UBA Workshop

Aviation Particle Emissions and Airport Air Quality

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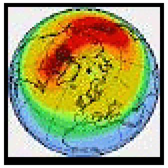

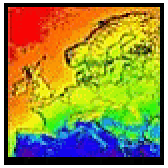

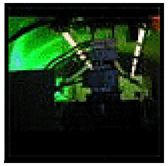

Definitions

Aerosols
suspension of liquid or solid particles in a gaseous medium

Size Range
< 10 nanometer (10^{-9} m) to approx. 100 µm (10^{-4} m)

Sources
gas-to-particle conversion by nucleation of gaseous species
condensation of gaseous species on existing nuclei
coagulation of particles
mechanical processes (dust, sea salt, ...)

Characteristic Parameters
- number concentration
- mass concentration
- size distribution
- chemical composition
- phase, volatility, solubility

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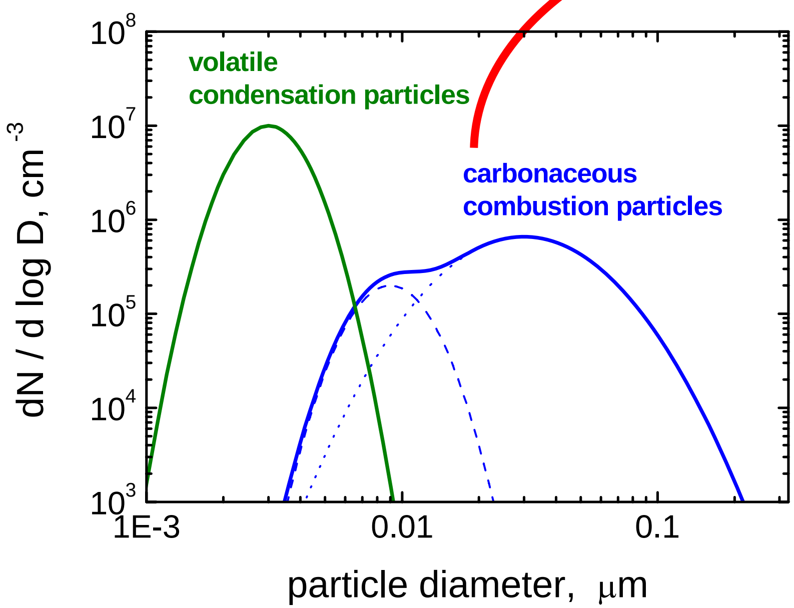
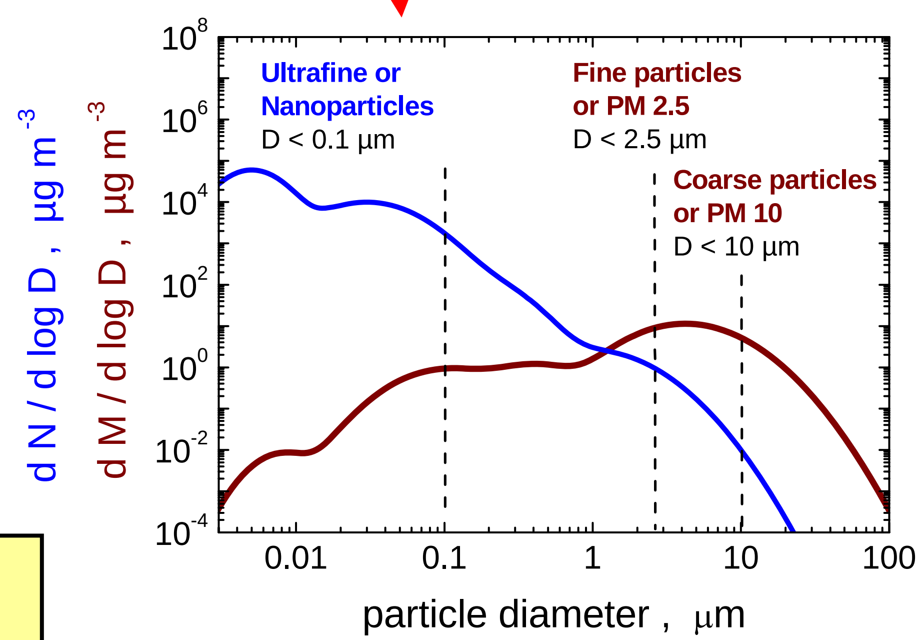
Particle Size Distributions

