Online Determination of “Aircraft Engine Nanoparticle Emission Indices” at Zurich Airport, Switzerland

C. Wahl[*], Th. Rindlisbacher[#], M. Kapernaum[*]
[*] Institute of Combustion Technology, (German Aerospace Center, DLR – Stuttgart)
[#] Federal Office for Civil Aviation, (FOCA-Bern, Switzerland)

In a cooperation of German Aerospace Center (DLR - Stuttgart), Federal Office for Civil Aviation (FOCA – Bern, Switzerland) and Unique Flughafen Zürich AG, we did nanoparticle measurements at Zurich airport. The test equipment was positioned close to the taxiway of runway 16. If winds are from west (which is often the case), the exhaust gases of passing aircrafts are transported by wind drift to our equipment. Because of high dilution of the exhaust gases with ambient air and the transient events we used fast and sensitive devices like Engine Exhaust Particle Sizer (EEPS) and a NDIR CO_2 photometer. The size range of the EEPS is 5.6 nm to 560 nm and time resolution is 10 Hz. Time resolution of the NDIR CO_2 photometer is 1 Hz.

The so called particle Emission Index (EI_{PM}) gives the mass of nanoparticles formed during combustion of 1 kg fuel. $EI_{PM\ mass} = mg_{particles} / kg_{fuel}$. The Emission Index is a clear indicator for the quality of a combustion process! To determine an Emission Index by CO_2 concentration measurement, it is necessary to know the carbon mass content of the fuel. The fuel normally used in civil passenger aircrafts is kerosene called JET-A1. Due to the strict specifications, the mass ratio of carbon to hydrogen is nearly constant. Therefore, burning of 1 kg of Jet-A1 forms always 3.16 kg of CO_2 (+- 3%). To determine an $EI_{PM,}$ it is necessary to measure the CO_2 concentration and particle concentration in parallel. Under stationary conditions this is normally no problem. In our case of highly transient events, both instruments must be fast enough to detect the maximum of the peaks. The Emission Indices can be calculated independent from exhaust gas dilution. It is assumed that CO_2 and particles are diluted always by the same factor.

The aerosol background at Zurich airport is very low. Therefore for nearly all passing aircrafts the corresponding particle cloud could be identified. (The nose is also a good detector. Whenever we smelled exhaust gas, we also had clear signals in CO_2 and particles.)
We calculated Emission Indices for particle mass as well as for particle number. The measured range of values is

$EI_{particle\ mass} = 53 - 214\ mg_{PM} / kg_{fuel}$ $EI_{particle\ \#} = 1.5 - 4.7\ E16\ \# / kg_{fuel}$

The geometric mean diameter measured is in the range of 9.4 to 13.5 nm, which is less than normally found at engine test rig measurements. The reason here may be the direct exhaust dilution with bypass- and fan air at engine exit.
(At rig tests, dilution is normally done at the end of the sampling line. Agglomeration takes place in the sampling line, due to high particle concentration.)

Within the “International Civil Aviation Organization (ICAO)” there is a working group called “Committee on Aviation Environmental Protection (CAEP)”. This CAEP committee developed a “First Order Approximation (FOA3)” for particle mass estimation (volatile + nonvolatile). For this PM Estimation method, values from the ICAO engine database are used (Smoke Number, UHC, Sulfur Conversion Factor, AFR, ….). Using the FOA3 method, the calculated range of values is

$EI_{PM\ FOA3}$ = 54 to 248 mg $_{PM}$ / kg $_{fuel}$

It should be mentioned that the engine power setting at “ICAO Taxi” is 7% of the maximum engine thrust. The real “Taxi” power setting in our measurements at Zurich is about 4% of maximum thrust.

Assignment of engine types to measured aircraft can be done on the basis of publicly available data. Our method is a simple technique to determine EI’s for the actual aircraft engine fleet.
The method should also work on streets with low “car frequency” to get EI’s for the actual car fleet.

The authors want to thank Peter Frei and Emanuel Fleuti of UNIQUE Flughafen Zürich AG for making this measurements possible.

