ACI EUROPE
AIRPORTS COUNCIL INTERNATIONAL

Ultrafine Particles at Airports

Discussion and assessment of ultrafine particles (UFP)
in aviation and at airports in 2012

ACI EUROPE Environmental Strategy Committee
Autumn 2012

The data in this publication is a result of a coordinated effort by the airports represented in the Environmental Strategy Committee of ACI EUROPE (Airports Council International). ACI EUROPE would like to thank all the airports involved in this study for their time and dedication, in particular Zurich Airport's Environmental Department which contributed significantly to the execution and completion of the study.

About ACI EUROPE

ACI EUROPE, the voice of Europe's airports, is the European region of Airports Council International, the only worldwide professional association of airport operators. ACI EUROPE represents over 400 airports in 46 European countries. Member airports handle 90% of commercial air traffic in Europe, welcoming nearly 1.5 billion passengers each year.

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Management Summary

Studies and subsequent conclusions in 2010 at Copenhagen airport in Denmark have raised concerns about health related impacts from ultrafine particles from airport activities. As ultrafine particles are currently not regulated in terms of emissions or concentrations, the overall understanding and coverage of the topic deserves additional efforts to gain a better understanding. The Environmental Strategy Committee of ACI EUROPE has taken the initiative to further investigate the topic of ultrafine particles at airports. To this end, this report first introduces the scientific aspect of ultrafine particles (nature, origin, health effects and current regulations).

Current air quality activities at airports covers all aviation related sources with emissions, concentration measurements and modelling as well as mitigation planning for regulated criteria air pollutants (e.g. NOx/NO_2, HC, PM). However, first studies for ultrafine particles in aviation were carried out in 2000 for aircraft engines, later also to include some airport related measurements.

Several airports, many of which are in Europe have recently addressed the topic of ultrafine particles, either in the light of initiatives at Copenhagen Airport or independent from it. Some of the studies are presented in this report while other programs are still on-going and will be published later.

Some of key findings of the studies are as follows:

- Ultrafine particle (UFP) concentrations in terms of average (and median) tend to be relatively high at airports (30,000-100,000), but a very high variability in number concentrations and particle sizes has been observed
- It seems that UFP from aircraft turbines on average tend to be smaller in size (10-16 nm) than from standard diesel/gasoline combustion engines (10-300 nm) but higher in numbers; as such, a source discrimination appears to be possible; aircraft turbine particle emissions also correlate with the sensory cognition of the typical aircraft exhaust smell
- The measurement setup (equipment, location) has a very significant impact on the results

In conclusion, any single measurement campaign is insufficient to properly describe the average UFP concentrations at an airport. Instead, only multiple long-term measurement campaigns at airports (e.g. like at Copenhagen) would be sufficiently robust to provide a clearer picture of UFPs' behaviour.

As a further conclusion, it can be stated that the current understanding of average, long-term concentrations of ultrafine particle at airports, particular in terms of dose exposure and human response is insufficient to conclude any dose-effect relationships. This also includes the question of linearity between particle number concentrations and possible human effects as well as the effects of various particle properties (e.g. surface properties).

Many activities are emitting ultrafine particles and people in their environment are subject to the resulting concentrations. The following figure displays some activities and/or measurement locations with UFP number concentrations with information on measurement duration or frequency. As can be seen, the concentrations measured at airports are comparable to those measured from other activities and there are no significant higher results from airport locations.

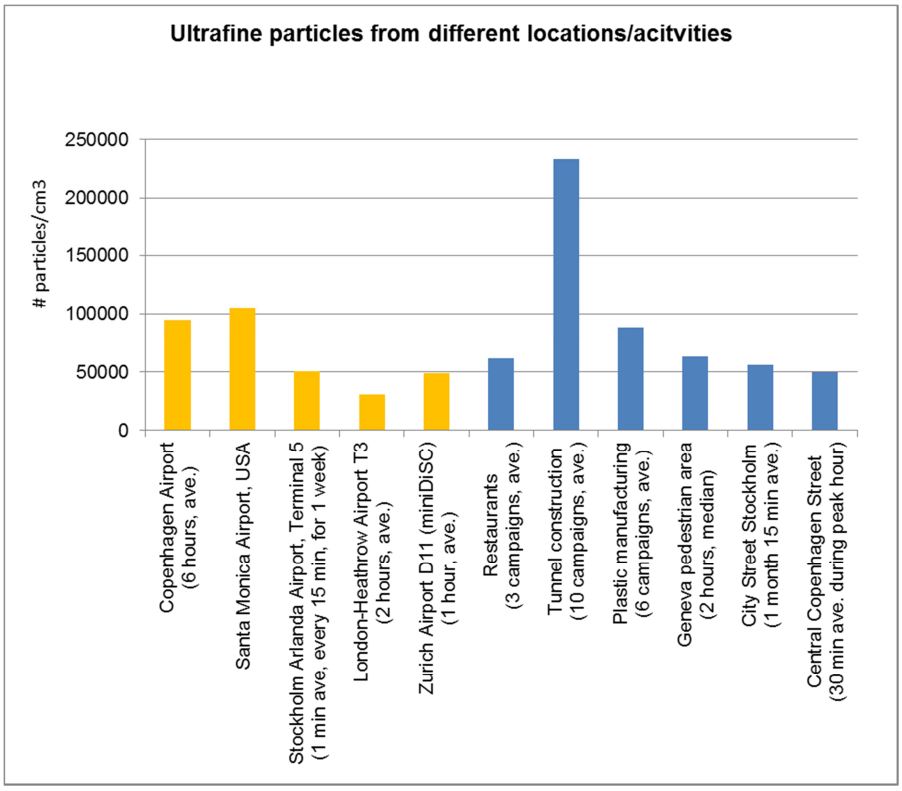


Fig 1: UFP emissions from various locations/activities

Experience from the various measurement campaigns has demonstrated the need for a very careful planning and execution of ultrafine particle concentration measurements. The range of the obtained results has further revealed that many effects contribute to the outcome of measurements: meteorological conditions or choice and location of the monitoring equipment. To this end, multiple measurement campaigns over longer periods of time and with multiple devices simultaneously are strongly recommended.

In the context of the discussion around ultrafine particles from aviation, the topic of regulations or definition of standards has been raised. Currently, there are no regulations pertaining to ultrafine particles. The main requirements for any standard setting process are:

1. Parameters to be regulated: For ultrafine particles, the question will be which parameters should be used, e.g. the mass weight, particle numbers, particle surface, physical-chemical properties of the surface (volatile or non-volatile) or the formation of reactive oxygen species
2. Standardization of measurement: Harmonization of measurement guidelines and standardization of measurement equipment (methods and technologies)
3. Standard-setting: Relevant for establishing standards are known dose-effect relationships, if possible on the basis of epidemiological and experimental studies. This requires both longer-term measurements and health impact studies
4. Applicability: Any new standards have to be applicable over the whole range of the relevant emission sources from all activities (transportation, manufacturing, etc)

There are three domains within which standards could be defined: emissions, ambient concentrations or workplace concentrations. For each domain, different regulatory entities may be responsible and different – already existing – tools and regulations can be used to potentially add text and standards for ultrafine particles. In the first place, usually the concentrations are being regulated as they are impact relevant. Subsequently and if needed, then emission standards for certain sources are developed and implemented.

1 Introduction

1.1 Background

Studies and subsequent conclusions in 2010 at Copenhagen airport in Denmark have raised concerns about health related impacts from ultrafine particles from airport activities. While the studies left ample room for further discussions with regard to the obtained results, it drew attention to a field of environmental and/or health impact that had not yet been explored intensively. Ultrafine particles are currently not regulated in terms of emissions or concentrations. As such, the overall understanding and coverage of the topic is still fairly low which justifies additional efforts to gain a better understanding.

1.2 ACI EUROPE Initiative

The Environmental Strategy Committee of ACI EUROPE has taken the initiative to further investigate the topic of ultrafine particles at airports. It has been acknowledged that any health related issues from emissions are more subject to the occupational health and safety (OHS) considerations than the environmental initiatives. However, in the light of the little information currently available and the lack of legal framework, it has been concluded that the environmental services are suited to accommodate the topic for the time being. This is also to explore if there is an environmental impact from UFPs that affects the communities surrounding airports in the overall discussion of particle emissions and concentrations in the ambient air.

1.3 About this report

This report aims to discuss the current knowledge on ultrafine aerosols in aviation and specifically at airports. It is acknowledged that this is a scoping study only and there may well be more information available which is not included or referenced in this study.

The study comprises the following sections:

- Section 1, this section, introduces the topic
- Section 2 of the study discusses the scientific aspects of ultrafine particles
- Section 3 describes past and current initiatives and studies in the field of ultrafine particles in aviation, mainly aircraft engine emissions
- Section 4 turns towards airports and describes the emission sources and their operations at airports in general before highlighting specific airport studies that deal specifically with ultrafine particle emissions or their assessment
- Section 5 looks beyond the aviation field towards other industries or geographical locations and ultrafine particle assessments
- Section 6 draws conclusions from the studies and evaluates the state of the knowledge
- Section 7 assesses existing measurement devices and guidelines and comes up with recommendations on how to potentially measure ultrafine particles at airports
- Section 8 discusses the regulatory framework on ultrafine aerosols
- Section 9 finally contains the annex with abbreviations and references

2 Scientific framework of ultrafine particles

2.1 General clarification

Commonly, the topic under discussion is called ultrafine particles, UFP. However, this term requires a more precise clarification and the general distinction between nano particles and ultrafine particles:

- Nano particles are deliberately produced particles and tubes with a diameter <100nm
- Ultrafine particles are solid particles and aerosols with a diameter <100nm (and their agglomerates) that are of natural origin (volcanos, sea) and from anthropogenic emissions (engine exhaust, welding, hot processes in general).[1] In this report, only ultrafine particles are discussed.

2.2 Nature of ultrafine particles

As stated above, ultrafine particles (UFP) are generally less than 100 nanometers (nm) in diameter and can be referred to as $PM_{0.1}$. They are very small and are invisible to the naked eye.

In a typical sample of air, UFP have negligible mass and so make up a very small proportion of measured PM_{10} and $PM_{2.5}$ concentrations. However, they may be important in causing health impacts, either due to their large surface area or due to their chemical makeup - UFPs can either be carbon-based or metallic, and then can be further subdivided by their magnetic properties.

UFP can not be detected by traditional techniques that rely on measuring mass. Instead, they are measured in terms of particle number which is typically determined per cubic centimetres (cm^3) of air. A number of different measurement techniques are outlined in chapter 9.

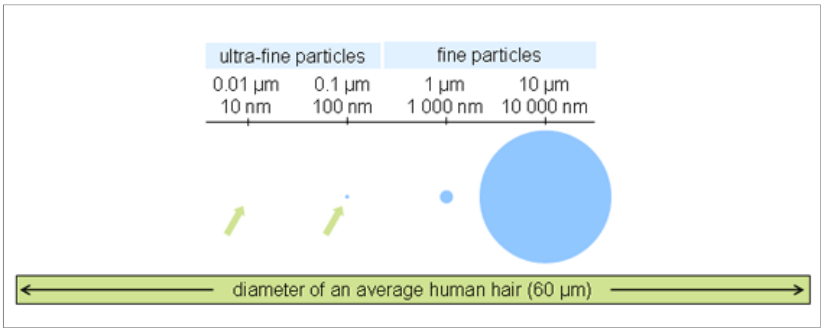


Fig 2: Representation of the diameter of ultrafine particles

2.3 Origin of ultrafine particles

Although airborne particles originate from many natural and anthropogenic sources (which include sand, dust, fires, vehicles, boilers and sea salt), UFP are normally only generated at very high temperatures, such as combustion processes - wood fires, industrial processes, vehicle engines, cooking fumes, and cigarette smoke are all common sources; as are the toner (carbon black) from copiers, laser printers and welding-fumes . The diagram below shows a number of particle types from well-known sources.

[1] SUVA*pro*: http://www.suva.ch/nano_1_d.pdf (July 2012)

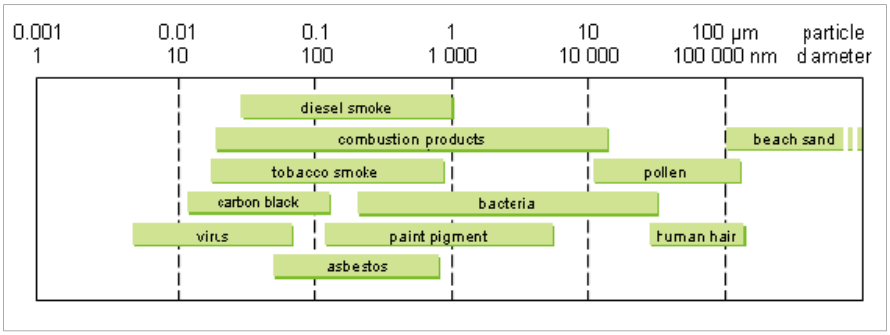


Fig 3: Range of particle sizes from well known sources

2.4 Health effects of ultrafine particles

In the field of environmental toxicology, there are four concurrent conditions necessary for something to be toxic or cancer-causing (carcinogenic):

1. Contaminant is present in the air: e.g. UFP from natural or human sources (e.g. volcanic activity or fuel combustion at high temperatures)
2. Pathway or exposure: inhalation
3. Dose: concentration x time
4. Response: effect on the body

In the case of airports and other outdoor locations, we certainly have 1. and 2. At this time, however, the dose and any response by the body is unknown due to the lack of clinic studies.

The small number of ambient monitors for UFP means that very few epidemiological studies have been carried out. In the work that has been done, studies with German and Finnish asthma patients, show exacerbation of symptoms had a stronger association with daily fluctuations of UFP than with larger particle fractions. One study on daily mortality in Germany showed fine and ultrafine particles had comparable effects; fine particles had more immediate effects but those of ultrafine particles were delayed for a few days. The immediate effects were clearer in respiratory cases, whereas delayed effects were clearer in cardiovascular cases (Wichmann and Peters, 2000).

Other studies show that particles (including UFP) which contain carbon black, nickel or cobalt can produce inflammation in the lung. In addition, UFP can pass through lung tissue and enter the blood stream where they can affect other tissues and organs.

Statistical evidence has been found that shows acute negative health effects are related to increased levels of airborne particles. These effects can include:

- Increased use of asthma medication
- Asthma attacks in patients having asthma
- COPD (chronic obstructive pulmonary disease) attacks
- Hospital admissions for cardiovascular diseases
- Deaths from heart attacks, strokes and respiratory problems

Evidence indicates that particles (including UFPs) emitted during combustion, although predominantly carbon-based, may also contain trace metals or organic compounds that may be responsible for the harmful effects once inhaled.

The human body is equipped with mechanisms to prevent coarse particles from entering the lungs – they are largely trapped in the nose and throat. The body is also able to ‘clean’ many smaller particles from the lungs that do pass through in to the lungs.

Due to their microscopic size, UFP can be penetrate deep into the lungs and be deposited in the alveoli; where gas exchange takes place. Evidence indicates UFP can pass through the lung tissue into the blood stream where it is transported to other organs and tissues in the body.

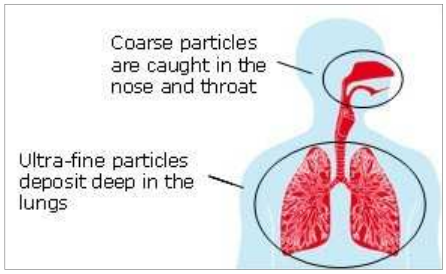


Fig 4: Areas of the respiratory system affected by particles

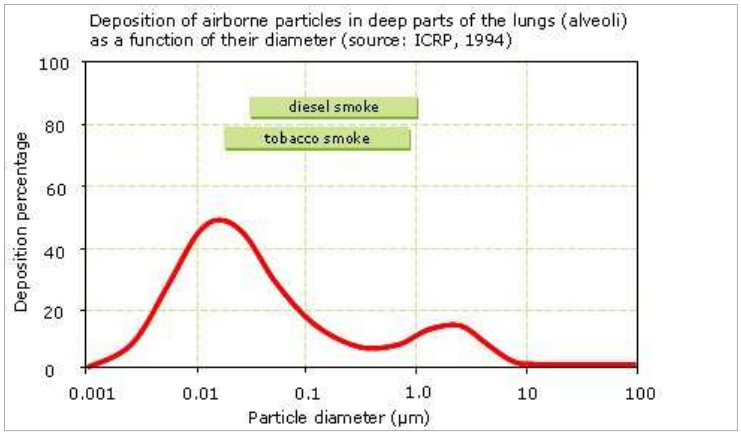


Fig 5: Deposition of airborne particles in the alveoli as a function of their diameter

Note, in common with larger particle fractions (e.g. $PM_{2.5}$ and PM_{10}) there is no threshold concentration below which no negative health effects occur.

2.5 How ultrafine particles are regulated

There is no standardised way of measuring ultrafine particles (UFPs) at the moment; as such, no air quality or occupational exposure limits are defined. However, scientific discussions are on-going on the formation of a standard. Nevertheless, it is possible to give some typical concentrations in a number of locations.

Location and source	**Typical particle number (particles/cm^3)**
Clean air in the Alps	< 1,000
Clean office air	2,000 – 4,000
Outside air in urban area	10,000 – 20,000
Polluted outside air (smog)	> 50,000
Cigarette smoke	> 50,000
Workplaces (e.g. welding)	100,000 – 1,000,000

Fig 6: Range of particle number concentrations typically observed in ‘clean’ and ‘polluted’ air

3 Airport air quality management

Airport air quality management is mainly driven by the necessity to comply with legislation. Therefore, airport operators subject to air quality regulations have come up with a complex framework aimed at understanding emission sources and the various factors that influence these emissions. In this context, it is worth noting that UFPs are not regulated.

3.1 Emission sources

The emission sources at airports are listed and described in ICAO Doc 9889[2]. They are usually grouped in four categories of which three are of special interest for airport operations. These three sources and associated activities are listed in the table below.

Not all listed emission sources are emitting ultrafine particles (e.g. fuel related activities).

