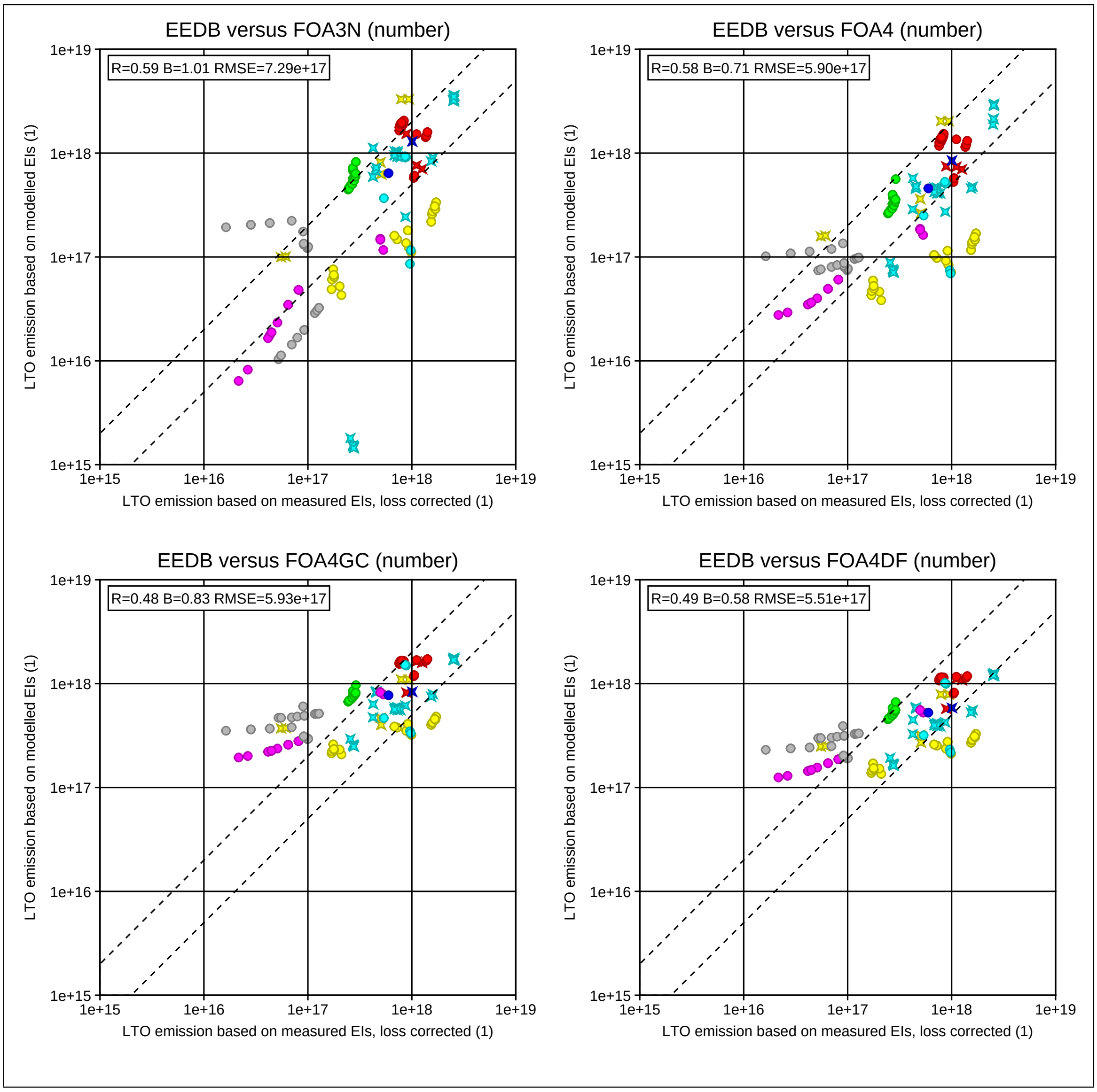

Figure 4: Comparison of measured and modelled nvPM mass emission over the certification LTO. Circles: TF, diamonds: MTF. The colours indicate the combustor type (red: PHASE, magenta: LEC, gray: TAPS, green: TECH, yellow: TALON, cyan: other) and the dark blue symbols the arithmetic averages over all TF and MTF engines, respectively.