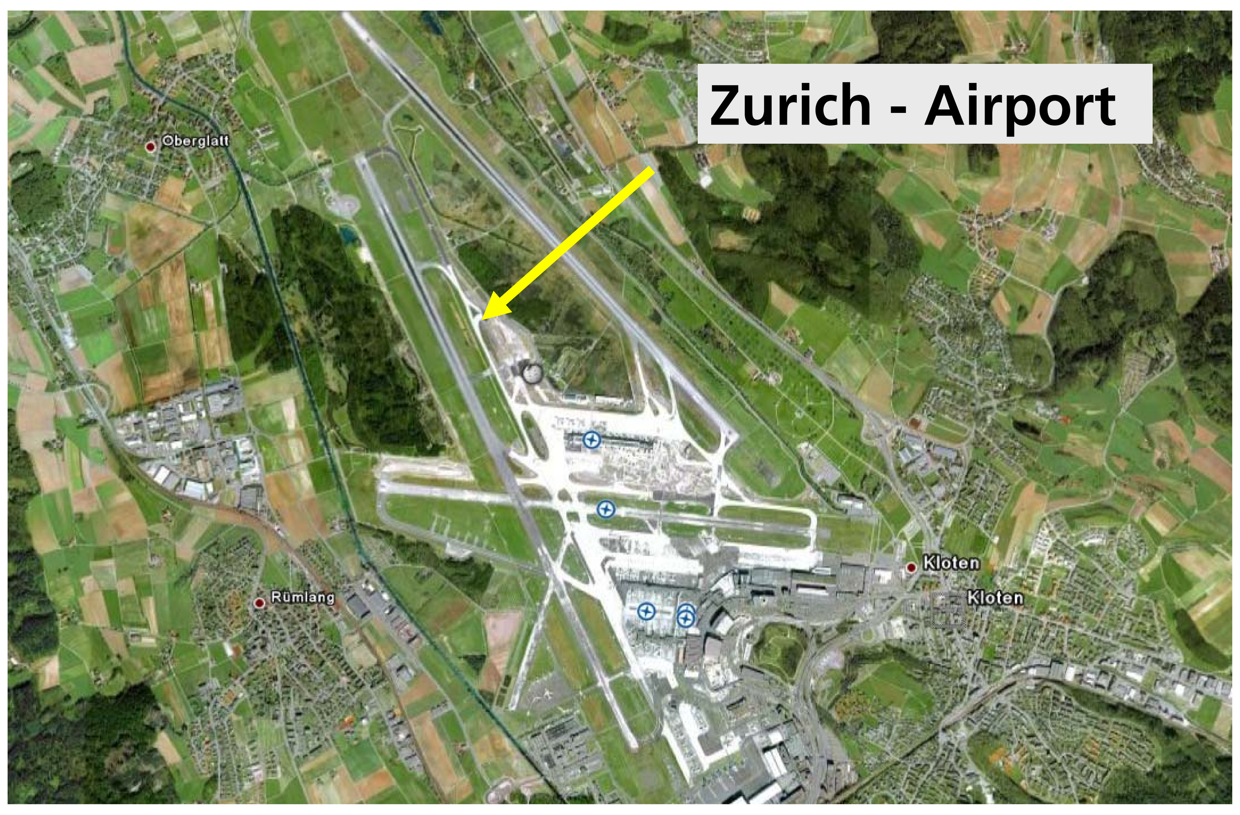
Please do not use this results out of the context of this presentation, due to the big error bars in CO_2 measurements (+- 20%) and the mentioned limitations.