Table 1: Airport emission sources and activities (*no UFP emissions)

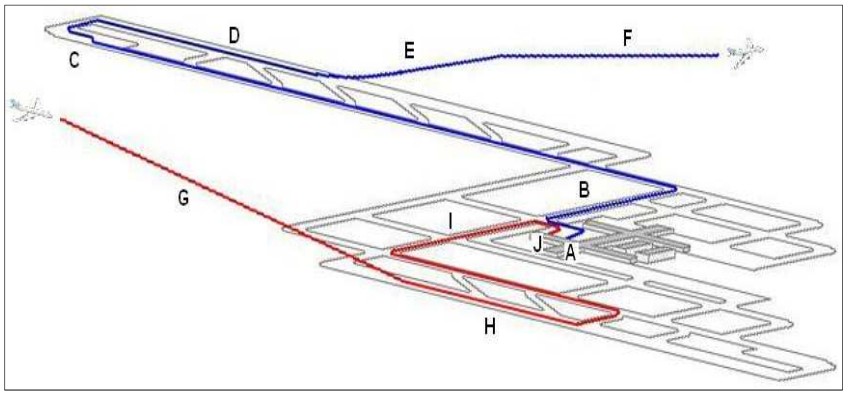
1. Aircraft	
Aircraft main engines	Emission during the landing and take-off cycle with approach, landing roll, taxi-in, taxi-out, take-off, initial climb and final climb
Aircraft APU	Auxiliary power unit for production of electricity, pre-conditioned air and bleed-air (for main engine start)
Brake and tire wear	Abrasion of brakes and tyres during landing and taxiing
2. Handling	
GSE	Ground support equipment for the service of the aircraft (e.g. tugs, GPU, stairs, belt loaders, high-loaders, etc)
Service vehicles	Vehicles servicing aircraft but also circulating on the airside road system (e.g. catering trucks, fuelling trucks, passenger busses, line maintenance, baggage and cargo tractors)
Aircraft re-fuelling*	Evaporation through aircraft fuel tanks (vents) or from related systems
De-icing*	Aircraft de-icing with ADF
3. Infrastructure	
Energy production	Power plants, furnaces, etc to produce heat (and cold) for airport infrastructure
Emergency generators	Combustion engines to produce emergency energy
Aircraft maintenance	Aircraft service facilities, including engine run-ups
Airfield maintenance	Maintenance of green areas (lawn mowers) or hard surfaces (sweeper trucks) and surface de-icing
Fuel*	Storage, distribution and handling of fuel in fuel farms
Construction	Civil engineering or infrastructure construction activities
Fire training	Aircraft fire fighting and rescue training

[2] ICAO Doc 9889: Airport Air Quality Manual, 1st edition, 2011

3.2 Operations

3.2.1 Aircraft operations

Aircraft operation at and in the vicinity of airports are described within the LTO-cycle (landing and take-off). This cycle is vertically limited by the planetary boundary layer. However, for simplification, this is generally set at a fixed elevation of 3,000 feet above ground. The cycle consists of several segments[3].



Nr	LTO segment description (begin/end)	Thrust	Duration
A	Start-up: starts at pre-ignition, ignition, start-up to established idle, ends with all engines established; usually done during push back or on stand	Idle	operational
B	Taxi-out: starts with taxi clearance; taxi out via specified routing, includes stop-and-go, ends close to departing runways	Idle/taxi	Operational
C	Queuing: starts with aircraft waiting to enter runway or on runway waiting for take-off clearance	Idle	Operational
D	Take-off: Acceleration from break-away until lift-off of aircraft	Take-off	Operational
E	Initial climb: starts with lift-off and ends with main power cut back (approx. 1500 ft, according to flight profile)	Take-off	Operational
F	Final climb: starts with engine cut back and ends at 3,000 ft AGL	Climb	Operational
G	Approach: starts at 3,000ft AGL and ends with touch-down on runway	Approach	Operational
H	Roll-out: starts with touch-down and ends with exiting the runway, can include the use of thrust reversers (at idle or more)	Idle (or more)	Operational
I	Taxi-in: starts with exiting the runway and ends with arriving at the parking stand via the specified routing	Taxi	Operational
J	Parking: starts with stopping at the parking position and ends with the engine shut down.	Idle	Operational

Fig 7: ICAO advanced LTO-cycle

3.2.2 Aircraft handling

The handling of aircraft is of special interest in the current discussion. This process usually begins with the preparation of the aircraft stand for the arriving aircraft and it ends with the release of the stand after the aircraft has departed.

During the ground handling operations, a relevant number of ground service equipment is in operation around the aircraft. They may either remain on the aircraft stand or could move away after completing their service. Many of the machines or vehicles are equipped with a combustion engine, fuelled by diesel, gasoline or CNG (or even LPG); some may now be electric.

[3] ICAO Doc 9889: Airport Air Quality Manual, 1st edition, 2011

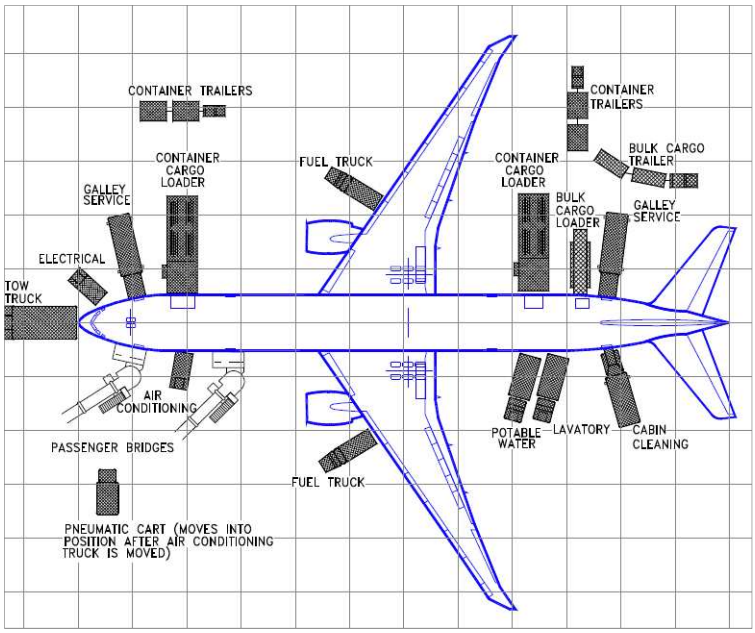


Fig 8: Typical handling layout of a B-777ER on a terminal stand[4]

3.3 Current air quality assessments at airports

Traditionally, the local air quality at airports has focused on substances regulated by legislation, generally both in terms of emission limits or concentrations standards. Specifically, only little work has been conducted in relation to work-place concentrations of gaseous substances. Of this work, again only few included particles or even ultrafine particles.

Most of the air quality assessments at airports include the following:

- Emission inventory compilation of substances like NOx, HC, CO, CO_2, PM, using current state-of-the-art emission models with agreed methodologies and emission factors. In the case of PM, only total PM is calculated as mass per time unit.
- Dispersion modeling of those substances, but mainly NO_2 (from the NOx), again with the available dispersion models (Gaussian or Lagrangian models). In the case of PM, often all emitted PM is treated as PM_{10}. However, some models use assumptions on a $PM_{2.5}$ fraction (of all PM emitted)
- Ambient concentration measurements of primary (NO/NO_2, SO_2, PM_{10}, $PM_{2.5}$) or secondary pollutants (O_3), often on a permanent basis and evaluation in respect to the applicable regulatory framework (e.g. annual mean mass values).

Studies related to more specific pollutant speciation and in relation to workplace exposure are in the domain of occupational health and safety rather than environment. Since there is very limited knowledge on the behaviour of UFP and there are sparse and scattered measurements of UFPs in ambient air quality this has to be addressed to determine if it is of environmental impact. Measurements at both Santa Monica and Copenhagen airports show that UFP can be measured over far longer distances than expected (this has to be investigated further).

[4] http://www.boeing.com/commercial/airports/acaps/777rsec5.pdf (July 2012)

4 Ultrafine particles in aviation

4.1 Aircraft related initiatives and studies

Starting in the early 2000, several studies and measurement campaigns have been commissioned on the topic of aircraft exhaust particles that also include the fraction of ultrafine particles. The following presents a selection of those studies only.

APEX studies (Unites States)
The fine particulate matter (PM) emissions from aircraft operations at large airports located in areas of the U. S. designated as non-attainment for the National Ambient Air Quality Standard (NAAQS) for PM-2.5 (particles <2.5 µm in aerodynamic diameter) are of major environmental concern. In general, the majority of the available PM emissions data for commercial aircraft engines is limited and does not completely characterize volatile components resulting from atmospheric cooling and dilution. To address the need for improved aircraft PM emissions data, the Aircraft Particle Emissions eXperiment (APEX) was organized in 2003[5]. The APEX program is a major collaborative effort between the National Aeronautics and Space Administration (NASA) and a number of other research organizations including the U.S. Environmental Protection Agency's (EPA's) National Risk Management Research Laboratory (NRMRL) in Research Triangle Park, North Carolina.

The objectives of the three APEX sampling campaigns (APEX-1, -2, and -3) were to update and improve emission factors (indices) and chemical source profiles for aircraft-generated fine PM and, if possible, to assess the effect of fuel properties (e.g., sulfur content) and engine operating conditions (e.g., cold vs. warm) on PM formation.

During APEX-1, -2 and -3, ground level measurements were conducted by EPA in the engine exhaust plume, primarily at a single point located a distance of 30 m behind the engine exit. There was a total of 24 tests conducted during the three APEX campaigns. A CFM56-2C1 engine mounted on a DC-8 airframe was used throughout the nine APEX-1 tests to investigate the effects of fuel composition on emissions at various power settings. Three types of fuel were used: a base fuel (JP-8 or Jet-A1), a high-sulfur fuel (JP-8 doped with approximately four times the sulfur content of the base fuel), and a higher-aromatic JP-8. During APEX-2 and -3, each engine was run with the available Jet-A fleet fuel it would use during normal commercial operations. The same engine family used during APEX-1, the CFM56 mounted on B737 airframes, was also included in all four APEX-2 tests and two of the eleven APEX-3 tests. These tests provided further characterization of the fine particulate emissions from these widely-used jet engines. Five additional turbine engines of various sizes were also studied in APEX-3. These additional turbine engines included a General Electric CJ610-8ATJ turbojet (in use on a Lear Model 25), Rolls Royce AE3007A1E and AE3007A1P mixed turbofans (in use on the Embraer ERJ145), a Pratt and Whitney PW4158 turbofan (in use on the Airbus A300), and a Rolls Royce RB211-535E4-B mixed turbofan (in use on the B757).

A typical measurement result is shown in the next figure for the CFM56-2C1 engine.

[5] US EPA: APEX, October 2009

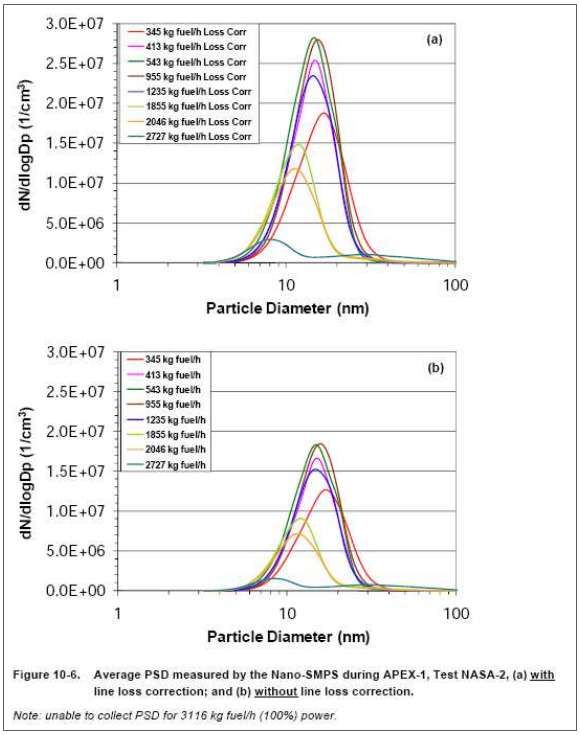


Fig 9: Typical results of particle number/size distribution during APEX 1

Based on the experimental data collected, the following conclusions were reached for ultrafine particles:

- The particle size distributions of the emissions found in the study were generally unimodal and lognormally distributed with electrical mobility diameters ranging from ~3 to slightly larger than 100 nm. At higher power levels, a small accumulation mode was also observed.
- Both the geometric mean diameter (GMD) and geometric standard deviation (GSD) of the particle size distribution (PSD) also varied with engine and fuel type, thrust, and environmental conditions. The GMD ranged from approximately 10 to 30 nm (electrical mobility diameter) and the GSD ranged from 1.4 to 2.
- In general, the largest GMDs and GSDs were obtained at high power conditions. The observations suggest that the PSDs produced by the engines tested under power conditions of <30% rated thrust were unimodal and consisted of primary nuclei particles, whereas for thrust levels >85%, accumulation mode particles were formed, and the PSD curves became broader.
- A comparison of measurement techniques for PM mass, number, and size indicated significant discrepancies between instruments. Of particular note is a comparison of the EIM obtained by the Nano-Scanning Mobility Particle Sizer (SMPS) and the time-integrated Teflon filter sampling. The filter-based method always produced higher values than the SMPS-based method and there was no linear correlation between the two techniques.
- Of the various instruments used to measure PM mass, number, and size, the SMPS appears to be the most reliable. The lack of correlation with the filter-based technique is disturbing, however, and an area worthy of further investigation.

SAMPLE

SAMPLE is the project on the “Study on Sampling and Measurement of Aircraft Particulate Emissions”[6]. Methods for measuring particle mass concentration and composition, particle number concen-

[6] EASA: Study on sampling and measurement of aircraft particulate emissions. EASA.2008.OP.13, October 2009

tration and particle size distribution were tested and evaluated under real conditions with respect to their applicability for aircraft engine exhaust certification applications.
The work performed in SAMPLE used the Combustor – Hot End Simulator (HES) test rig at Cardiff University, UK, which was initially developed during the European FP5 programme PARTEMIS. This test rig served as a stable aircraft engine simulator providing particles of physical-chemical properties similar to real aircraft engines.
The Combustor - HES operation conditions were designed such that the physico-chemical properties of the generated combustion particle cover the widest possible range from low smoke emissions associated with high organic matter emissions to high smoke emissions associated with low organic matter emissions. The operation conditions chosen for the SAMPLE runs do not refer to any real engine ICAO LTO cycle operational conditions.

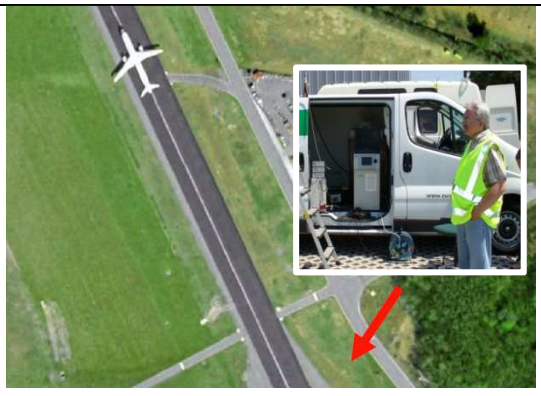
Key results on conclusions on number-based assessment methods:

- Condensation Particle Counter (CPC) based instruments are highly robust tools for the measurement of particle number concentrations. Dilution of sample gas prior to the measurement is required.
- The definition of a standard method requires an agreement on the 50% detection efficiency diameter of the applied instrument. Measured non-volatile particle size distributions indicate a bi-modal size distribution with the smaller mode centred at 15 – 16 nm. Modelling results for the hot sample line indicate a volatile particle mode below 10 nm in diameter. From these results, a 50% detection efficiency diameter of 10 nm appears appropriate.
- Indirect methods for the measurement of particle number concentrations, such as Differential Mobility Spectrometry, should not be considered as a standard methodology since they show a larger scatter of data than direct methods like condensation particle counters.
- Differential Mobility Spectrometry appears to be a well reproducible method for measuring particle size distributions in aircraft engine exhaust.

The study has been continued into SAMPLE II with more in-depth analysis of the measurement techniques in 2009.

Swiss FOCA

The Swiss Federal Office for Civil Aviation, together with DLR conducted particle measurements at Zurich airport in 2008. Aircraft exhaust emissions were measured when taxiing to runway 16 at a source distance of approximately 70m. The results are presented for 11 aircraft engine combinations and provide emission indices (EI) in particle # /kg fuel as well as the particle size diameter.



Results for particle mass and particle number EI's determined from exhaust plume during aircraft taxi (~ 4% power setting)

Number	Reg	Type	Engine	Measured Taxi EI_PM_mass (mg/kg)	Measured Taxi EI_PM_number (#/kg)	Geometric mean diameter (nm)
1	-	BA46	ALF 507	161	$1.48 * 10^{16}$	9.4
2	-	B735	CFM56-3C-1	165	$4.70 * 10^{16}$	11.6
3	-	F100	MK650-15	214	$3.06 * 10^{16}$	11.5
4	-	A320	CFM56-5B4/2	146	$3.11 * 10^{16}$	13
5	-	A321	CFM56-5B1/2P	154	$4.30 * 10^{16}$	13.5
6	-	A332	PW4168A	53	$2.84 * 10^{16}$	9.8
7	-	A343	CFM56-5C4/P	79	$3.70 * 10^{16}$	11
8	-	A343	CFM56-5C4/P	114	$3.90 * 10^{16}$	12.3
9	-	A319	CFM56-5B6/2P	105	$3.40 * 10^{16}$	12.4
10	-	A346	TRENT 556-61	85	$2.30 * 10^{16}$	10.8
11	-	A320	V2500-A1	115	$3.00 * 10^{16}$	11

Fig 10: FOCA measurement results at Zurich airport 2008

4.2 Airport related initiatives and studies

Several airports, many of which are in Europe have recently addressed the topic of ultrafine particles, either in the light of initiatives at Copenhagen Airport or independent from it. Some of the studies are presented below. The first part of the measurements of elemental carbon (EC) as a marker for the diesel exhaust particulate matter have been carried out at the Oslo Airport (OSL), the busiest airport in Norway. The results from OSL and other airport studies will be published at a later stage.

Measurements (over shorter or longer duration) have been done at airports in the USA as well. However, not all data has been analysed or reviewed to be included in this study.

4.2.1 Copenhagen Airport, Denmark

Following measurements of PAH at the apron at the Leonardo Da Vinci Airport in Rome (Cavallo et al., 2006), a thorough survey of air pollution relating to working in the environment of Copenhagen Airport was started in 2009. Under certain meteorological conditions air pollution was observed to be spread outside the airport boundary which led to the development of greater cooperation between environmental and worker health departments.
The Copenhagen survey was carried out during the period 2009 to 2011 by DCE - Danish Centre for Environment and Energy, Aarhus University (DCE) for Copenhagen Airports A/S - and is published as a scientific report: Assessment of the air quality on the apron of Copenhagen Airport Kastrup in relation to working environment (Ellermann et al. 2011). The aim of the survey was to map air pollution at the apron and to determine the principal emission sources. The survey included air pollutants suspected to impact the health of workers on the apron. These were:
Nitrogen oxides (NO and NO_2), sulphur dioxide (SO_2), the mass of particles with diameter below 2.5 µm ($PM_{2.5}$), particle number and their size distribution, particulate elemental carbon (soot), polycyclic aromatic hydrocarbons (PAH) and selected volatile organic compounds (VOC).