Combustion Emissions

important source for nanoparticles

Urban Atmosphere





Chemical Composition

elemental carbon

organic carbon (incl. PAH)

sulphate + water

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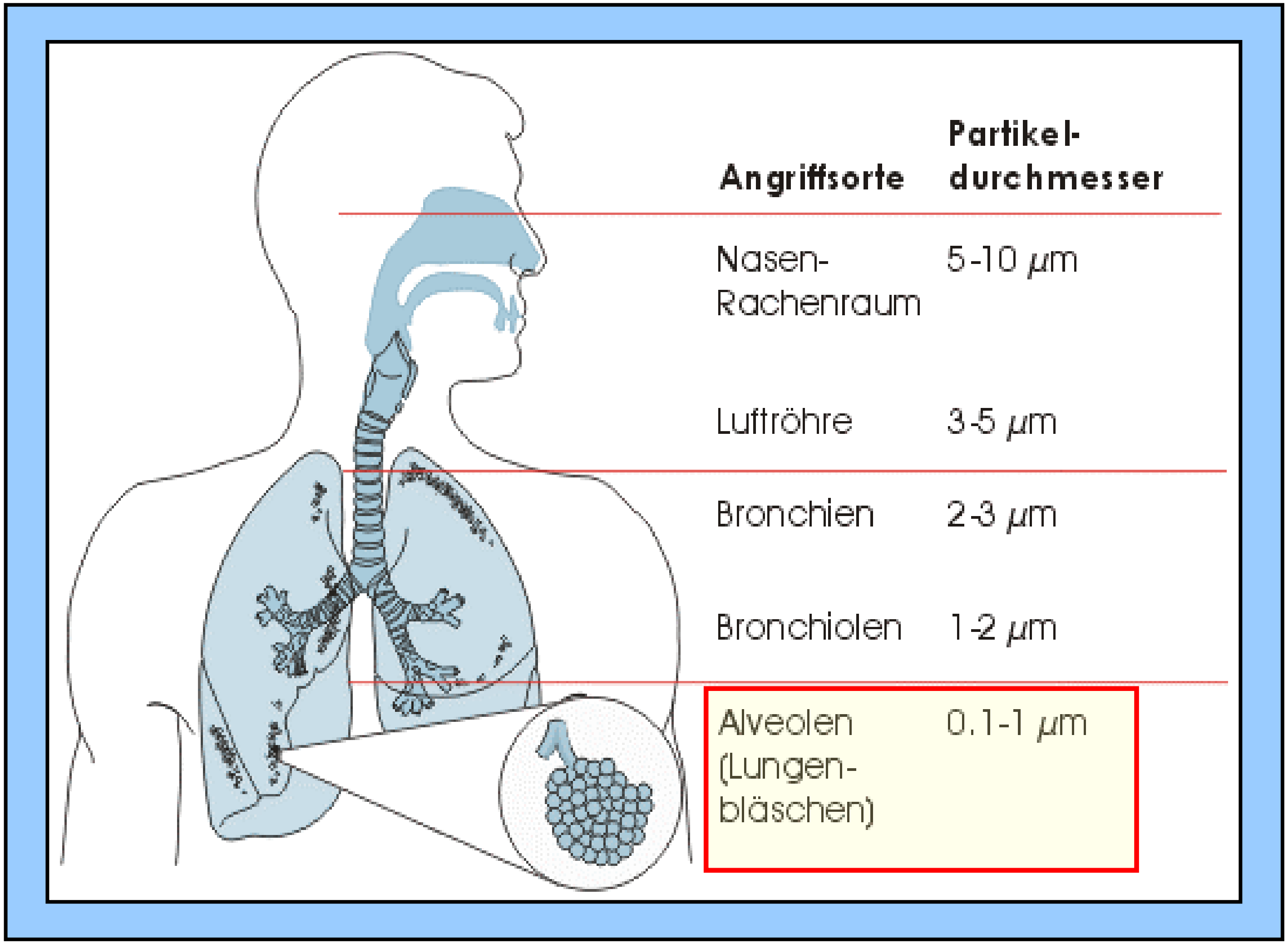
Health Effects



Relevance of Nanoparticles

Properties of nanoparticles compared to coarse and fine mode particles

- high number concentration, urban air 10^4 - 10^5 cm^{-3}
- low mass concentration, ≤ 5% of total mass
- high mobility and high penetration depth into the respiratory tract
- high surface / volume ratio, large potential for carrying toxic compounds into the respiratory tract
- no efficient cleaning mechanism of the respiratory system for insoluble ultrafine particles deposited in the alveoles
- no efficient cleaning technologies for nanoparticle emissions for technical (combustion-) processes
- Atmospheric residence times in an urban atmosphere:
  D = 0.1 - 10 µm 1 week
  D = 0.01 µm 15 min