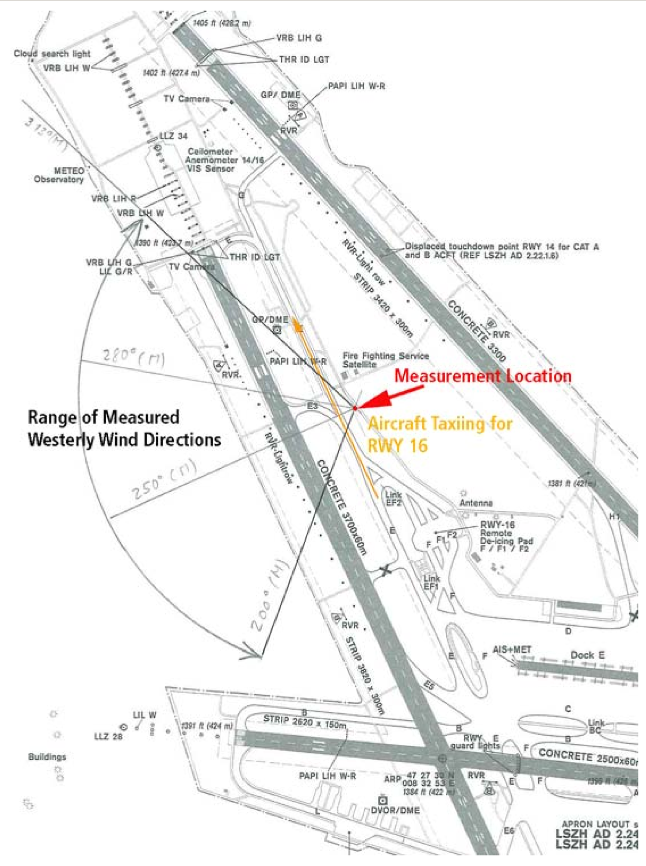
Institute of
Combustion Technology

Aircraft Engine Nanoparticle Emission Indices, Measurements at Zurich Airport, Switzerland

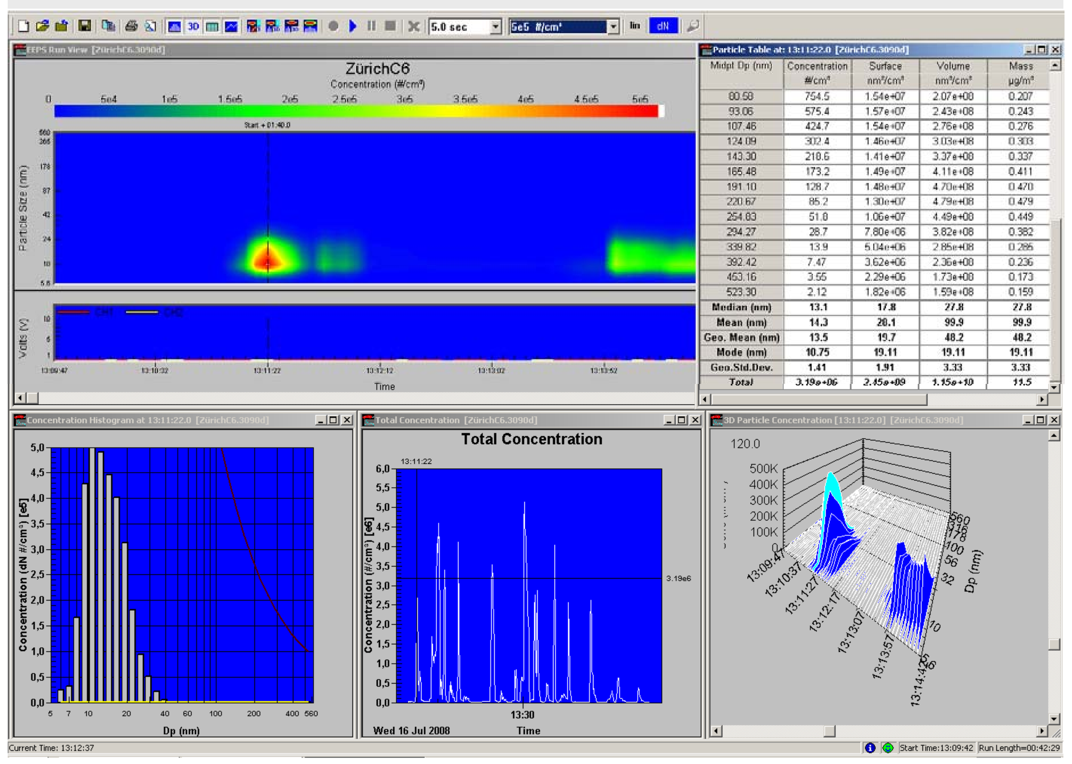
Claus Wahl*, Manfred Kapernaum* — *German Aerospace Center, DLR Stuttgart, Germany
Theo Rindlisbacher#, — #FOCA – Federal Office for Civil Aviation, Bern, Switzerland