The survey was based on a combination of measurements, compilation of an emission inventory and model calculations. The main elements were:

- Measurement of nitrogen oxides and $PM_{2,5}$ at the apron close to Gate B4 (Station B4). Measurements of these compounds on the outskirts of Copenhagen Airport (Station East and West) are also included in the study. These measurements were performed by DCE for Copenhagen Airports A/S in connection with the air quality monitoring at Copenhagen Airport.
- Measurements of particle number (6 – 700 nm in diameter) and particle size at Gate B4 and at the two stations on the outskirts of the airport (Station East and West). Ultrafine particles (diameter below 100 nm) accounted typically for 75-95% of the particle number with diameter between 6 and 700 nm (measurements 24/7 on the apron (Gate B4) from August 2010 to May 2011).
- Measuring campaign with the measurement of the spatial distribution of air pollution at the apron.
- Measuring campaign with the measurement of PAH, selected VOC, particulate organic carbon and elemental carbon (soot).
- Measuring campaign with the measurement of sulphur dioxide at Gate B4.
- Compilation of an emission inventory on the sources at the airport. The inventory includes emissions of nitrogen oxides, $PM_{2.5}$, VOC, carbon monoxide (CO) and total fuel consumption (jet fuel, diesel, etc.).

- Model calculations that include NOx and $PM_{2.5}$. Model calculations for the apron itself are performed with a spatial resolution of 5 m x 5 m in order to best address the location of sources relative to the working areas and the buildings impact on the dispersion of air pollution.

The study has led to the following main conclusions:

- The concentrations of nitrogen oxides and sulphur dioxide on the apron were compared with levels measured on H.C. Andersens Boulevard (HCAB), one of the busiest streets in Copenhagen (approximately 60,000 vehicles per day). Concentrations measured on the airport were below those on HCAB and were also below the EU air quality limit values for these two compounds.
- Measurements of VOC include substances that are partly found in the background air and partly expected to come from sources at the apron (vehicles and aircraft); and which can cause adverse health effects. The concentrations of VOC were at a similar level found as in urban background air in Copenhagen. N-octane and trimethyl benzene, which are related to jet fuel, were 2 to 6 times higher than levels measured at urban background sites. Apart from benzene, no other VOCs were measured at HCAB, and can therefore not be compared with the levels at a busy street. Concentrations of benzene were lower on the apron and also met the EU limit value there.
- Measurements also included aldehydes, which can cause irritation of eyes, nose and throat and can originate from burning of jet fuel. The average concentrations (8 hour mean values) of aldehydes at the apron are significantly below the levels expected to give irritation[7].
- The study included a number of aspects on particle pollution in the airport. The results show that the particle number (6 – 700 nm) was about two to three times higher at the apron compared to HCAB (32,000⇔16,000 and 39,000⇔13,000 particles/cm^3 - Mean levels for two ½ year periods, measured with equal equipment (see inserted table 3.3 below) and 85-90% of the particle number consisted of particles with a diameter between 6 – 40nm. This particle fraction accounted for the difference between the particle number at the apron and HCAB. The ultrafine particles originated from the combustion of jet fuel and diesel at the apron. At the outskirts of the airport, the particle number is about 20 – 40 % lower than at HCAB.
- The larger particles with diameters up to 2.5 µm are measured by their mass and called $PM_{2.5}$. The $PM_{2.5}$ level at the apron is approximately equivalent to HCAB while the $PM_{2.5}$ level at Station East and West lies between the levels measured at HCAB and as the urban background in Copenhagen. These particles originate mainly from sources outside the airport.
- The content of PAH in the particles at the apron was about one third or less compared to concentrations measured at HCAB. The PAH levels were also below the levels measured at the apron at the Leonardo Da Vinci Airport in Rome (Cavallo et al., 2006). The EU has set a limit value for air quality of benzo[a]pyrene, which is considered as representative for the carcinogenic PAH. Measurements at the apron showed that the limit value is not exceeded.
- Measurements also included the amount of elemental carbon (EC, also known as soot) in the particles. The levels at the airport were slightly less than half of the level measured at HCAB. On the other hand, the amount of particulate organic carbon (OC) was at the same level as at HCAB, indicating that there must be a source of these substances on or near to the airport. This has not been studied in detail.

[7] Woodruff, T.J., 2007

Table 3.3. Average number of particles with diameter in the range 6 – 700 nm per cm^3 ambient air, including particles with diameter 6-40 nm, 40 – 109 nm and 109 – 700 nm. In addition, results from the urban busy street (HCAB), urban background (HCOE) of Copenhagen, and rural background (Lille Valby/Risoe) are shown for comparison. Measurements at HCAB, HCOE and Lille Valby/Risoe are from the Danish Air Quality Monitoring Program (Ellermann et al., 2011), and The *Particle project 2008-2011* supported by the Danish EPA, Miljøstyrelsen (Massling et al., 2011).

Particle number cm^{-3}	August – December 2010				January – June 2011			
	Total number	6-40 nm	40-109 nm	109-700 nm	Total number	6-40 nm	40-109 nm	109-700 nm
Station B4	31900	27900	3100	900	38600	32600	4600	1400
Station West					11000	7500	2500	1100
Station East	10000	7500	1800	700				
HCAB	16100	9900	4700	1600	13400	7800	4100	1400
HCOE	5500	2300	2200	1000	6500	2300	2800	1400
Lille Valby/Risoe	3700	1400	1500	900	4000	1200	1700	1000

Fig 11: Copenhagen measurements at various locations (2010/2011)

A geographically detailed emission inventory was compiled for nitrogen oxides (NO + NO_2), particulates ($PM_{2.5}$), volatile organic compounds and carbon monoxide (CO). The uncertainty of the inventory was relatively high due to the many hundreds of different air pollution sources at the apron. For nitrogen oxides and particulates, the greatest share of emissions originated from handling vehicles, followed by the aircraft's APU, aircraft main engines and the smallest proportion from the general traffic at the apron. For the volatile organic compounds and CO the emissions were dominated by contributions from aircraft main engines. Furthermore, the emission inventory indicates that up to half of the particle emissions from aircraft main engines were due to the high sulphur content of about 900 ppm in jet fuel. The combustion of sulphate-rich fuels leads to the formation of sulphur-containing ultrafine particles. Measurements of sulphur dioxide also indicate a linkage between sulphur and the large particle number.

Model calculations show higher concentrations of nitrogen oxides at the apron compared to the measurements. A detailed comparison between model results and measurements indicate that the most likely reason for this difference is the emissions inventory over estimates emissions at the apron. It was not possible to review the basic input data behind the emission inventory within the framework of this study. Instead, the model results were adjusted empirically on the basis of the measurements. In this way the model calculations could be used to determine the spatial distribution of pollution and the relative source contributions.

The calculations showed that nitrogen oxides (NO_x) at the apron originated primarily from background (44%) and handling (41%) with smaller contributions from the APU (7%), main engines (7%) and traffic at the apron (1%). $PM_{2.5}$ at the apron came primarily from background (91%) with smaller contributions from handling (5.5%), APU (3.4%), main engines (0.4%) and traffic at the apron (0.1%).It is expected that handling, APU and main engines are the major sources for particle number while the background plays a minor role. Measures taken to reduce the high particle number at the apron should include all major emission sources.

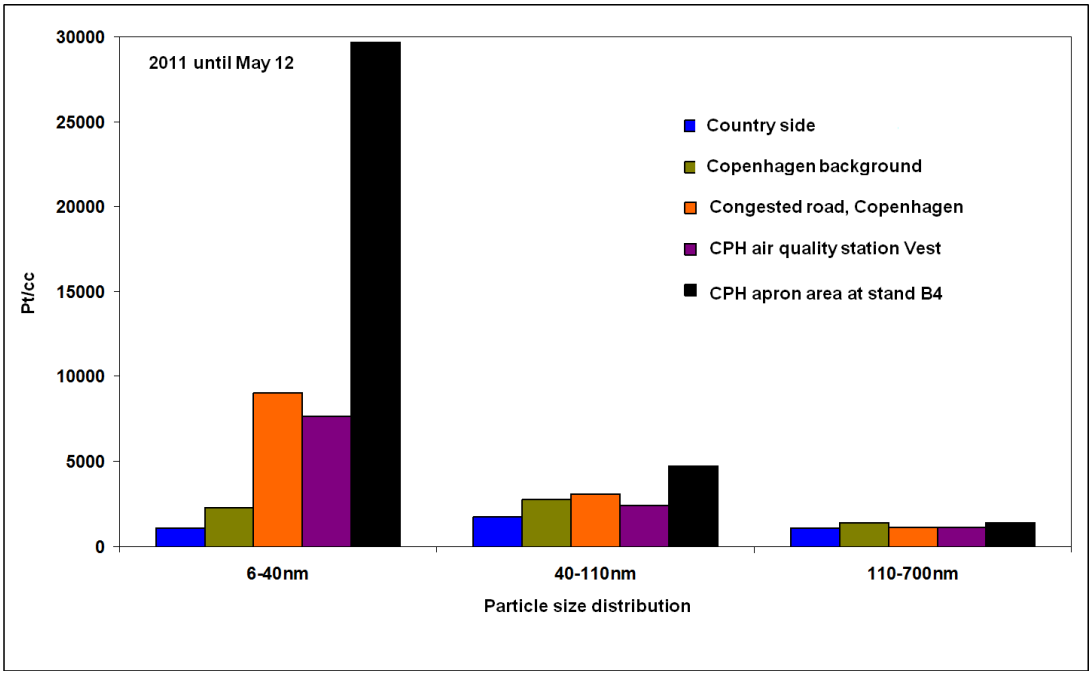


Fig 12: Particle size distribution (background, road and airport, Aug 2010 – May 2011):
Blue is background in country side, green is Copenhagen background, Orange HCAB (Congested road, Copenhagen) Purple is CPH air quality station Vest (near the sea) and black is CPH apron area at stand B4 (approximately in the middle of the airport apron).

In summary it can be concluded that for the majority of the investigated air pollutants (nitrogen oxides, $PM_{2.5}$, PAH, VOC, particulate organic and elemental carbon) the concentrations at the apron are below the levels measured at HCAB. Furthermore, at the apron there is no measured exceedance of the air quality limit values for those air pollutants where limit values exist. The particle number is the only deviation from this picture, since the levels measured at the apron are about two to three times higher than at HCAB. There is no air quality limit value for particle number.

Model calculations show that the apron is the place where airport workers are most likely to be exposed to elevated levels of nitrogen oxides and $PM_{2.5}$, as well as to high particle numbers.

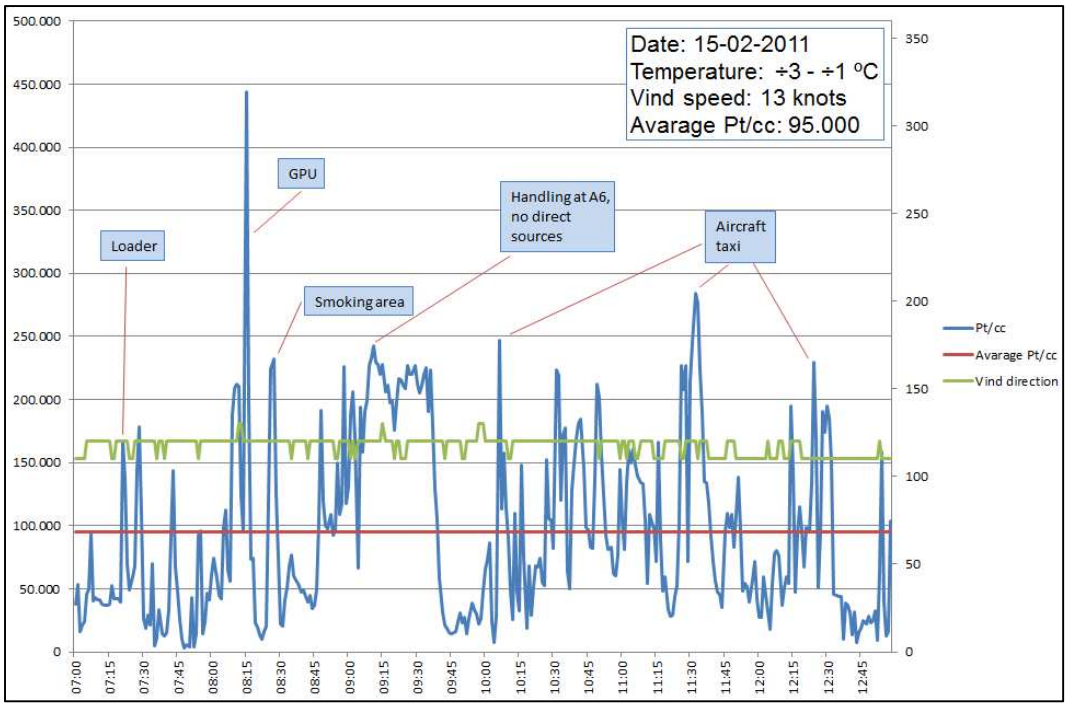


Fig 13: Example measurements with handheld P-Trak (1 minute mean levels)
Blue is particle count, red is the particle count mean level and green represents wind direction.

Copenhagen Airport has carried out additional measurements to determine the level of exposure to ultrafine particles for personnel at the apron – using handheld measurement equipment (P-Trak). This was done as a supplement to the long term measurement campaign that was initiated by CPH and described in the DCE report. In general, average levels (during working hours for ramp personnel) of UFP/cm^3 are between 32,000 – 95,000 on the apron around aircraft handling (P-Trak) – highest average levels for the most congested road in central Copenhagen are between 40,000 – 50,000 UFP/cm^3 (1/2 hour mean level, DMPS). Aircraft engines and APU have been observed to cause significant amounts of UFP and they are observed to be spread over long distances under windy conditions.

Copenhagen Airport has, on a voluntarily basis, established continuous monitoring stations for UFP at two locations. One at the central apron and one at the western boundary close to residential areas. Measurements started in August 2010 and are done 24/7. From the start of 2013 the monitoring will be done with a CPC which supersedes the DMPS equipment from DCE – this means that CPH has been measuring continuously for 2½ years and will continue measurements to collect data for documentation on effects from remediation initiatives.

The challenge at CPH is that 3 handling personnel were diagnosed with cancer and that the health authorities have related this to working on the airport apron due to exhaust from diesel engines. Copenhagen Airport has, on a voluntarily basis, established continuous monitoring stations for UFP at two locations. One at the central apron and one at the western boundary close to residential areas.

Copenhagen Airport is addressing the issues with a public accessible action plan that involves all major stakeholders including unions and authorities.

4.2.2 Zurich Airport, Switzerland

GPU-Measurements 2005

Commissioned by Zurich Airport, the Laboratory of IC-Engines and Exhaust Gas Control of the Berne University of Applied Sciences, supported by both handling agents Swissport and Jet Aviation Handling Ltd (today dnata) and SR-Technics (additional measurement devices and infrastructure) performed exhaust gas measurements on 6 GPU in 2005[8]. To simulate operations, a dummy load was applied at about 30% and 60% of the electrical performance. The rational of the study was to derive actual emission factors to be used for emission inventory calculations. The Ground Power Units were Cummins and Deutz turbodiesels of 139-149 kW, built between 1994 and 2004.

Particle measurements were done using a SMPS-size spectra analyzer with NanoMetdiluter directly at the exhaust pipe. The following figures show the measurement equipment and a typical particle size and number distribution.

Measurement Equipment	Particle Measurements	Exhaust Gas Measurements

Fig 14: Measurement equipment for GPU measurements

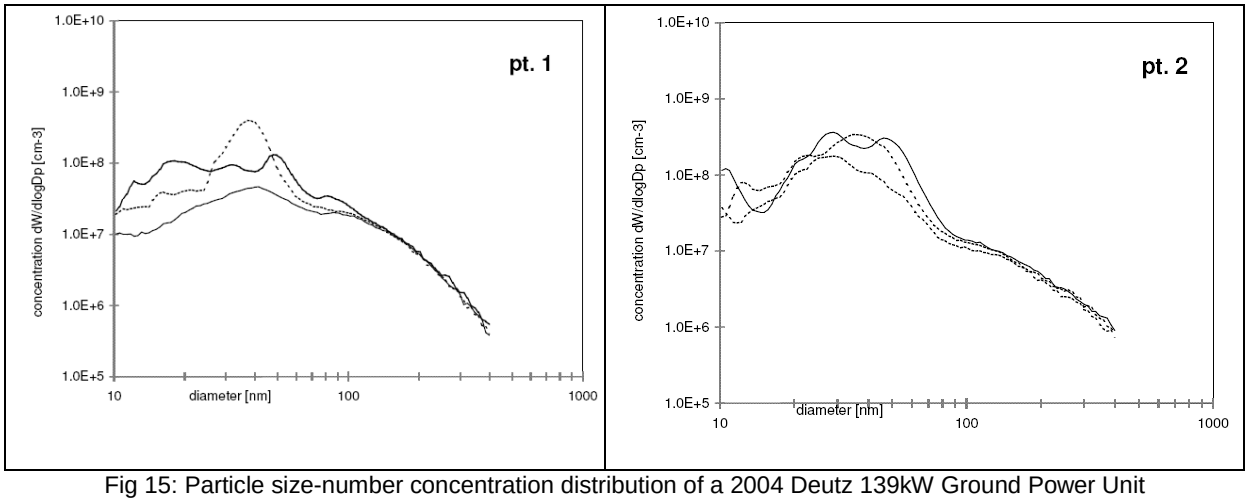


Fig 15: Particle size-number concentration distribution of a 2004 Deutz 139kW Ground Power Unit (pt.1 = 30% dummy load, pt. 2 = 60% dummy load); 3 samples each with NanoMet-diluter at exhaust pipe

The results show typical diesel exhaust particle sizes from 15-70nm with particle numbers in the exhaust pipe of 1.0^{+8}.