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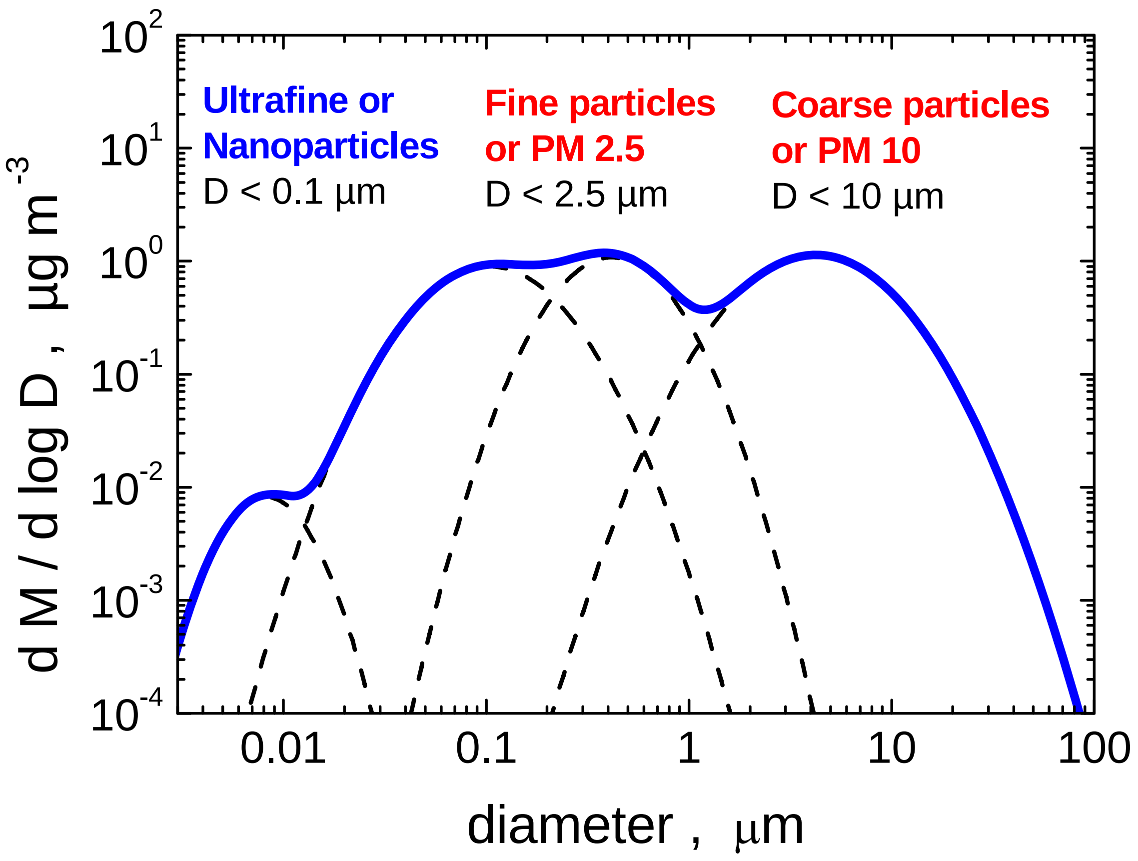
Air Quality Regulatory Parameters



mass-based parameters are dominated by the fine/coarse particle mode
number-based parameters are dominated by the nanoparticle mode

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Particle Emissions from Aircraft Engines

Experiments performed under the lead of DLR Institute of Atmospheric Physics:

SULFUR experiments (1994 - 1999)	airborne experiments on the impact of the fuel sulphur content on the particle emissions of aircraft engines under cruise conditions
Partikel und Zirren (PAZI) (2000 - 2003)	national programme on the investigation of the interaction of aviation-related particles and cirrus clouds, field studies, combustion experiments and aerosol chamber studies contributed
PartEmis experiment (2000 - 2003)	test rig studies on the impact of operation operation conditions, fuel sulphur content and turbine sectors on the properties of particles emitted from an aircraft engine