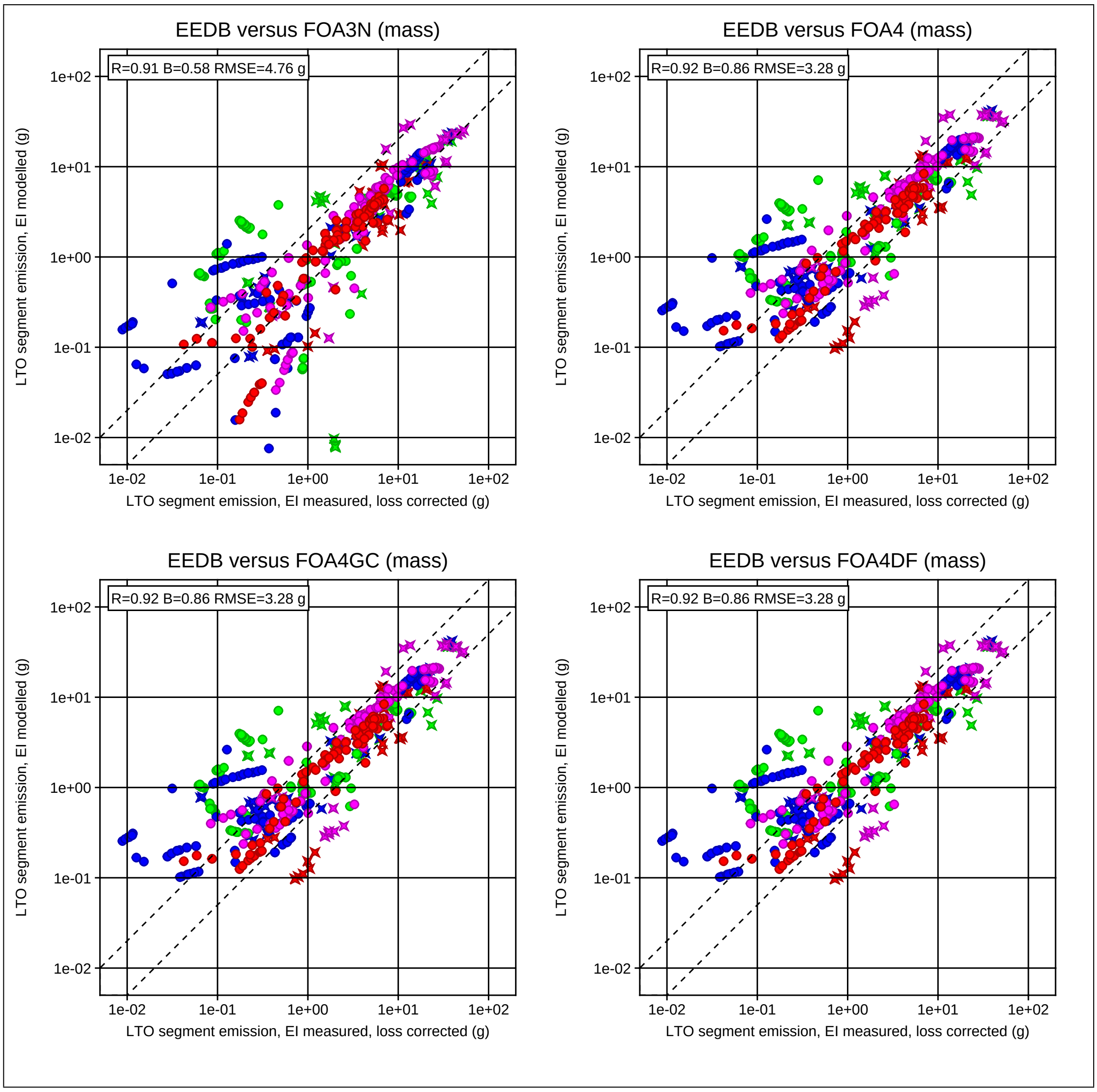

FIGURE 5: Comparison of measured and modelled nvPM mass emissions over an LTO segment. Red: TO, magenta: CO, blue: AP, green: ID, circles: TF, diamonds: MTF.