Aircraft handling 2012

A screening measurement campaign was conducted in July and August 2012, where three and two aircraft rotations, respectively, were measured during arrival, handling and departure (between 45-90 minutes). All aircraft were Airbus A320, equipped with CFM56-5B4 engines. Two aircraft were handled

[8] Flughafen Zürich AG (Unique): Ground Power Unit (GPU) Exhaust Emissions at Zurich Airport. Zurich, September 2006

at an open stand, three at a terminal stand. The weather was sunny, with winds of 4-6 m/s, wind direction between 250°-290° and temperatures between 16- 20°C during the first campaign and 2 m/s wind from 180-220° at 25°C during the second campaign.

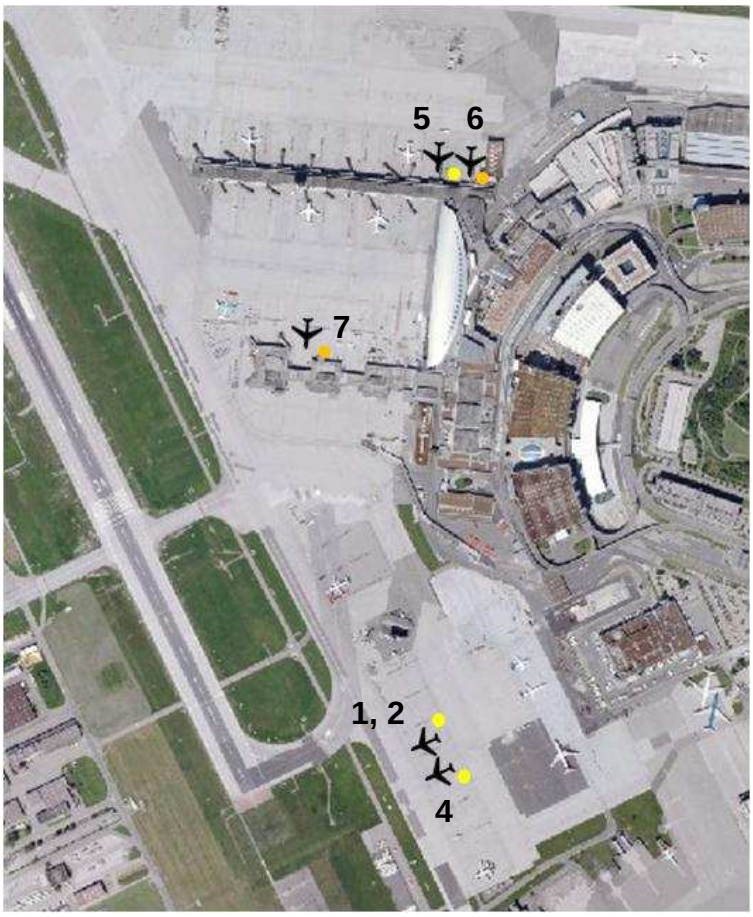


Fig 16: Measurement points and locations Zurich airport (MP1-7)
(yellow: July 2012, orange: August 2012)

The measurement equipment for the first set of measurements consisted of a stationary SMPS, P-Trak and EDB (electrical diffusion battery) close to the aircraft, together with sensors for measuring in parallel DME (diesel motor emissions), PAC (poly aromatic compounds), VOC (volatile organic compounds), formaldehyde, CO, NO and NO_2. In addition, two ramp workers were equipped with a portable particle counter devices (minidisc). For the second set of measurements, only the P-Trak and the minidisc have been used in a stationary setup.

The following table shows the results for the measurement points 4, 5 and 6 during the full duration of the activity (arrival, handling, departure). Three main conclusions can be drawn from the results at Zurich airport:

1. The particle number concentrations at pier stands tend to be higher than at remote stands (MP 4 vs. MP 5). This could be due to the facts that the pier stands are closer to areas of additional activities (e.g. taxiways) and that the wind effects are different due to the influence of buildings.
2. The (almost) same location and the exactly same procedure can result in different results (MP 5 vs. MP 6). This is due to the meteorological influence and the influence of close by other sources.
3. A source discrimination for particle sizes and numbers seems possible with aircraft particles showing smaller sizes than diesel engine particles. Typical aircraft turbine related particles were found in a very good correlation with the sensory cognition of the typical “aircraft turbine smell”. The better the smell was detected, the higher the particle numbers and smaller their sizes were.

Table 2: Results of Zurich airport UFP measurements

MP	Location description	Number #/cm³	Particle size nm
1	Stand D09 Remote	30'000-35'000	37-38
2	Stand D09 Remote, Ramper	124'000	31
4	Stand D11 Remote	30'000-60'000	35-36
5	Stand A05 Pier	80'000-160'000	18-21
6	Stand A03 Pier	60'000-90'000	26-27
7	Stand B39 Pier	50'000-90'000	28-38

Person related measurements show higher concentrations with particle numbers of 124,000 particles/cm^3 average. This is most likely due to the proximity of the workers to the sources. Background concentrations, with very little combustion related activities were found to be in the range of 3,000-10,000 particles/cm^3.

The measured particle sizes range between 10 nm and 70 nm. When a typical exhaust smell from an aircraft engine was detected, the particle sized dropped to 10-16 nm while the concentrations increased.

The following graphs show typical particle size distributions from an SMPS-scan for different source activities (aircraft engine exhaust and diesel equipment exhaust).

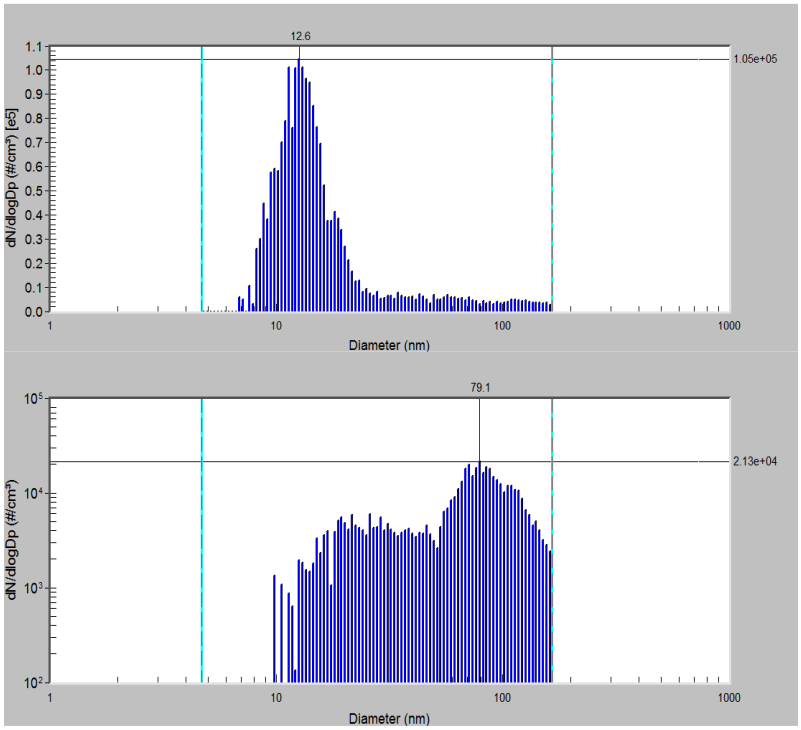


Fig 17: Typical SMPS-scan size distribution for aircraft (top) and GSE (bottom)

4.2.3 Heathrow Airport, UK

In May 2012, a screening assessment was carried out for one day at Heathrow Airport on the ramp at Terminals 3 and 5 - locations that are central within airport and on the west, respectively. Sampling

was undertaken near the northern edge of the both terminal buildings. On the day in question, wind direction was north to north easterly and air temperature ranged from 7 to 10^0C. The Terminal 3 location was further from the airport buildings and more exposed than that at Terminal 5.

Monitoring for UFP was also carried out whilst the sampling vehicle was driven around the airport perimeter road and along the nearby M4 and M25 motorways.

Sampling was undertaken using the following instruments:

- TSI condensation particle counter (CPC) for UFP. It measures particle diameter in the size range 0.007 to 3 µm approximately
- GRIMM portable dust monitor for PM_{10}, $PM_{2.5}$ and PM_1
- TRI Odyssey 2001 gas monitor to measure NO_2 concentrations

Monitoring on the ramp at Terminals 3 and 5 showed many high, short-lived "events", which quickly returned to the concentration baseline - 10,000 UFP/cm^3 and 20,000 UFP/cm^3 respectively. Peak levels were similar at both locations – approximately 70,000 UFP/cm^3. The majority of "events" correlated with activity recorded at each location and appears to originate both from taxiing aircraft and ground support equipment (e.g. push-back tugs, fuel trucks, ground power units) and rapidly returned to baseline levels once the source activity ceased.

Average concentrations over the sampling periods were approximately 31,000 UFP/cm^3 for Terminal 3 and approximately 42,000 UFP/cm^3 for Terminal 5. The higher average concentration and baseline at Terminal 5 was probably due to the more sheltered position of the sampling point on the day of the monitoring.

There was no obvious correlation between particle number measurements and the three particulate mass fractions (PM_{10}, $PM_{2.5}$ and PM_1), which was expected as these larger particles are from different sources than UFP. However, there was little correlation between particle number and NO_2 concentrations, which was unexpected as the combustion sources of the ultrafine particles were also expected to contribute to these concentrations.

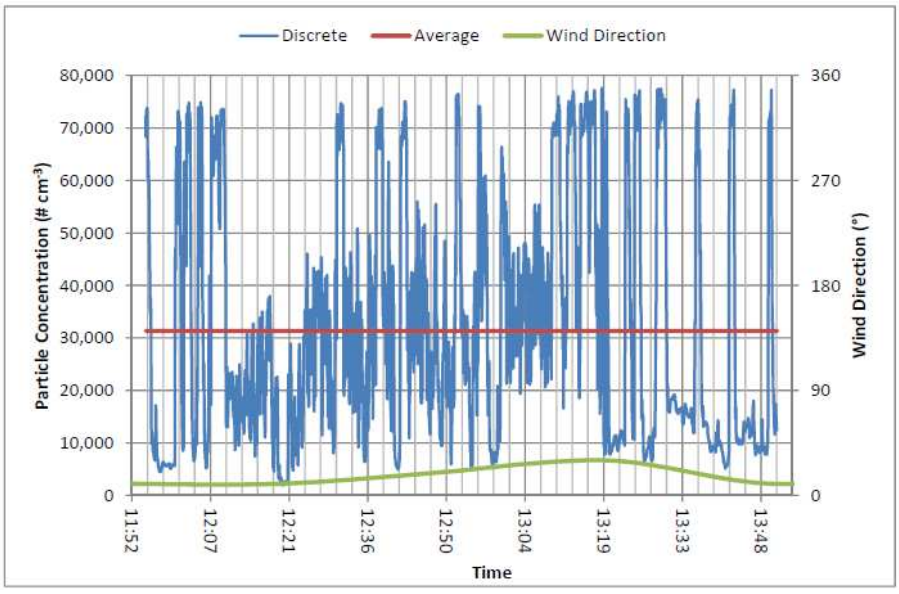


Fig 18: Terminal 3 – entire sampling period

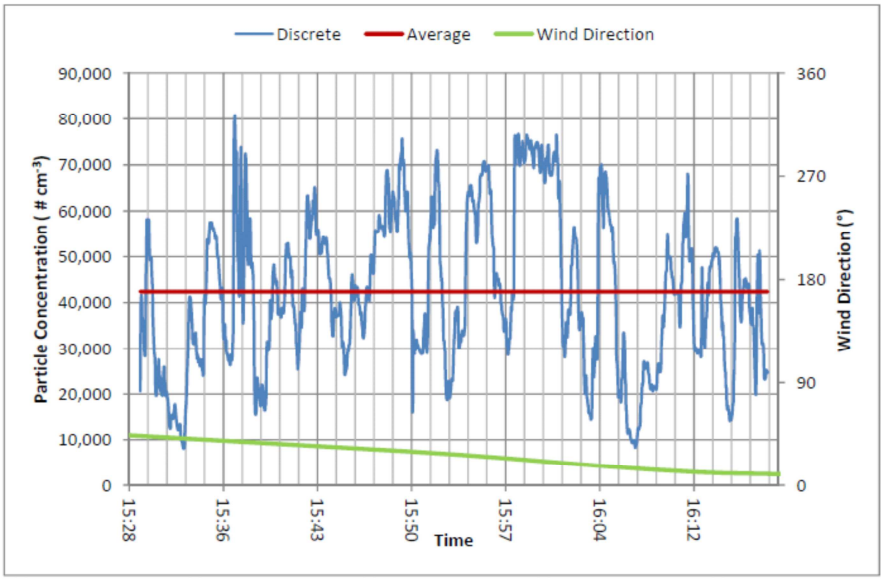


Fig 19: Terminal 5 – entire sampling period

UFP measurements were also taken whilst the sampling vehicle was driven around the airport perimeter road and along local motorways. The results showed:

- Higher particle number concentrations were measured on the western and southern perimeter road compared to the eastern and northern sections. Road and traffic conditions encountered during the drive at least partially accounted for the difference in measured concentrations, but a portion was thought to originate from airport operations as the prevailing wind on the day of sampling was from the north and north east.
- Equally high particle concentrations were measured on the M4 and M25 motorways as on the airport perimeter roads. They are too far from the airport for operations to have had any influence on concentrations. The predominant source was the heavy traffic using the roads at the time the measurements were taken.

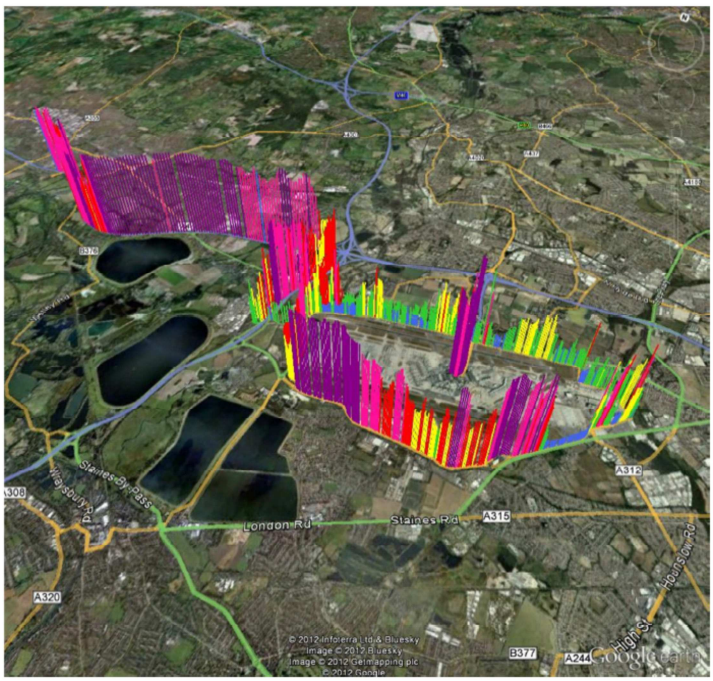


Fig 20: Particle number concentrations on the perimeter road and on adjacent motorways

4.2.4 Stockholm Arlanda Airport, Sweden

In August-September 2012, measurements of ultrafine particles (UFP) were carried out for three weeks at Stockholm Arlanda Airport on the initiative of Swedavia; for one week on the ramp at gate 4, Terminal 5 (1 in the figure below), and for two weeks at gate 32 (2), Terminal 4. Meteorology, wind and temperature, was also measured (M).

Sampling was undertaken using a TSI condensation particle counter (CPC) for UFP (TSI 3775). It measures particle diameter in the size range from 0,004 µm. Concentrations were measured as 1-minute averages which were collected every 15 minutes and calculated as 15 minutes average, hour average and 24 hours average.

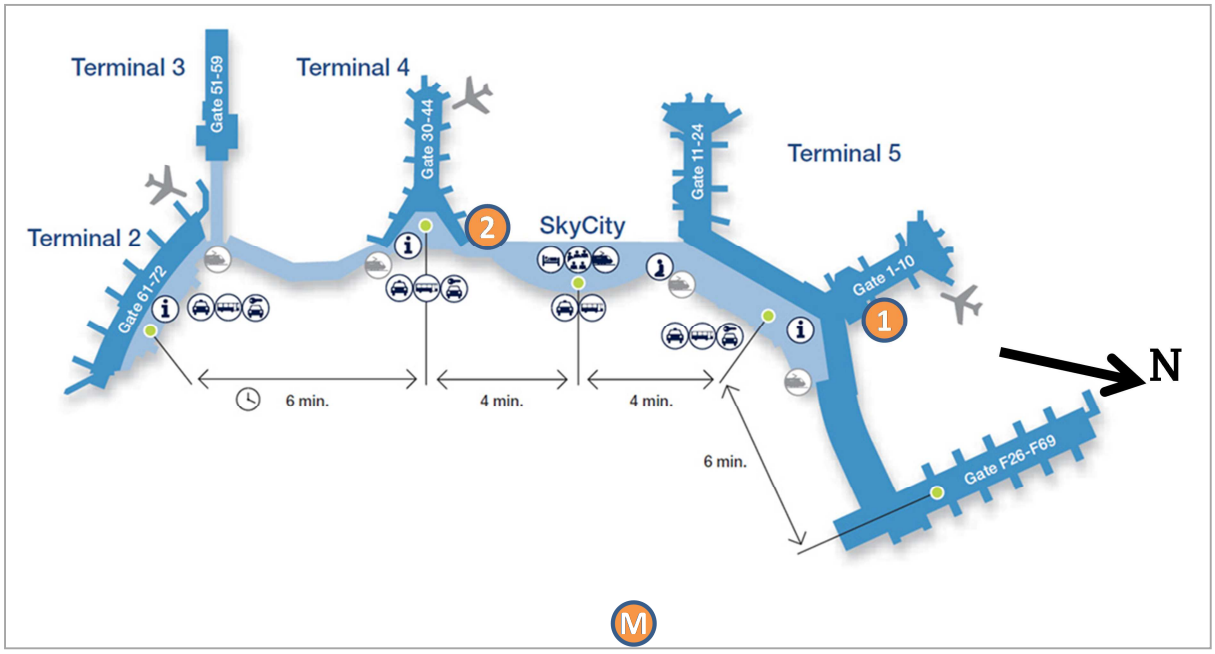


Fig 21: Measurement setup Stockholm Arlanda Airport

The result from monitoring on the ramp at the busy gate 4 at Terminal 5 shows that the average concentration of ultrafine particles for the sampling period was 50,700 UFP/cm^3 and the average concentration for gate 32 at Terminal 4 was 35,600 UFP/cm^3. Both the higher frequency of aircraft movements and less favourable weather conditions have contributed to the higher concentrations during the first monitoring period at Terminal 5 compared to the second period at Terminal 4.