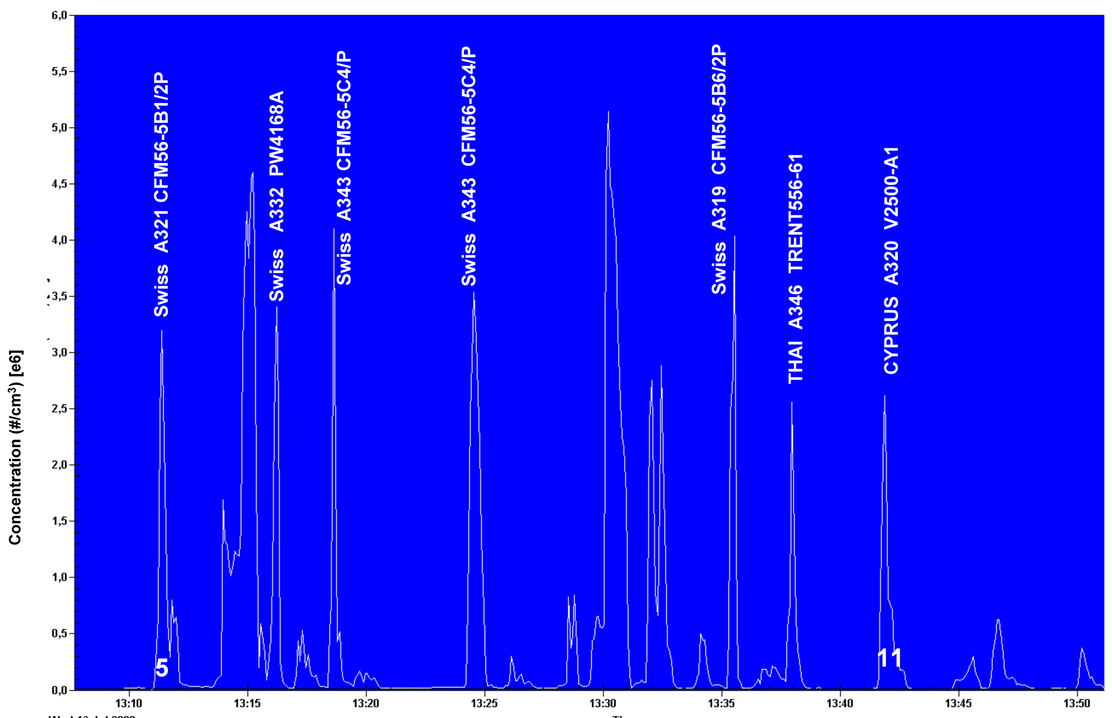
Emission Index EI = mg pollutant / kg burned fuel