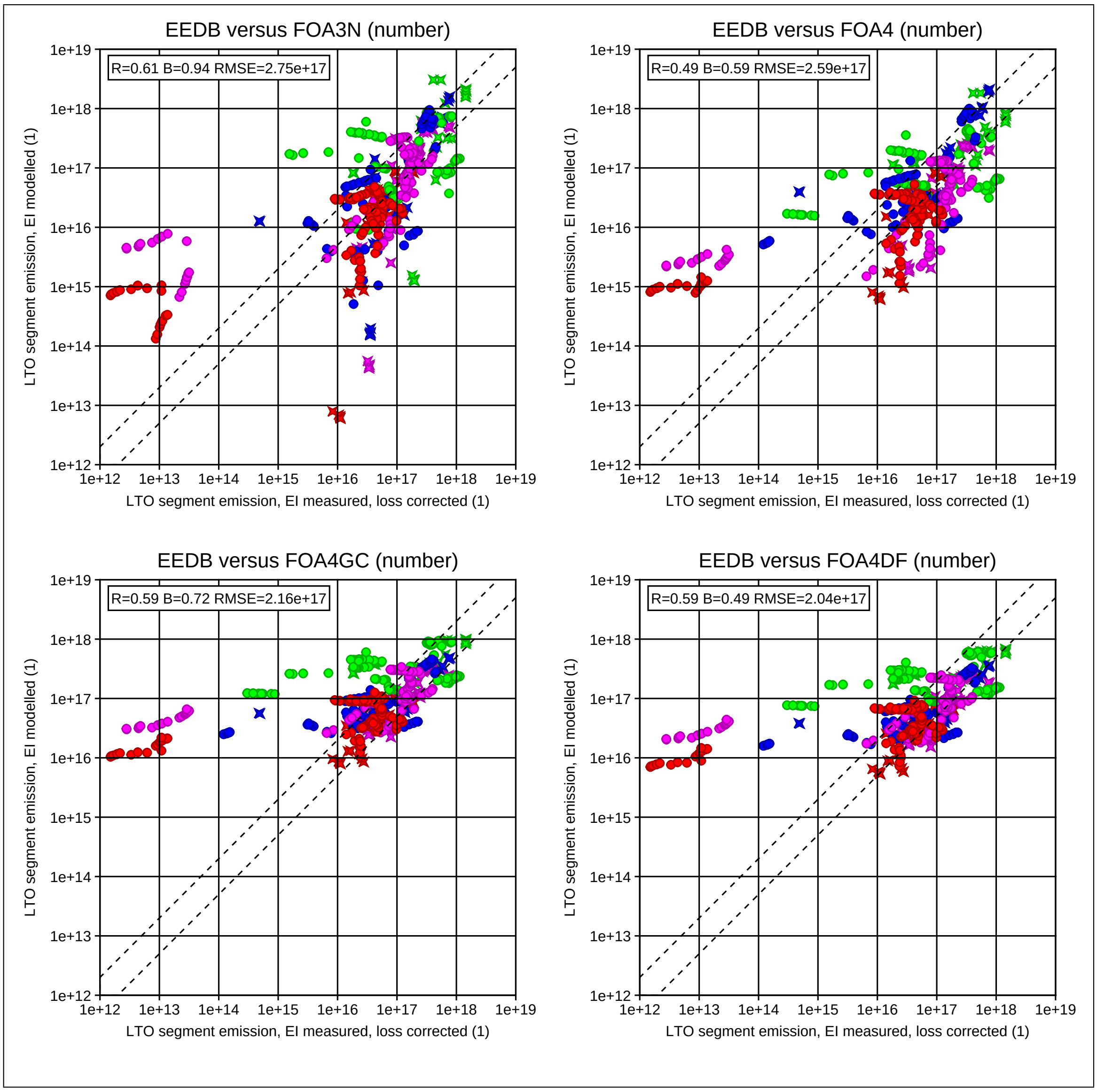

FIGURE 6: Comparison of measured and modelled nvPM number emissions over an LTO segment. Red: TO, magenta: CO, blue: AP, green: ID, circles: TF, diamonds: MTF.

B. Lognormal distribution of particle diameters

B.1. Theory

If there are $N \gg 1$ spherical particles with different diameters, the number of particles with a diameter smaller than a given diameter D can be written as

$$N_<(D) \;=\; NF(D) \tag{33}$$

with the number distribution function $F(D)$. By definition, $F(D)$ monotonously increases from $F(0) = 0$ to $F(\infty) = 1$. Function $F(D)$ can be defined by a number density function as

$$F(D) \;=\; \int_0^D f(x)\,\mathrm{d}x \tag{34}$$

$$f(D) \;=\; \frac{\mathrm{d}F(D)}{\mathrm{d}D} \tag{35}$$

with $f(D) \geq 0$, $f(\infty) = 0$, and $\int_0^\infty f(x)\,\mathrm{d}x = 1$.

Further parameterisation is usually based on the logarithm of the diameter. With the variable substitution $L = \ln D$ and $y = \ln x$ one obtains

$$F(L) \;=\; \int_{-\infty}^L g(y)\,\mathrm{d}y \tag{36}$$

$$g(y) \;=\; xf(x)\,. \tag{37}$$

For $g(y)$, a Gaussian or normal distribution of the form

$$g(y) \;=\; \alpha \exp\left[-\frac{(y-L_\mathrm{m})^2}{2s^2}\right] \tag{38}$$

$$\text{with } \alpha \;=\; \frac{1}{\sqrt{2\pi}s} \tag{39}$$

is applied with standard deviation $s = \ln\sigma$ and median $L_\mathrm{m} = \ln D_\mathrm{m}$. Insertion into Equation (36) gives

$$F(L) \;=\; \int_{-\infty}^L g(y)\,\mathrm{d}y \;=\; \alpha \int_{-\infty}^L \exp\left[-\frac{(y-L_\mathrm{m})^2}{2s^2}\right]\mathrm{d}y \tag{40}$$

or

$$F(D) \;=\; \int_0^D f(x)\,\mathrm{d}x \;=\; \alpha \int_0^D \exp\left[-\frac{(\ln x - \ln D_\mathrm{m})^2}{2s^2}\right]\frac{1}{x}\,\mathrm{d}x\,. \tag{41}$$