The result shows that the concentrations of UFP varied over a 24 hour period. There were increased concentrations during the day from 06:00-22:00, with the greatest concentrations from 07:00-09:00 and 17:00-19:00. Night time levels are lower than 5,000 UFP/cm^3. The majority of peaks appear to correlate with aircraft arrival s or departures at the stand where the measurements were carried out or at a gate nearby.

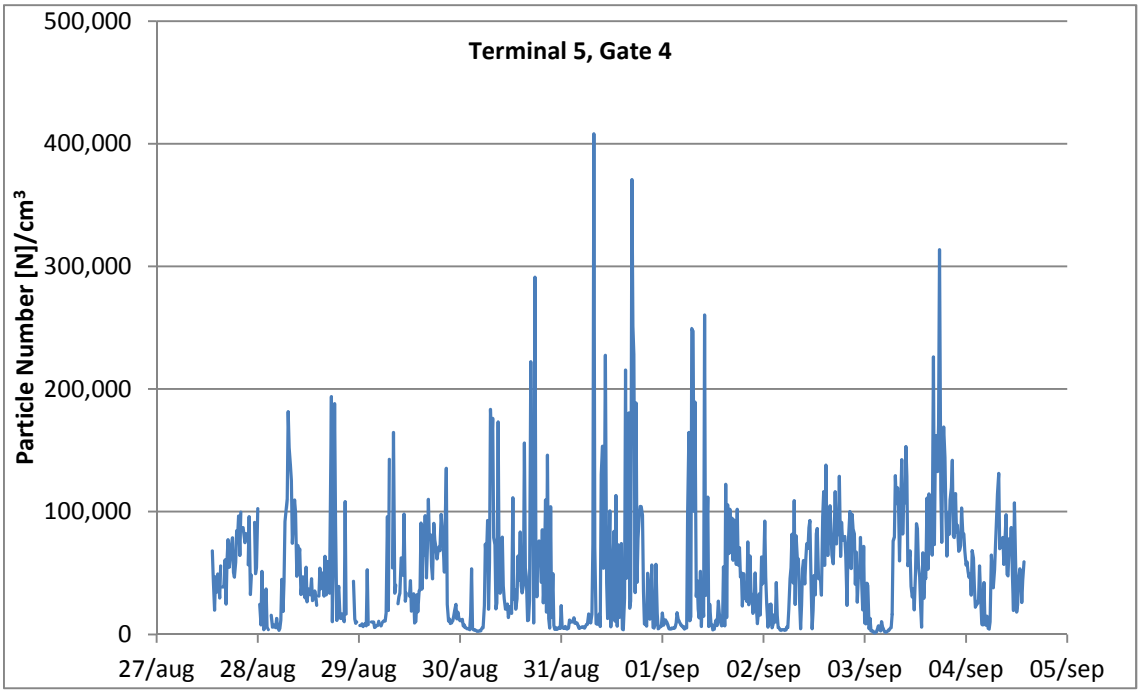


Fig 22: Terminal 5 – Number of ultrafine particles (size range from 0,004 µm) 15 minutes average

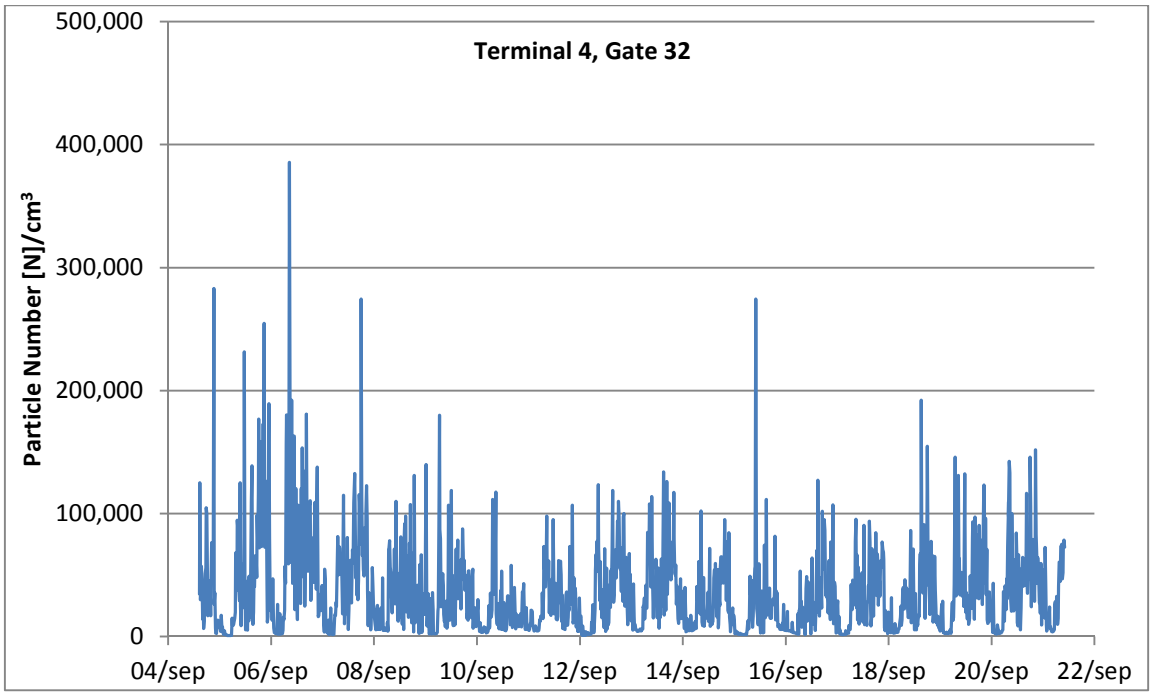


Fig 23: Terminal 4 – Number of ultrafine particles (size range from 0,004 µm) 15 minutes average

4.2.5 Los Angeles World Airport[9]

Real time number concentrations and size distributions of ultrafine particles (UFPs, diameter <100 nm) and time integrated black carbon, $PM_{2.5}$ mass, and chemical species were studied at the Los Angeles International Airport (LAX) and a background reference site. At LAX, data were collected at the blast fence (140 m West from the take-off position) and five downwind sites up to 600 m from the take-off runway and upwind of the 405 freeway. Size distributions of UFPs collected at the blast fence site showed very high number concentrations, with the highest numbers found at a particle size of approximately 14 nm. The highest spikes in the time series profile of UFP number concentrations were correlated with individual aircraft take-off. Measurements indicate a more than 100-fold difference in particle number concentrations between the highest spikes during take-offs and the lowest concentrations when no take-off is occurring. Total UFP counts exceeded 10^7 particles/cm^3 during some monitored take-offs.

Field sampling was performed during three time periods. The summer field study took place September 23-29, 2005. Sampling was performed over 24 h intervals continuously, starting at 12:00 pm on September 23 and ending at 14:00 pm on September 29, 2005. The winter field study, took place over five days from February 22 to March 2, 2006, was limited to the blast fence and upwind sites. The third phase of the field work, near field downwind study, focusing on spatial impact of take-off emissions was conducted May 15-26, 2006. Only data collected under prevailing wind conditions (eastward from the ocean) were used in the following data analysis to avoid potential contamination from traffic emissions on the 405 freeway.

Fig 24: Locations of background reference sites (AQMD) and study sites at LAX.
Red marked sampling sites at blast fence (BF), 140 m distance from take-off position, and additional five sampling locations 220 m, 250 m, 310 m, 410 m, and 610 m from the take-off position.

A Scanning Mobility Particle Sizer (SMPS, TSI Classifier model: 3080, DMA model; 3081/CPC 3025), measuring particles in sizes from 6.15 to 225 nm was used at the LAX blast fence. A second Scanning Mobility Particle Sizer (SMPS, TSI Classifier model: 3080, DMA model: 3081/CPC 3785) was used to measure particle concentrations and size distributions, ranging from 7.64 to 289 nm at the AQMD background site. The two SMPSs were used to conduct near continuous monitoring by performing particle counts over short time intervals at the blast fence and further downwind sites simultaneously to better capture the spatial impacts of take-off emissions. In these measurements, the DMA (differential mobility analyzer) of the SMPS was adjusted to monitor a specific particle size and the CPC was used to count particle concentrations at the desired size every second, providing a real-time monitoring approach that could capture temporal variability in particle number concentrations.

[9] Zhu, Y., et al., Aircraft emissions and local air quality impacts from takeoff activities at a large International Airport, Atmospheric Environment (2011), doi:10.1016/j.atmosenv.2011.08.062

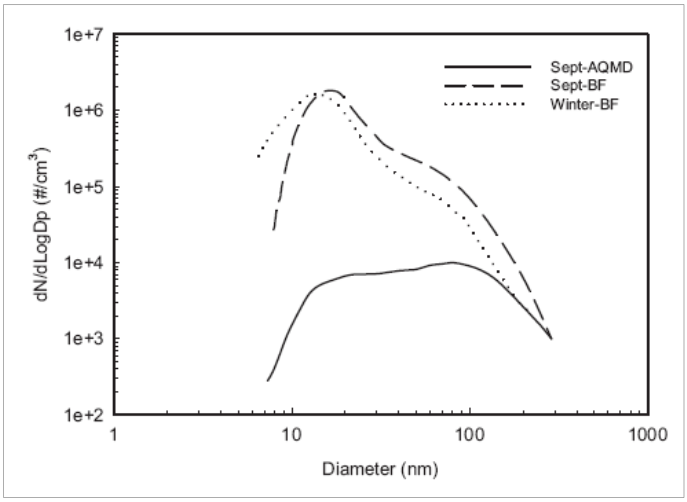


Fig 25: Size distribution of UFP at near source (BF) and background (AQMD) sites (aggregated for each location/sampling time)

To further investigate the contribution of take-off activities to UFP emissions, size specific particle counts over 1 s intervals were measured by setting the DMA of the SMPS to a fixed particle size, to capture changes in particle concentration due to isolated aircraft take-off events. A typical example of a take-off cycle is shown in figure below, which depicts the time profile of the concentration of 30 nm particles at the blast fence while an aircraft prepared for take-off from LAX. The aircraft travelled east on the 25R taxiway to the blast fence for departure.

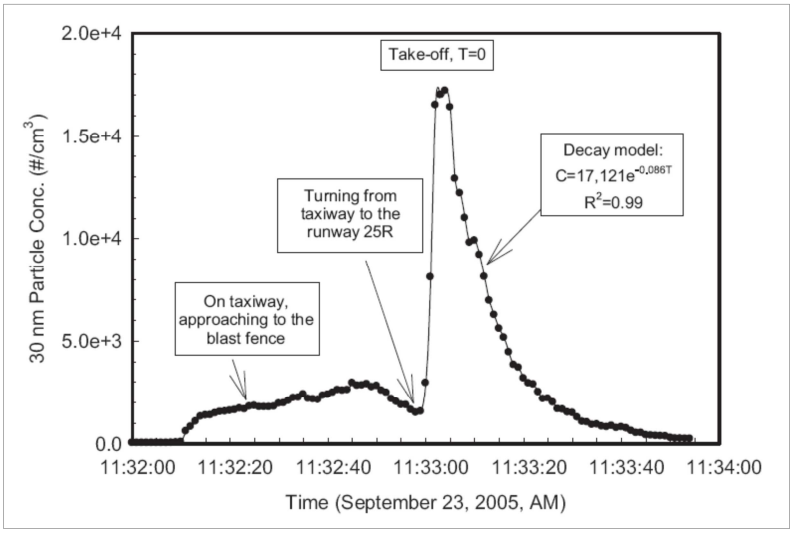


Fig 26: Temporal profile of 30 nm particles during a take-off event

4.2.6 Santa Monica Airport[10]

Real time air pollutant concentrations were measured downwind of Santa Monica Airport (SMA) in California, using an electric vehicle mobile platform equipped with fast response instruments in spring and summer of 2008. SMA is a general aviation airport operated for private aircraft and corporate jets in Los Angeles County, California. An impact area of elevated ultrafine particle (UFP) concentrations was observed extending beyond 660 m downwind and 250 m perpendicular to the wind on the down-wind side of SMA (figure below).

[10] http://pubs.acs.org/doi/pdf/10.1021/es900975f (July 2012)

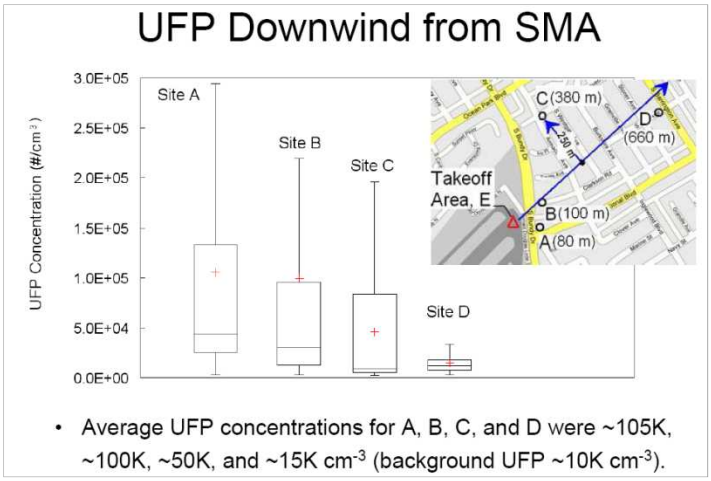


Fig 27: Downwind UFP concentrations

Aircraft operations resulted in average UFP concentrations elevated by factors of 10 and 2.5 at 100 and 660 m downwind, respectively, over background levels. The long downwind impact distance (i.e., compared to nearby freeways at the same time of day) is likely primarily due to the large volumes of aircraft emissions containing higher initial concentrations of UFP than on-road vehicles. Aircraft did not appreciably elevate average levels of black carbon (BC), particle-bound polycyclic aromatic hydrocarbons (PB-PAH), although spikes in concentration of these pollutants were observed associated with jet take-offs. Jet departures resulted in peak 60-s average concentrations of up to 2.2×10^6 cm^{-3}, 440 ng m^{-3}, and 30 µg m^{-3} for UFP, PB-PAH, and BC, respectively, 100 m downwind of the take-off area. These peak levels were elevated by factors of 440, 90, and 100 compared to background concentrations. Peak UFP concentrations were reasonably correlated ($r^2 = 0.62$) with fuel consumption rates associated with aircraft departures, estimated from aircraft weights and acceleration rates. UFP concentrations remained elevated for extended periods associated particularly with jet departures, but also with jet taxi and idle, and operations of propeller aircraft. UFP measured downwind of SMA had a median mode of about 11 nm (electric mobility diameter), which was about half of the 22 nm median mode associated with UFP from heavy duty diesel trucks (figure below).

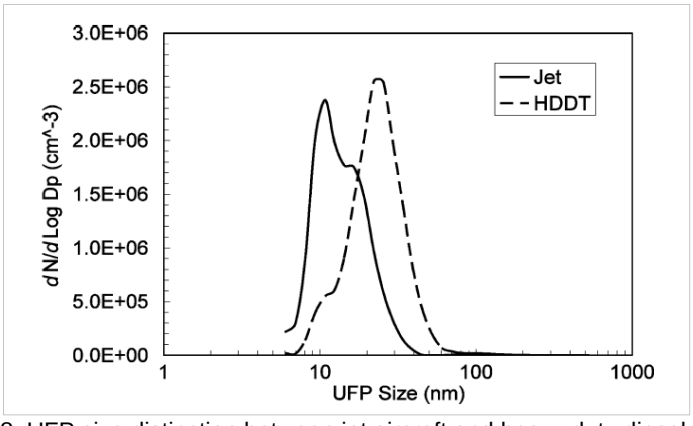


Fig 28: UFP size distinction between jet aircraft and heavy duty diesel truck

5 Ultrafine particles in other industries

5.1 Emission sources and exposure

Generally speaking, all work places may be subject to ultrafine particle emissions, be this in manufacturing, construction, services or administration. However, concentrations of ultrafine particles can be found not only in work places, but also in break rooms,.

One very common emission source with exposure is smoking. The following figure shows a typical staff smoking room concentration graph on a weekday before lunch (Friday, 20th January 2006, 1 sec-time resolution, measured with a P-Trak)[11].

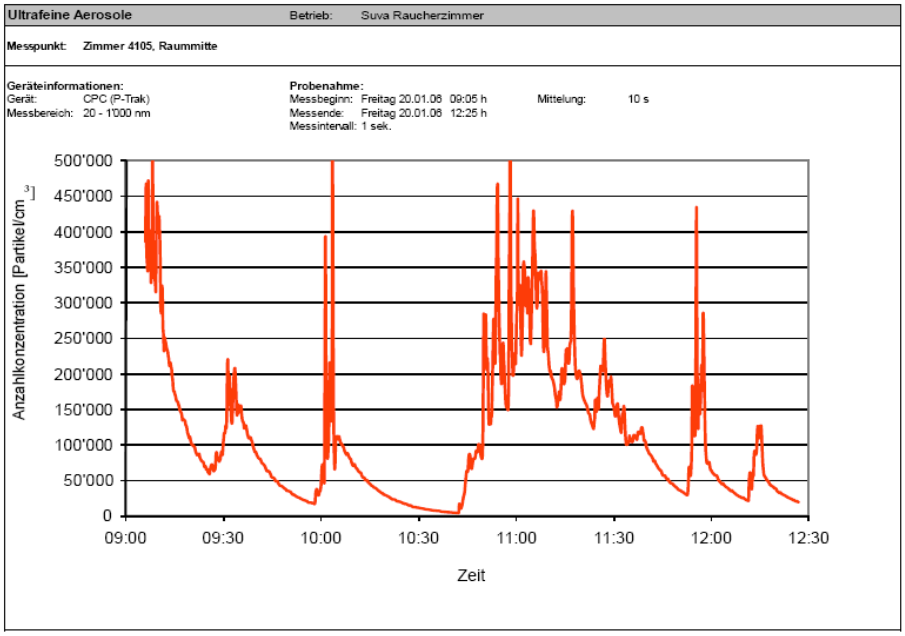


Fig 29: Typical smoking room concentrations (time dependent, from 09:00-12:30)

Extensive measurement of the Swiss SUVA at workplaces between 2004 and 2008 show a wide range of ultrafine particle concentrations.[12]

Table 3: Measurement of UFA at different work places 2004-2008 by SUVA

	Number concentration (#/cm³)				Size (nm)	# measurements
Activity	**Minimum**	**Maximum**	**Average**	**Median**	**Average**	
Outside air	2,600	58,000	14,600	10,300	56	16
Indoor rooms	660	53,000	9,000	4,000	41	11
Restaurants	24,000	110,000	61,700	51,000	43	3
Road traffic	23,000	330,000	99,500	59,000	35	11
Internal company traffic	36,000	174,000	83,000	78,500	55	10
Tunnel construction	27,000	830,000	233,000	165,000	69	10
Closed shooting range	100	420,000	141,000	2,500	69	3
Crematory	34,000	41,000	37,500	37,500		2
Welding	540	2,700,000	522,000	203,000	75	14
Plastic manufacturing	4,900	174,000	88,300	79,500	63	6

[11] http://www.suva.ch/nano_1_d.pdf (July 2012)
[12] http://www.sgah.ch/downloads/ultrafeineaerosole.pdf (July 2012)

Chemical production	116,000	116,000	116,000	116,000	37	1
Powder coating	13,000	41,000	25,700	23,000	53	3
Gravel works	4,800	36,000	16,800	9,600	63	7
Nano technology	2,200	2,000,000	239,000	14,000	60	29

5.2 Case studies

5.2.1 Swiss cities

In winter 2012, the Swiss Traffic Club and the association “doctors for environmental protection” launched a study to assess the PM and UFP concentrations in city centers of 8 Swiss cities[13]. For this purpose, a pedestrian was equipped with a portable PM and UFP measurement device and made an “everyday walking tour” of between 45 minutes to 2 hours in the respective city center. During this time, the PM_1, $PM_{2.5}$, PM_{10} mass and the UFP number concentrations (10-300 nm) were measured. The study was done in January and February 2012, without special selection of the weather or traffic situation. To this end, the results are not comparable among the cities or against other measurement campaigns.