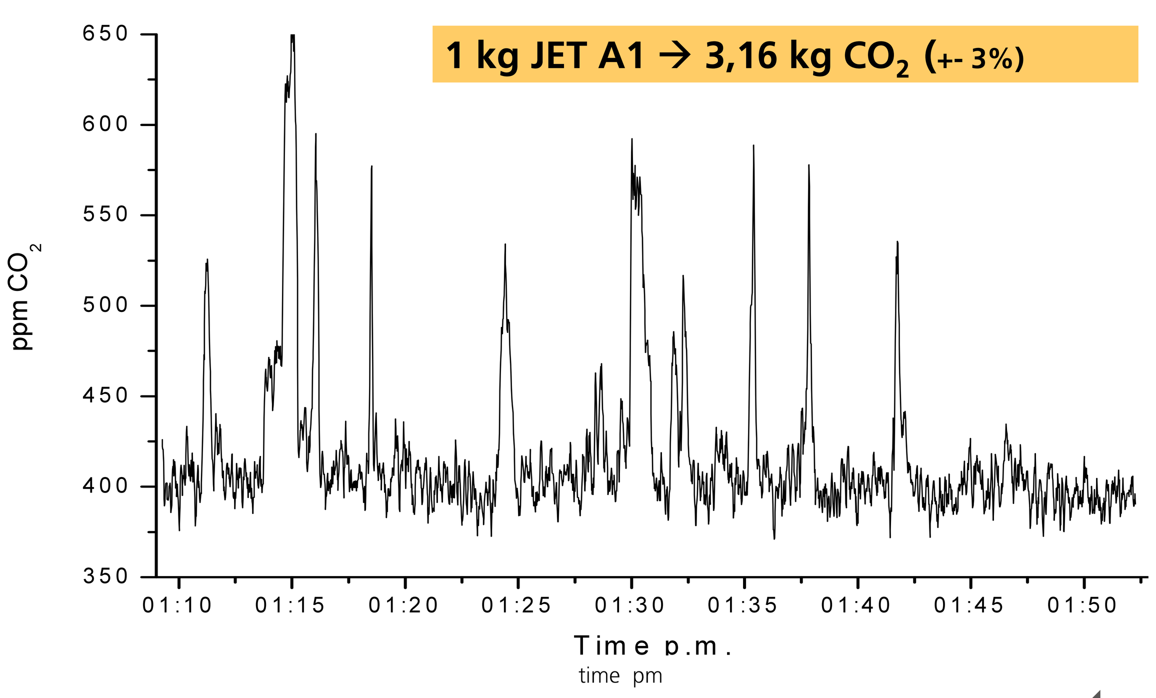


Online EEPS Particle Measurement





Online CO_2 Measurement



Aircraft		measured values	Engine	EI PM	EI#
HB-xxx SWISS **A321**		# = 3,18e6/ cm³ mass = 11,5 µg / m³ d = 13,5 nm CO_2 = 120 ppm	**CFM56-5B1/2P** DAC	**EI PM = 154mg**	**EI# = 4,3e16**
HB-xxx SWISS **A332**		# = 3,41e6/ cm³ mass = 6,3 µg / m³ d = 9,8 nm CO_2 = 193 ppm	**PW4168A**	**EI PM = 53 mg**	**EI# = 2,84e16**
HB-xxx SWISS **A343**		# = 4,10 e6/ cm³ mass = 8,7 µg / m³ d = 11 nm CO_2 = 176 ppm	**CFM56-5C4/P**	**EI PM = 79 mg**	**EI# = 3,7e16**
HB-xxx SWISS **A343**		# = 3,53 e6/ cm³ mass = 10,3 µg / m³ d = 12,3 nm CO_2 = 145 ppm	**CFM56-5C4/P**	**EI PM = 114 mg**	**EI# = 3,9e16**
HB-xxx SWISS **A319**		# = 4,04 e6/ cm³ mass = 12,5 µg/ m³ d = 12,4 nm CO_2 = 191 ppm	**CFM56-5B6/2P** DAC	**EI PM = 105 mg**	**EI# = 3,4e16**
HS-xxx THAI **A346**		# = 2,56 e6/ cm³ mass = 9,6 µg/m³ d = 10,6 nm CO_2 = 182 ppm	**TRENT 556-61**	**EI PM = 85 mg**	**EI# = 2,3e16**
5B-xxx Cyprus **A320**		# = 2,62 e6/ cm³ mass = 10,1 µg/ m³ d = 11 nm CO_2 = 141 ppm	**V2500-A1**	**EI PM = 115 mg** EI's +/- 20%	**EI# = 3,0 e16**

Highest measured values:

Aircraft	Engine	EI PM	EI#
UR-xxx Ukraine International B737- 500	**CFM56-3C-1**	**EI PM = 165 mg**	**EI# = 4,7 e16**
D-xxxx STAR ALLIANCE Fokker 100	**TAY MK650-15**	**EI PM = 214 mg**	**EI# = 3,1 e16**

Outlook:
- **CO_2 measurements will be improved (5,11m FT-IR instead of 10 cm ND-IR)**
- **distinction between volatile and nonvolatile particles**
- **next measurements planned in July 2009**

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Dr. Claus Wahl
Institute of Combustion Technology
Pfaffenwaldring 38 – 40
D – 70569 Stuttgart
Claus.wahl@dlr.de

Theo Rindlisbacher
FOCA Federal Office for Civil Aviation
Mühlestrasse 2
CH- 3003 Bern / Ittingen
Theo.Rindlisbacher@bazl.admin.ch

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