B.2. Some useful relations

1. The n-th moment of the diameter distribution is given by

$$A_n = \int_0^\infty x^n f(x)\,\mathrm{d}x \tag{42}$$

$$= \int_{-\infty}^\infty \exp[ny]\,g(y)\,\mathrm{d}y \tag{43}$$

$$= \alpha \int_{-\infty}^\infty \exp[ny] \exp\left[-\frac{(y-L_\mathrm{m})^2}{2s^2}\right] \mathrm{d}y\,. \tag{44}$$

   Variable substitution $\lambda = y - L_\mathrm{m}$ and quadratic expansion gives

$$A_n = D_\mathrm{m}^n \alpha \int_{-\infty}^\infty \exp[n\lambda] \exp\left[-\frac{\lambda^2}{2s^2}\right] \mathrm{d}\lambda \tag{45}$$

$$= D_\mathrm{m}^n \exp\left[\frac{1}{2}n^2 s^2\right] \alpha \int_{-\infty}^\infty \exp\left[-\frac{(\lambda - ns^2)^2}{2s^2}\right] \mathrm{d}\lambda \tag{46}$$

   so that

$$A_n = D_\mathrm{m}^n \exp\left[\frac{1}{2}n^2 s^2\right]\,. \tag{47}$$

2. The median diameter μ_n is defined by the value of λ that is required as upper bound of the integral in Equation (46) such that it takes half its total value. This is the case for $\lambda = ns^2$ or

$$\mu_n = D_\mathrm{m} \exp\left[ns^2\right]\,. \tag{48}$$

   $n = 0$ recovers the median number diameter $\mu_0 = D_\mathrm{m}$, $n = 3$ gives the volume mean diameter $\mu_3 = D_\mathrm{m} \exp\left[3s^2\right]$.

3. The total mass M of N particles with density ρ is obtained from Equation (47) using $n = 3$ and multiplication with $(\pi/6)\rho N$, thus

$$M = \frac{\pi}{6}\rho N D_\mathrm{m}^3 \exp\left[\frac{9}{2}s^2\right] \tag{49}$$

   which is a useful relation for converting number to mass and vice versa.

4. The geometric mean diameter D_g for a set of diameters D_i with weights w_i is defined as

$$D_\mathrm{g} = \left(\prod_{i=1}^n D_i^{w_i}\right)^{1/n} \quad \text{or} \quad \ln D_\mathrm{g} = \frac{1}{n}\sum_{i=1}^n w_i \ln D_i \tag{50}$$

which in integral form becomes

$$\ln D_\mathrm{g} = \int_{-\infty}^{\infty} y g(y)\,\mathrm{d}y \tag{51}$$

$$= \alpha \int_{-\infty}^{\infty} y \exp\left[-\frac{(y - L_\mathrm{m})^2}{2s^2}\right] \mathrm{d}y\ . \tag{52}$$

Variable substitution $\lambda = y - L_\mathrm{m}$ and integration yields for the right hand side the value $L_\mathrm{m} = \ln D_\mathrm{m}$, hence $D_\mathrm{g} = D_\mathrm{m}$, so median number diameter and geometric mean diameter (GMD) are the same. Parameter σ defined by $s = \ln\sigma$ is called the geometric standard deviation (GSD).

B.3. Some useful numbers

The following table provides values of N/M for different geometric mean diameters and the typical values $\rho = 1$ g/cm^3 and $\sigma = 1.8$. The fraction N/M can refer for example to the fraction of emission rates, emission indices, or total emissions.

The given ranges may be useful for consistency checks of emission data on the number and mass of ultrafine particles.

GMD in nm	N/M in 1/µg	N/M in 1/g	N/M in 1/kg
10	$4 \cdot 10^{11}$	$4 \cdot 10^{17}$	$4 \cdot 10^{20}$
20	$5 \cdot 10^{10}$	$5 \cdot 10^{16}$	$5 \cdot 10^{19}$
30	$1 \cdot 10^{10}$	$1 \cdot 10^{16}$	$1 \cdot 10^{19}$
40	$6 \cdot 10^{9}$	$6 \cdot 10^{15}$	$6 \cdot 10^{18}$
50	$3 \cdot 10^{9}$	$3 \cdot 10^{15}$	$3 \cdot 10^{18}$
100	$4 \cdot 10^{8}$	$4 \cdot 10^{14}$	$4 \cdot 10^{17}$
Range	$4 \cdot 10^{8..11}$	$4 \cdot 10^{14..17}$	$4 \cdot 10^{17..20}$