The UFP were measured using the portable minidisc, a handheld instrument measuring the ultrafine particle number concentration, the average particle size and the lung deposited surface area (LDSA) with a time resolution of 1 second. Particles in the size range from 10-300 nm can be measured in a concentration range of 10^3 - 10^6 particles / cm^3. The next table displays the summary results for all cities, while the figure displays the results for the city of Geneva.

Table 4: UFP results Swiss Cities, winter 2012

City	Time	Median [nm]	Median [part/cm^3]	Minimum [part/cm^3]	Maximum [part/cm^3]
Lucerne	Late AM	55	18,244	1,298	615,463
Basel	Late AM	51	30,102	602	933,822
Biel	Late AM	46	25,398	1,376	978,634
Geneva	Morning	35	62,969	703	930,338
Berne	Morning	38	7,894	251	785,500
Lugano	Morning	37	38,066	4,102	991,732
Chiasso	Late AM	56	20,106	7,472	951,790
Lausanne	Early PM	50	24,308	15,193	970,375

[13] VCS/Vereinigung “Aerztinnen und Aerzte für Umweltschutz”: Test parcours for the measurement of particle concentrations in 8 Swiss cities. 2012 (German only).

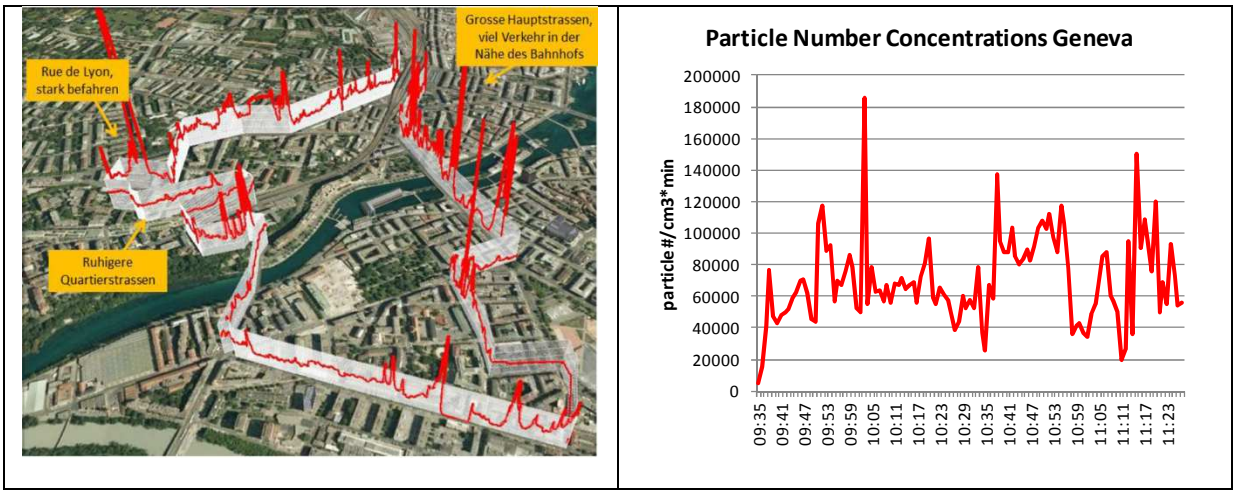


Fig 30: Particle number concentration in Geneva
(6th February 2012; Time: 9:30 – 12:30; weather: sunny, light wind, -3℃)

The results obtained show general trends despite the variable weather situations: along major roads and particularly on intersections, pedestrians are exposed to significantly higher concentrations of fine particles than at other locations. Singular events like a stop light or the passing of a motorbike can increase the number concentrations of UFP very quickly.

5.2.2 Street traffic in Stockholm

The Stockholm and Uppsala Air Quality Management Association conducts permanent air quality measurements on Hornsgatan street in downtown Stockholm. Hornsgatan is a 24m wide, four lane street surrounded by 24m high houses on both sides, thus being a rather symmetric street canyon with a unity height/width aspect ratio. Traffic volume is about 35,500 vehicles per day during weekdays, with an average of 5% of heavy duty vehicles, mostly buses which mainly use ethanol. Of the light duty vehicles, there is an average of 5% diesel fueled cars, mainly taxis. The traffic flow is determined by the traffic light crossing at the eastern end of the block (figure). The cars heading westwards from the traffic lights, pass the monitors under heavy acceleration and they also have to run up a 2.3% slope. In contrast, the traffic heading eastwards are running downhill towards the traffic light, typically in a deceleration phase.

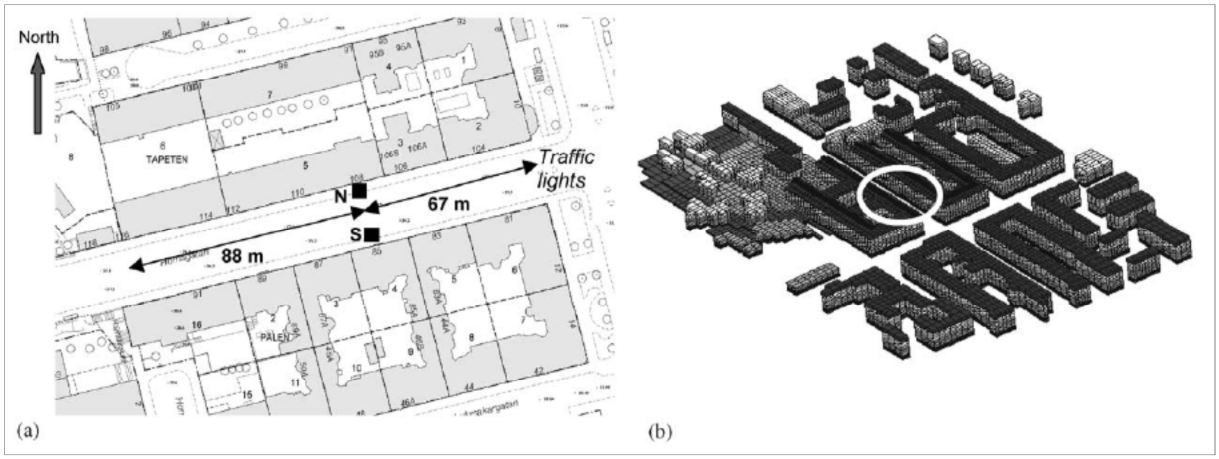


Fig 31: (a) Hornsgatan monitoring station South (S) and North (N).
The houses are of similar height, 24 m, total street width is 24 m, the four lanes together approximately 13m wide. Uphill slope westward is 2.3%. (b) 3D perspective of model grid from Southeast, monitoring site Hornsgatan marked with a circle.

The next figure shows a randomly chosen 5-day hourly mean value concentration graph for particle number concentrations[14]. As can be seen, there is a high variability in the particle number concentrations, ranging from as little as approximately 7,000 to as high as approximately 125,000 particles/cm3.

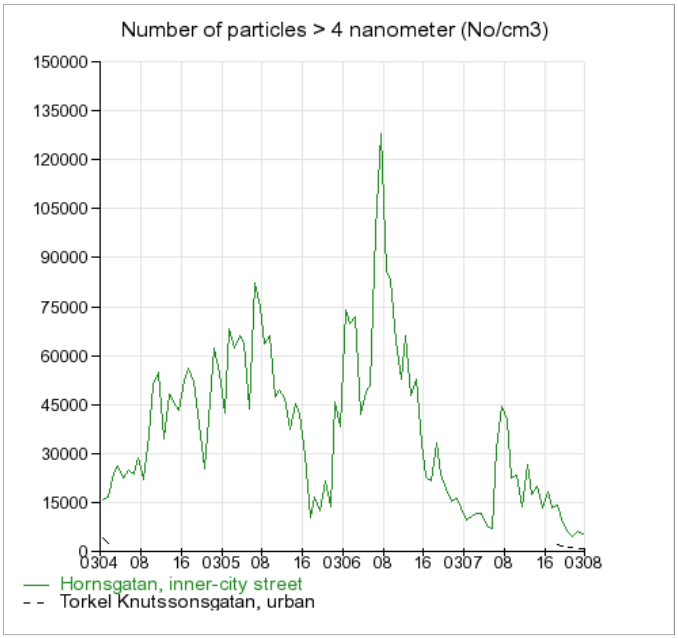


Fig 32: Hourly mean value particel number concentration in Stockholm (4.3.2012-8.3.2012)

A differential mobility particle sizer (DMPS) was installed during the period June–December, 2002, at the station named North (N) in a previous figure[15]. The DMPS instrument yields particle number concentrations in 14 size intervals, from 20 to 450nm in diameter. In parallel a CPC 3022 measures total number (ToN) with a lower cutoff of 7 nm. The size distribution found in the street canyon is presented as it was measured, without correcting for the urban background contribution. For this study, it is the shape of the size distribution that is of most importance, and the local contribution of the traffic inside the street canyon is assumed to have a dominating influence over both total number as well as the size distribution. The urban background contribution to total number concentration is about 16% during daytime and 10–15% during hours of high concentrations.

The measured particle size distribution data set covers a six week long period of total number and DMA size distribution data, all averaged to hourly values. As the DMA has a cutoff at 20 nm, while the CPC counts particles down to 7 nm, we use the difference between total CPC and total DMA as a measure of particle number in the size range 7–20 nm. The average size distribution is shown in the next figure, in which also the size distribution found inside the car tunnel is given. The shape and peak of the two distributions are similar, with the difference that the street measurement shows number concentrations about one order of magnitude lower as compared to the tunnel.

[14] www.slb.nu/elvl, visited 30.8.2012
[15] Refer to Reference [17] for more details

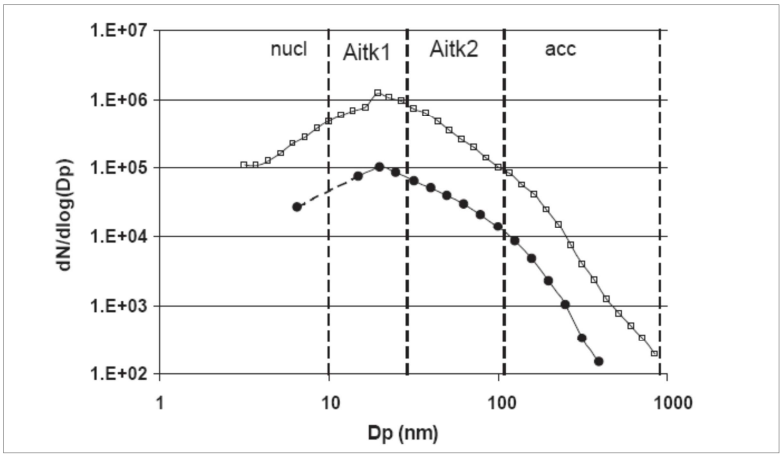


Fig 33: Monitored size distribution during workdays.
Hornsgatan October 02–November 20 2002 (heavy line, circles) and Stockholm car tunnel 26 January–12 February, 1999 (thin line, rectangles). Unit: /cm^3. Limits for model size bins are marked as broken bars.

Additional studies cover the annual variations and the influence of dry or wet roads. The next figure shows the monthly average total particle number (PNC, or ultrafine particle) and PM10 concentrations at Hornsgatan in central Stockholm (street canyon)[16]. The concentrations represent the contribution from the local traffic on this street since the measured urban background concentrations of PM10 and PNC have been subtracted. The monthly mean values were obtained from hourly measurements taken from January 2001 to May 2005. Vertical bars indicate standard deviation of diurnal averages. Only months with data covering more than 50% of the time have been included (for PM10 the averages are based on between 111 and 149 days; for PNC the averages are based on between 24 and 94 days).

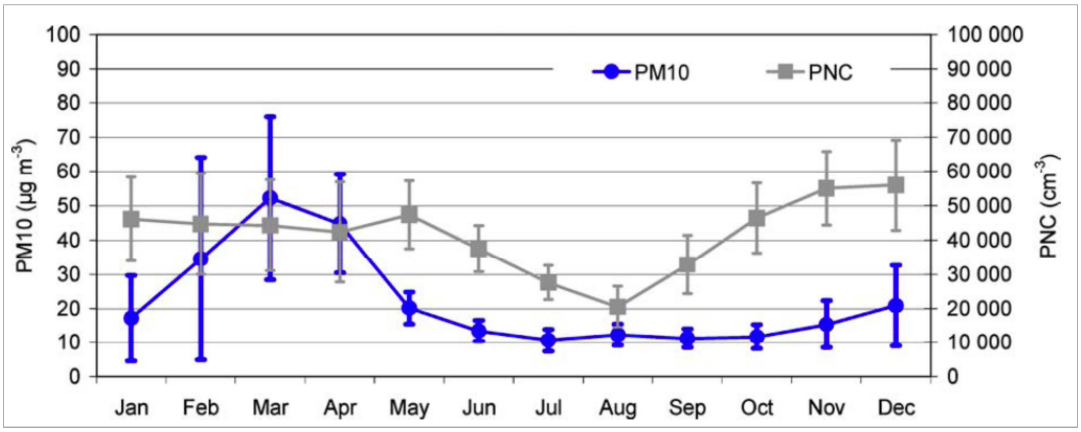


Fig 34: Monthly average particle number concentrations at Hornsgatan street in Stockholm

The following figure shows the variation of the hourly mean PNC and PM10 levels at Hornsgatan during wet and dry road surface conditions. During this period road surface wetness and PM10/PNC were measured at the same street. During the shaded periods the street surface was dry and during the unshaded periods it was wet.

[16] Refer to Reference [18] for more details

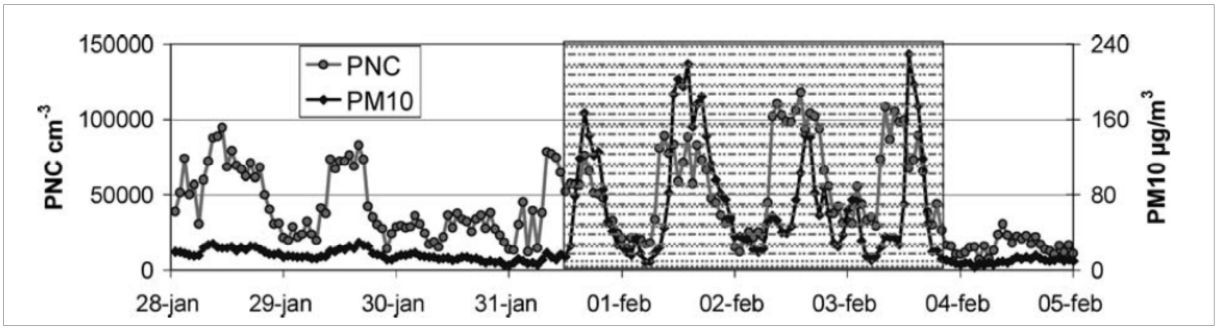


Fig 35: Influence of dry (shaded) and wet (clear) road surface on particle number concentrations

6 Conclusions

6.1 Ultrafine particles in aviation

The various measurement campaigns at airports in Europe and North America have provided a number of evidences in the process of emission and measurement of ultrafine particles in aviation that lead to the following main conclusions:

- Ultrafine particle (UFP) concentrations in terms of average (and median) tend to be relatively high at airports (30,000-100,000), but a very high variability in number concentrations and particle sizes has been observed
- It seems that UFP from aircraft turbines on average tend to be smaller in size (10-16 nm) than from standard diesel/gasoline combustion engines (10-300 nm) but higher in numbers; as such, a source discrimination appears to be possible; aircraft turbine particle emissions also correlate with the sensory cognition of the typical aircraft exhaust smell
- Higher levels of UFPs are not only measuerd at airports. Also in other environments, UFP of the same or even higher levels have been measured (chapter 4)
- The measurement setup (equipment, location) has a very significant impact on the results

Most of the studies performed have been done over a relatively short period of time (hours), even if done somewhat repeatedly. Only the street traffic studies in Stockholm and Copenhagen and measurements at Copenhagen Airport have been going on for several years; however, the UFP measurements in Stockholm are measured every second and different mean values are calculated from these measurements on a 15 minute interval and the measurements in Copenhagen on a 30 minute interval while most campaigns with handheld equipment is done on a second or minute interval. As could see from the cited studies and measurement campaigns, average particle number concentrations varies among airports (Heathrow airport: 31,000 average, Copenhagen: 95,000, Santa Monica Airport: 105,000) and among other activity profiles.

There are several factors influencing the measurement results:

- Exact measurement location (distance to source)
- Meteorological conditions: wind speed and direction, humidity (wet or dry surfaces)
- Emission exhaust dynamics (e.g. exhaust air parcel velocity)
- Equipment used to undertake monitoring (with/without thermo desorber)

Even if taken with the same measurement set-up (source, equipment, locations), completely different results can be obtained under different meteorological conditions.

In conclusion, any single measurement campaign is insufficient to properly describe the average UFP concentrations at an airport. Instead, only multiple long-term measurement campaigns at airports (e.g. like at Copenhagen) would be sufficiently robust to provide a clearer picture of UFPs' behaviour. A number of pre-requisites have to be met to ensure that these measurements are scientifically sound and can therefore be exploited. The subsequent sections thus provide guidance on measurements.

As a further conclusion, it can be stated that the current understanding of average, long-term concentrations of ultrafine particle at airports, particular in terms of dose exposure and human response is insufficient to conclude any dose-effect relationships. This also includes the question of linearity between particle number concentrations and possible human effects as well as the effects of various particle properties (e.g. surface properties).

6.2 Ultrafine particles in various industries

Many activities are emitting ultrafine particles and people in their environment are subject to the resulting concentrations. The following figure displays some activities and/or measurement locations with UFP number concentrations with information on measurement duration or frequency. As can be seen, the concentrations measured at airports are comparable to those measured from other activities and there are no significant higher results from airport locations.

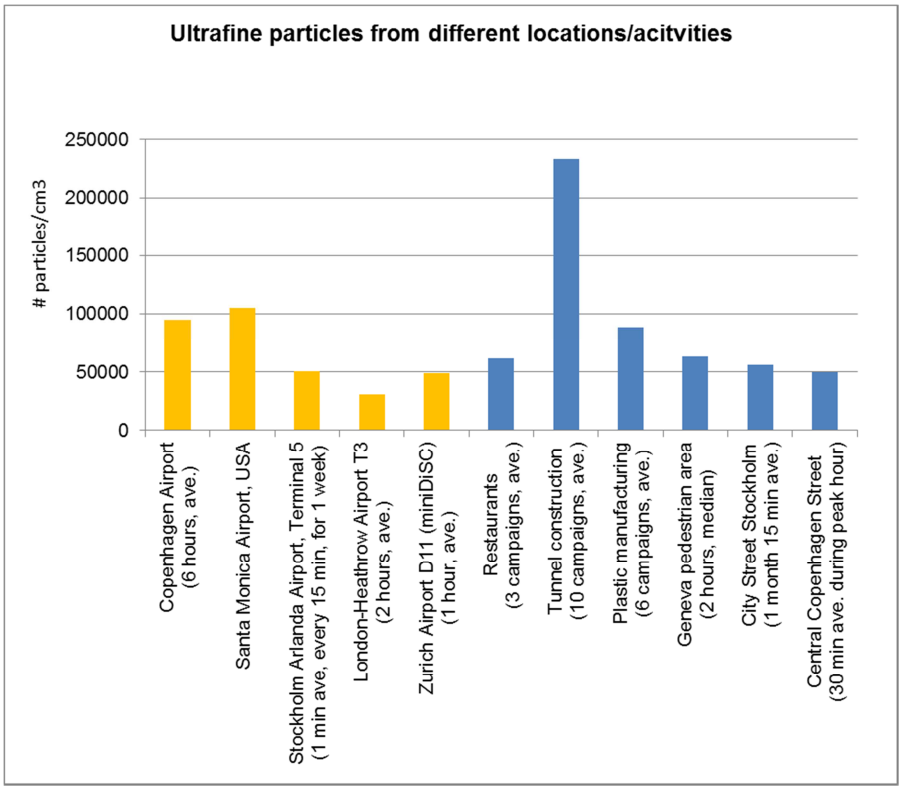


Fig 36: UFP emissions from various locations/activities

7 Measurement of ultrafine particles

7.1 Existing equipment

For the assessment of ambient ultrafine particles, several measurement devices have been used in the past and the present. While there may well be a range of different equipment in use and potentially suitable, only some are described in more detail in the annex of this report:

- SMPS (Scanning Mobility Particle Sizer) is a method to determine the number size distribution of submicron particle particles. It uses a measurement system consisting of an electric charger, a mobility classifier, a counter, and PC control; this equipment may be too slow to account for fast moving process (e.g. aircraft turbine exhaust)
- CPC (Condensation Particle Counter) is a method that accurately measures concentrations over a wide range with an optical system
- ELPI (Electrical Low Pressure Impactor) is a cascade impactor that measures particle number concentrations as a function of aero-dynamic diameter
- P-Trak is a hand-held device that measures the particle number concentrations with an optical system; this device is less suited to account for monitoring UFP at airport as it has a range starting at 20nm only and it only delivers concentration numbers and not on sizes.
- miniDiSC is a portable particle counter device for measuring particles; this is a suitable device to very fast obtain information on number and size of particles
- The EDB (electrical diffusion battery) is a portable device for measuring particle number / size distributions

During the Zurich airport measurement campaign, several measuring equipment was operated simultaneously: SMPS (from TSI) EDB (prototype version), miniDiSC and P-Trak (from TSI).

The following table shows the differences observed for high, medium and low concentrations for both number concentrations and particle sizes.

Table 5: Measurement comparison for UFP

Comparison	Equipment	Number #/cm³	relative deviation	particle size nm
during total period	EDB (10-200nm)	40'000	1.00	29
	miniDiSC (10-300nm)	73'000	1.83	33
	p-Trak (20-1000nm)	28'000	0.70	---
high concentrations	EDB	206'200	1.00	17
	miniDiSC	411'600	2.00	13
	p-Trak	114'700	0.56	---
medium concentrations	EDB	79'600	1.00	19
	miniDiSC	153'900	1.93	18
	p-Trak	48'500	0.61	---
low concentrations	EDB	9'500	1.00	39
	miniDiSC	13'200	1.39	46
	p-Trak	8'900	0.94	---

7.2 Measurement guidelines

Several guidelines have been endorsed for the assessment of gaseous or solid substances in the closer vicinity of workplaces. Generally, those guidelines cover two main domains:

- Guidelines pertaining to measurement organization and requirements (qualification of personnel and equipment, process flow)[17]
- Description of measurement equipment and their application[18]

7.3 Recommendations for airports

Experience from the various measurement campaigns has demonstrated the need for a very careful planning and execution of ultrafine particle concentration measurements. The range of the obtained results has further revealed that many effects contribute to the outcome of measurements: meteorological conditions or choice and location of the monitoring equipment.

To this end, multiple measurement campaigns over longer periods of time and with multiple devices simultaneously are strongly recommended. Further recommendations pertaining to measurement planning, campaign, analysis and reporting are described in more detail in the annex of this report.

8 Regulatory aspects for ultrafine particles

In the context of the discussion around ultrafine particles from aviation, the topic of regulations or definition of standards has been raised. A standard setting process is initiated under the belief that regulations are beneficial to limit the emission of gaseous substances or to limit the exposure to gaseous substances to the degree they are no longer posing a health or environmental risk or at least an acceptable health or environmental risk.

8.1 Current regulatory framework[19]

There are no published international standards for nano objects. The National Institute of Occupational Safety and Health in the USA (NIOSH) has suggested a reference value of 0.1 mg/m^3 (a-fraction) for titanium dioxide nano particles. In Great Britain, The British Standards Institution (BSI) recommends a reference value of 0.01 fibre per milliliter for carbon nano tubes and fibres. According to the evaluation of NIOSH and BSI and the current data basis, both values are listed as reference values in the 2011 standards list. However, these standards apply to nano objects and not to ultrafine particles.

8.2 Pre-requisites for regulations

There are four main areas of requirements to be outlined:

5. Parameters to be regulated: For ultrafine particles, the question will be which parameters should be used, e.g. the mass weight, particle numbers, particle surface, physical-chemical properties of the surface (volatile or non-volatile) or the formation of reactive oxygen species
6. Standardization of measurement: Harmonization of measurement guidelines and standardization of measurement equipment (methods and technologies)
7. Standard-setting: Relevant for establishing standards are known dose-effect relationships, if possible on the basis of epidemiological and experimental studies. This requires both longer-term measurements and health impact studies

[17] TRGS 402, 2010, SAA PM
[18] ISO/TR 27628
[19] SUVA, Abteilung Arbeitsmedizin (Marcel Jost, Claudia Pletscher): Nanopartiel und ultrafeine Partikel am Arbeitsplatz. Factsheet, Version January 2011

8. Applicability: Any new standards have to be applicable over the whole range of the relevant emission sources from all activities (transportation, manufacturing, etc)

8.3 Standard setting domains and respective bodies

There are three domains within which standards could be defined: emissions, ambient concentrations or workplace concentrations. For each domain, different regulatory entities may be responsible and different – already existing – tools and regulations can be used to potentially add text and standards for ultrafine particles. In the first place, usually the concentrations are being regulated as they are impact relevant. If it can be demonstrated or reasonably predicted that anticipated measures (e.g. avoiding emissions, mitigating impacts) will not be sufficient to meet the standards, then emission standards for certain sources are developed and implemented.

8.3.1 Emission standards

The ICAO is the standard setting body for any emissions related to aircraft. The current gaseous emission standards are endorsed in Annexe 16, Volume II to the Chicago Convention (for NOx, HC, CO and Smoke). Within ICAO, the Committee on Aviation Environmental Protection, CAEP, with its working groups (mainly WG 3 on emissions and MDG on modelling) is the responsible body.
The ICAO Assembly, through Resolution 37-18 Appendix H, specifically requests the Council to develop certification requirements for non-volatile PM emissions while continuing to monitor progress in scientific and technical understanding of volatile and non-volatile components of PM emissions. This work is currently being undertaken through CAEP Working Group 3 in close cooperation with SAE-E31 (US Society of Automotive Engineers, Aircraft Exhaust Emissions Measurement Committee).

For internal combustion engines, the European Commission has endorsed directive 2002/88/EC, amending directive 97/68/EC relating to measures against the emissions of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery. Similar standards are in place in other parts of the world. They currently don't contain standards on ultrafine particles, but any amendments could fit into any such existing regulation.

8.3.2 Ambient concentration standards

The European Commission has endorsed ambient concentration standards for a several gaseous primary and secondary pollutants through several directives, e.g. 1999/30/EC or more recent 2008/50/EC on ambient air quality and cleaner air in Europe. Such legislation is backed by similar standards in other parts of the world[20]. However, such regulation can vary depending on local, national or regional priorities or circumstances. They currently don't contain standards on ultrafine particles, but any amendments could fit into any such existing regulation.

8.3.3 Workplace concentration standards

The European Commission has endorsed several directives related to occupational exposure to chemical agents, e.g. Directive 2009/161/EU - indicative occupational exposure limit values. These limits – similar on countries outside the EC – cover a range of substances found in various occupations; the list usually is not complete. However, the above mentioned directive is the third list (to present). This indicates the dynamics in the manufacturing and service-oriented industry and could allow for further amendments.

[20] ICAO Doc 9889, Airport Air Quality Manual, 2011, Chapter 2

9 Annexe

9.1 Abbreviations

APU	Auxiliary Power Unit (kerosene fuelled little aircraft built-in turbine for power and air-conditioning production)
CAEP	Committee on Aviation Environmental Protection
CNG	Compressed natural gas
CO	Carbon monoxide
DLR	German Aerospace Center, Cologne
EC	European Commission or European Community
GPU	Ground Power Unit
GSE	Ground Support Equipment (diesel, gasoline, CNG or electric driven machinery)
HC	Hydrocarbon
ICAO	International Civil Aviation Organisation
LDSA	Lung deposited surface area
LPG	Liquefied petroleum gas
MDG	Modelling and Database Group
NOx	Nitrogen oxides
OHS	Occupational Health and Safety
PM	Particulate matter
PNC	Particle Number Concentration
UFA	Ultrafine aerosols (range of ≤100 nm)
UFP	Ultrafine particles (range of ≤100 nm)
WG	Working Group

9.2 References

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9.3 Ultrafine particle measurement devices (selection)

9.3.1 SMPS[21]

SMPS (Scanning Mobility Particle Sizer) illustrated in the next figure is a method to determine the number size distribution of submicron particles. It uses a measurement system consisting of an electric charger, a mobility classifier, a counter, and PC control.

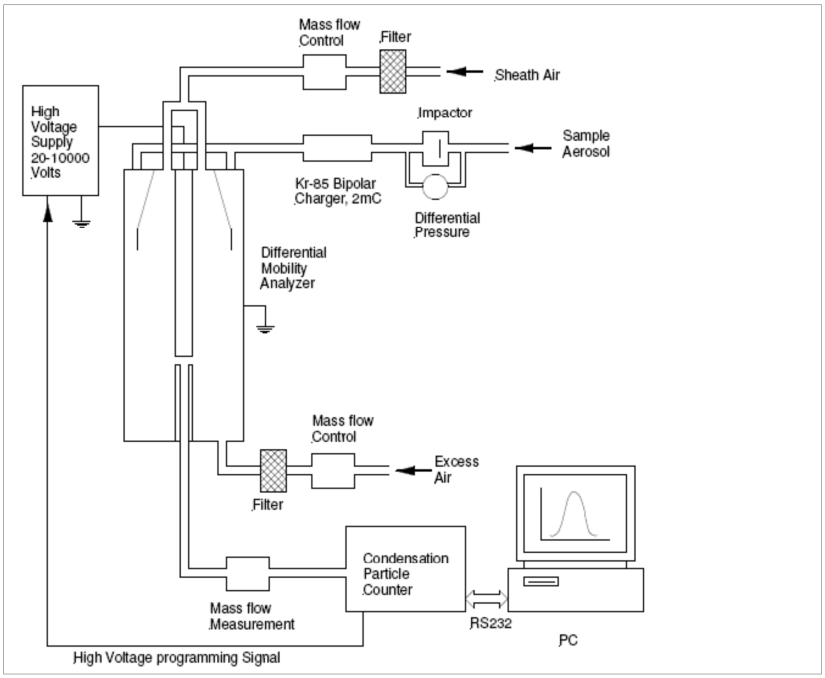

Fig 37: Scanning Mobility Particle Sizer block scheme

The particle is first guided into a neutralizer. This is a chamber in which the air is ionized by beta rays from a radioactive source (85Kr). Positively and negatively charged ions diffuse onto the surface of the particles until a charge equilibrium is established. The probability for 100 nm particles to carry one elementary charge is about 20% for positive and 40% for negative charging, while the rest of the particles leave the neutralizer with zero electric charge - hence the name “neutralizer”.

The charged particles are now classified by their mobility in a Differential Mobility Analyzer (DMA). The DMA is a long condenser through which a laminar flow of particle free air is guided. For practical reasons it has cylindrical geometry. The particles enter through a narrow slit at the upper end of the DMA. When a voltage is applied between outer and inner electrode, the charged particles are dragged towards the centre. Their velocity is determined by the equilibrium of electric force and friction with the suspension air - small particles move faster, larger ones are slower. While the particles move in radial direction, the laminar air flow carries them along the cylinder axis. Thus, they hit the centre electrode below the inlet, large particles later and further downstream than small ones. At its lower end the centre rod has a narrow outlet slit where particles of a certain size arrive. This size can be tuned by varying the voltage applied to the electrodes.

The other particles are either deposited on the walls or they are transported out of the DMA with the

[21] Berne University of Applied Sciences, School of Engineering and Information Technology, Results of GPU Measurements at Zurich Airport, 26. October 2005. Report B174 (not published)

sheath air. The number concentration of the size selected particles is determined using a Condensation Particle Counter (CPC). Since the particles are too small for optical detection, they have to be magnified by condensing volatile material onto their surface. This is accomplished by guiding the fine particles through saturated vapour of butanol (or vapour of another volatile substance) and subsequently cooling the mixture. The vapour molecules use the particles as condensation nuclei for the formation of droplets, one out of each particle. The final size of the butanol droplets is around one micron which is just large enough to be detected using light scattering.

By computer control the DMA voltage is increased so that larger and larger particles are fed into the CPC. The software combines CPC counts with particle size calculated from the DMA voltage and calculates a size spectrum.

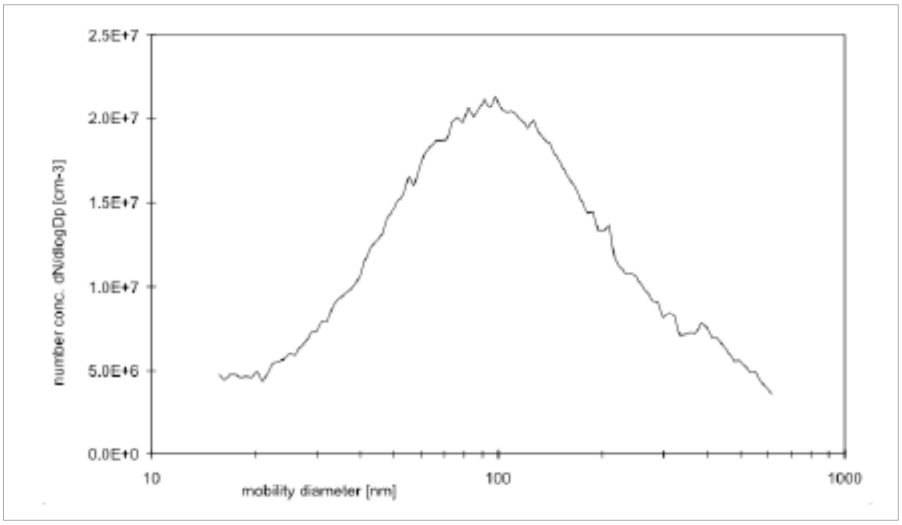

Fig 38: Typical size spectrum from SMPS measurement.
The particles were emitted from a diesel engine at low rpm and high load.

9.3.2 ELPI[22]

The ELPI (Electrical Low Pressure Impactor) as shown in a block diagram is a 12 (13) stage cascade impactor that measures particle number concentrations as a function of aero-dynamic diameter.

[22] Berne University of Applied Sciences, School of Engineering and Information Technology, Results of GPU Measurements at Zurich Airport, 26. October 2005. Report B174 (not published)

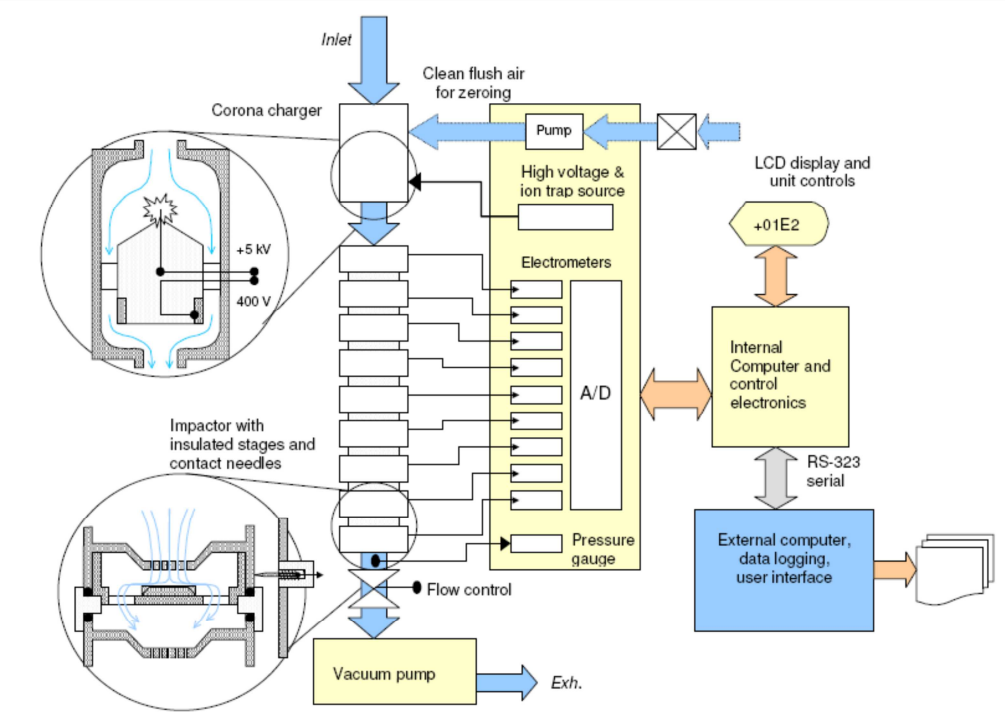

Fig 39: ELPI block diagram

An impactor is a size selective element where the particle is guided through a nozzle behind which a plate forces the gas flow to change direction abruptly. Due to their inertia, particles cannot follow the bent gas streamlines but are driven towards the plate. Only friction with the gas makes them accommodate with the new flow direction. Depending on their size-to-mass ratio - that is, their mass density - the particles are deposited on the plate and thereby removed from the particle flow. The diameter defined by this separation process is called the aerodynamic diameter. The size limit between particles that pass the impactor and those being deposited on the plate – the cutoff diameter - depends on the velocity in and pressure drop across the nozzle, the geometry of the impactor and, as stated before, particle mass density. By variation of these parameters, usually the pressure behind the nozzle, the cutoff diameter is adjusted to the desired value.

In the ELPI, 12 impactor stages operate in sequence, each with a smaller cutoff diameter. Thus, particles collected in one stage belong to one size class which is limited by the cutoff diameters of the two subsequent impactor stages. After size classification, the deposited particle load has to be quantified. In classical impactor design, the particle mass deposited on the plate is determined by gravimetric analysis, but this technique has shortcomings as it needs high particle loads to be accurate, and analysis is carried out after measurement - the method is off-line. In order to make ELPI an on-line instrument, particles are electrically charged before they enter the cascade impactor. Each impactor collector plate is connected to an electrometer amplifier. Thus, instead of collecting deposited particle mass, the plates take up the electric charge of the impinging particles and pass it on as measurement current.

Number size distributions are calculated from the measured current, the size dependent average charge per particle, and the deposition probability per impactor stage. The time resolution is around one second; the covered particle size range is from 30 nm to 10 mm.

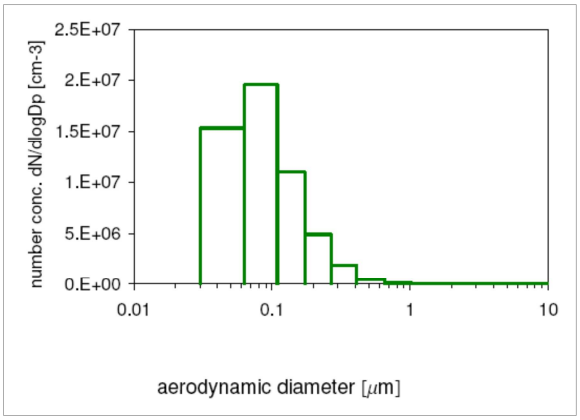

Fig 40: Typical ELPI size distribution. Particles were sampled from the exhaust pipe of a common rail diesel passenger car at 70 km/h on a roller dynamometer

9.3.3 P-Trak[23]

Particles are drawn through the P-TRAK Ultrafine Particle Counter using a built-in pump. Upon entering the instrument, particles pass through a saturator tube where they mix with an alcohol vapor. The particle/alcohol mixture is next drawn into a condenser tube where alcohol condenses on the particles causing them to grow into droplets that can be counted more easily. The droplets then pass through a focused laser beam, producing flashes of light. The light flashes are sensed by a photodetector and counted to determine particle concentration.

- Concentration Range: 0 to 5 x10^5 particles/cm^3
- Particle Size Range: 0.02 to greater than 1 micrometer (20 - >1000nm)
- Temperature Range: Operation 32 to 100℉ (0 to 38° C)

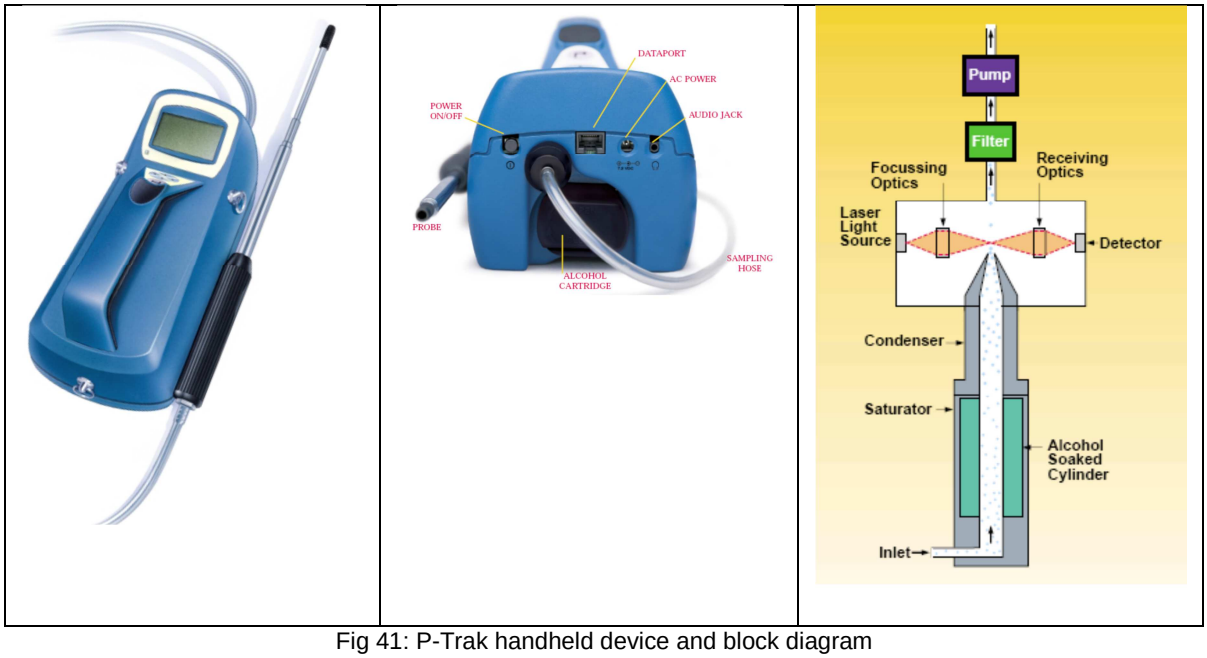

Fig 41: P-Trak handheld device and block diagram

[23] TSI Incorporated: P-Trak™ Ultrafine Particle Counter, P/N 2980128, 1999

9.3.4 MiniDisc

The miniature diffusion size classifier (or miniDiSC for short) is a new instrument for nanoparticle measurement. It was designed with ease of use in mind - it is truly handheld: it operates without working fluids or radioactive sources, operates in any orientation and on-the-go. It can be used for personal exposure monitoring or quick walk-through surveys of an area of interest, such as a workplace, or an urban area with heavy traffic. Its concentration detection limit is ideally suited for typical ambient particle concentrations. The miniDiSC is less accurate than traditional particle instruments such as CPC (condensation particle counter) and SMPS (scanning mobility particle sizer), available from e.g. TSI or Grimm, but this is often more than compensated for by its smaller size and easier handling. In general, measured concentrations and average diameters agree to within 30% with CPC and SMPS. Compared to its main competitor (the handheld CPC) it is smaller, easier to use and also delivers an average particle diameter and lung-deposited surface area and not only the particle number concentration.[24]

Particles are firstly charged in a unipolar manner in a diffusion charger. They are subsequently led through a diffusional precipitator in which a part of the particles is precipitated. The diffusional precipitator current is measured and a value for the number concentration is evaluated from the current. A single diffusional precipitator may be used for this. According to preferred embodiment, a means for measuring the influence current and/or a particle electrometer are additionally present, by way of which one may measure a complete current. The latter additionally permits the evaluation of the average particle size. Additionally, one may determine an elementary carbon total quantity from the average particle size with the help of a measurement of the photoelectric charging carried out in parallel.[25]

- Concentration range: 1,000 – 1,000,000 part/cm^3
- Particle size range: 10-300 nm
- Resolution: The miniDiSC has a time resolution of 1 second

Fig 42: MiniDiSC handheld particle counter

9.3.5 EDB

The electrical diffusion battery (EDB) is a new approach where particles are charged by a corona charger before entering the diffusion battery. The stages of the screen-type diffusion battery are insulated electrically. Each stage is connected to a current amplifier. These currents are used to derive the size distribution.

[24] www.fierz.ch/minidisc, (July 2012)

[25] http://www.freepatentsonline.com/7549318.html (July 2012)

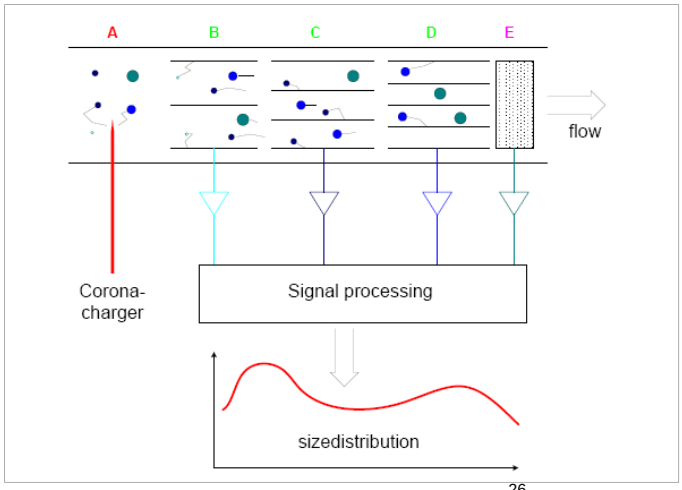

Fig 43: Electrical diffusion battery[26]

9.3.6 Condensation Particle Counter (CPC)

The TSI Model 3010 Condensation Particle Counter (CPC) measures total airborne number concentrations in the particle diameter range from 0.007 to approximately 3 µm. On entering the CPC, particles pass through a saturator where the working fluid (butan-1-ol) evaporates into the gas stream. The flow becomes saturated with vapour of the working fluid before passing into a condenser where supersaturation of the vapour occurs. Under this condition the vapour condenses onto the particles to form droplets larger in diameter than the original particles. The droplets pass through a laser on leaving the condenser, and light scattered by the droplets is collected and focused onto a photo-detector. The photo-detector converts the light signal to an electrical pulse that is recorded as a particle count.

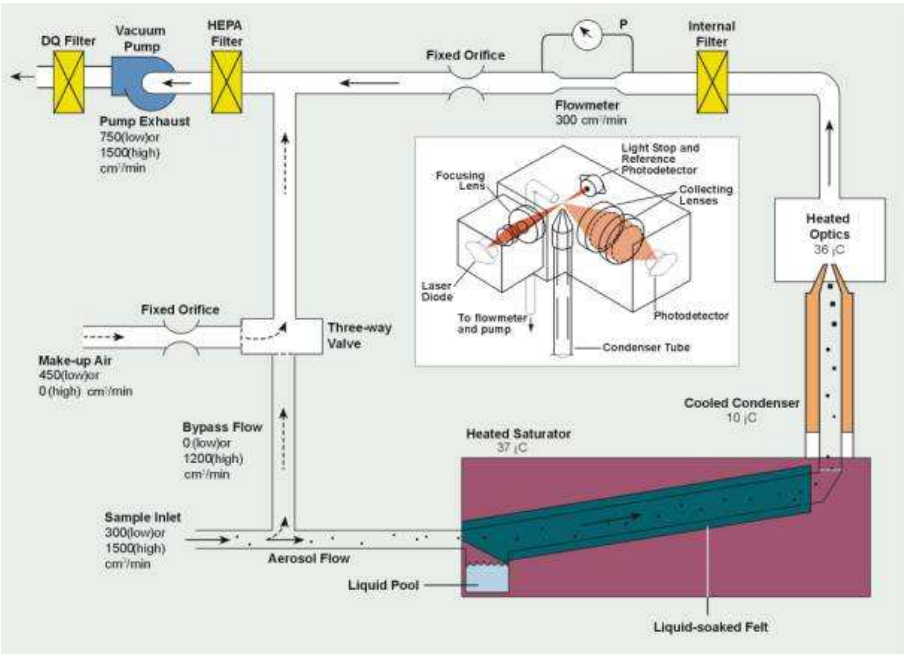

Fig 44: Condensation Particle Counter

[26] http://www.empa.ch/plugin/template/empa/*/70052/---/l=2 (July 2012)

9.4 Measurement recommendations for airports

9.4.1 General requirements

1. Qualification of measuring entity
   Whoever conducts the identification and assessment by measurement of the inhalation of hazardous substances exposure at the workplace must have the necessary technical and organizational prerequisites. This includes 1. the equipment for the performance of workplace measurements and 2. relevant literature (e.g. TRGS, sector- or activity-specific aids).

   A measuring body must be capable of handling and documenting in a proper fashion the following tasks which are part of the identification and assessment:
   1. Identification of the relevant boundary conditions
   2. Recording of the hazardous substances
   3. Sampling
   4. Transport and storage of the samples,
   5. Analysis (can also be performed by subcontract)
   6. Identification of the measured values
   7. Acquisition of measuring results and the finding (assessment)
   8. Archiving of crude data and reports.

2. Agreement of involved parties on the measurement campaign
   When conducting measurements at workplaces, it is paramount to obtain the permission of all involved parties to conduct such measurements. At airports, this can typically include:
   - The airport authority (Apron Control, Ramp Safety, Airport Duty Office)
   - The company or companies active at the measurement location (e.g. handling agent, airline (aircraft crew), other service provider)
   - Additional entities, e.g. staff representation party (union), regulating entities (OHS authority, environmental office, …)

9.4.2 Measurement planning

1. The purpose and aim of the campaign has to be identified and agreed (e.g. short-term or long-term exposure measurements, mean or min/max results, information on particle number, size and also chemical properties – or not, background, source specific concentrations)
2. Identification of location (sources) and reference location: the measurements locations should be chosen with regard to the aim of the sampling. This could be:
   - upwind or downwind, depending if the sampling should focus on background or direct emission situations
   - in the proximity of specific sources (e.g. downwind of a specific runway, taxiway or apron location) or distant to the source (e.g. outside the airport). In the case of a more remote sampling location, the potential influence of different sources has to be considered
3. Choice and justification of substances: While particles of different sizes might be the focus of the measurement campaign, it is recommended to include several other substances in the campaign as well. The results from other substances can help to better interpret the results of UFP measurements and support thesis that are developed from initial results. Typical additional substances that are recommended to be measured include (but are not limited to):
   - DME (diesel motor emissions)
   - VOC (volatile organic compounds)
   - Formaldehyde
   - polycyclic aromatic compounds

- o CO (carbon monoxide)
- o CO_2 (carbon dioxide)
- o NOx (nitrogen oxides)
- o O_3 (ozone)
- o $PM_{1, 2.5, 10}$

4. Choice of suitable equipment: Long-term experience has demonstrated the variability of particle size distribution from below 10nm to more than 500nm. In addition with situations found at airports, the measurement range has to cover 7nm to approximately 600nm. At the same time, particle concentrations of up to 10^8 particles/cm^3 have been found (sum of all sizes). In the case that the anticipated measurement equipment does not cover the full range, it is advised to use several, even different measurement devices (and methods) in parallel (co-location of monitoring device).
5. Additional specifications:
   - o The duration of the measurement campaign can be for the full workers shift or it can be over the length of a particular activity, e.g. during an aircraft handling event (turn-around of the aircraft)
   - o The on-site specific location with regard to the exposition has to be defined:
     - One option for sampling the air is to use portable sampling devices that can be carried by the workers without obstructing their work (such an equipment is e.g. the portable minidisc). Such equipment should be light weight, carried in front of the worker and internally powered.
     - Another option is to set the equipment up in the closer proximity of the emission source, but stationary, where the equipment can be larger and externally powered (e.g. the SMPS). Such equipment is usually sampling the air at heights of 1.5-1.8 m above ground
   - o It should be decided if also single particle analysis is conducted or not. For single particle analysis, an electrostatic separation and a visualization with a transmission electronic microscope and elemental analysis with radiation spectroscopy is applied. In this case, proper sampling equipment is needed.

9.4.3 Measurement campaign

The following steps should be observed when the sampling is performed:

1. Preparation of equipment: this can include calibration, zero-setting, reference gas handling and pre-heating of the sampling tubes to eliminate volatile components
2. Sampling: During the sampling, the equipment needs to be regularly checked for its proper functioning (power availability, unobstructed air inlet, reference gases or liquids)
3. Activity recording: all work place or background activity has to be seamlessly recorded in order to properly interpret the obtained measurement results. This could include the operation of ground support equipment (various types, tasks and durations) or activity in the background like taxiing aircraft or street traffic. All recorded activities require a time stamp.
4. Collection of secondary information like meteorological conditions or ambient air quality information. In the case of meteorological information, the wind speed and direction is most important, besides pressure, temperature and relative humidity.

9.4.4 Measurement analysis and reporting

1. The data analysis display is done as a particle size distribution diagram, number concentration with a differential scale (dN/dlog Dp, to allow for equipment comparison) and alternatively the number concentration over the full sampling range with additional information about the distribution (geometric mean, maximum and minimum of the size distribution). For particle numbers and sizes, both the mean and median values should be presented. The time resolution usually is one-

minute average values, so the results are displayed in # particles/cm^3*min. Additional analysis include the loss in the sampling tubes and surface and volume distribution if the majority of the particles are ball-shaped aggregates.

2. The interpretation of the results should be done based on the evidence (measured conditions and recorded activities) and on the proven causality.
3. The study report contains all information pertaining to the measurement campaign with the study setup (aim, locations, substances, equipment, results, secondary information and activities).