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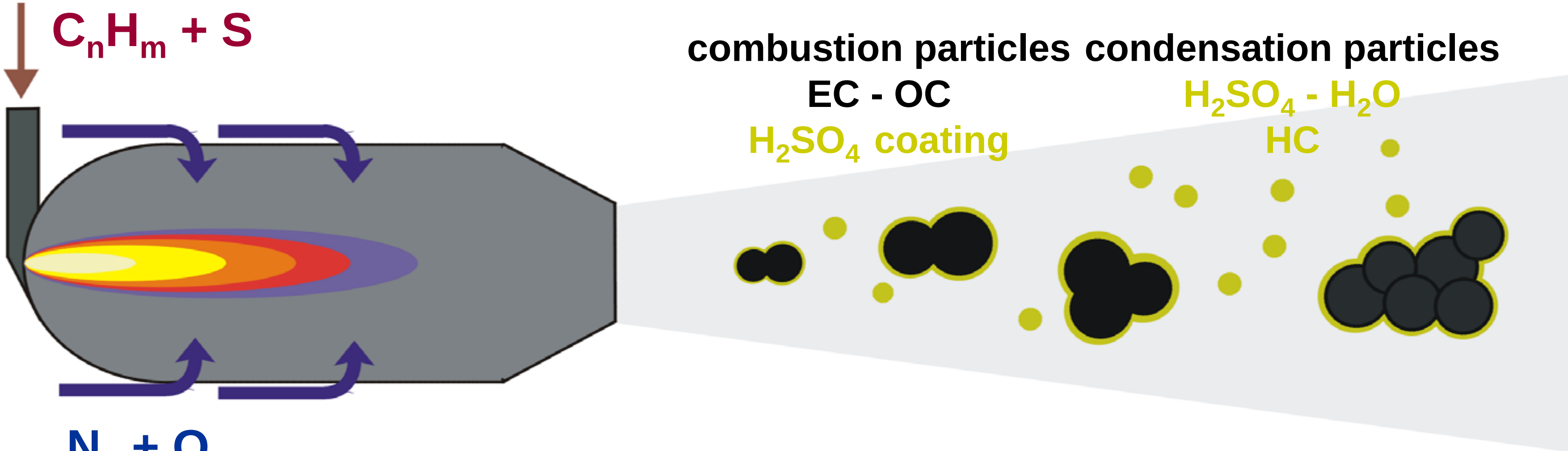
Particle Generation in a Gas Turbine



Exhaust products

$C_n H_m + S \Rightarrow$ carbonaceous combustion particles, SO_2 and H_2SO_4

Carbonaceous combustion particles	coated with sulphuric acid
Gas-phase sulphuric acid	
Volatile condensation particles	forming from gas-phase sulphuric acid by nucleation in the cooling exhaust gas

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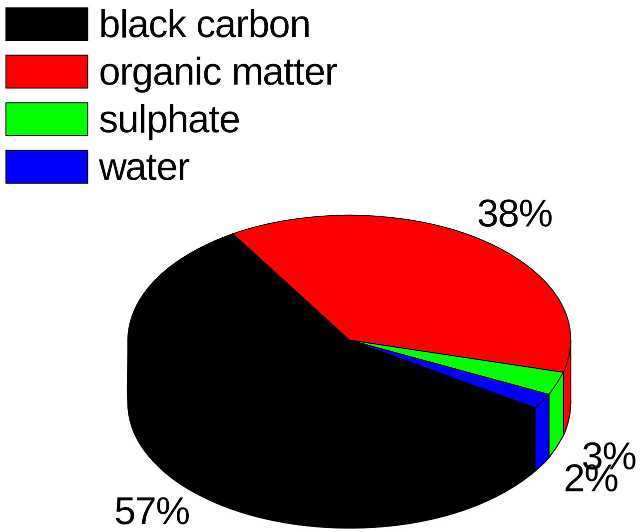
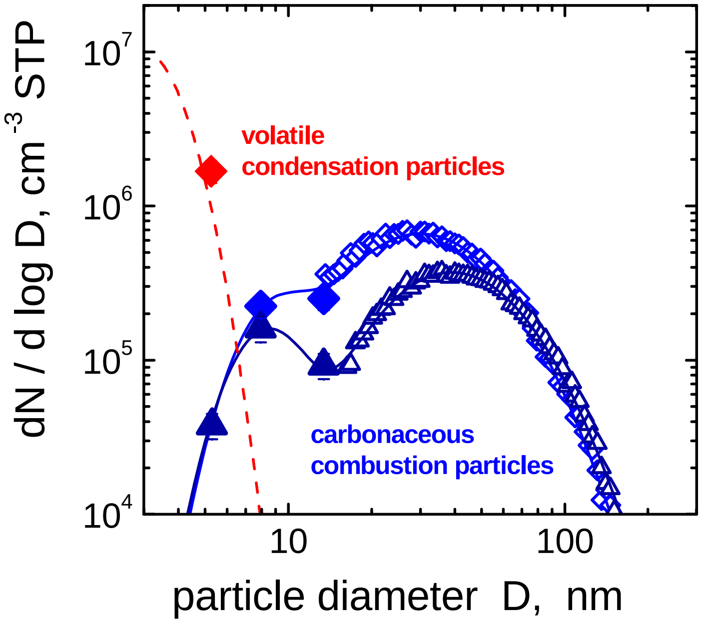
Aircraft Engine Exhaust Particles

Chemical Composition



Particle Size Distribution



- increasing particle emissions with increasing engine load
- decreasing organic fraction with increasing engine load
- emission of volatile condensation particles during ground operation unknown
- particle emission properties for APU's unknown

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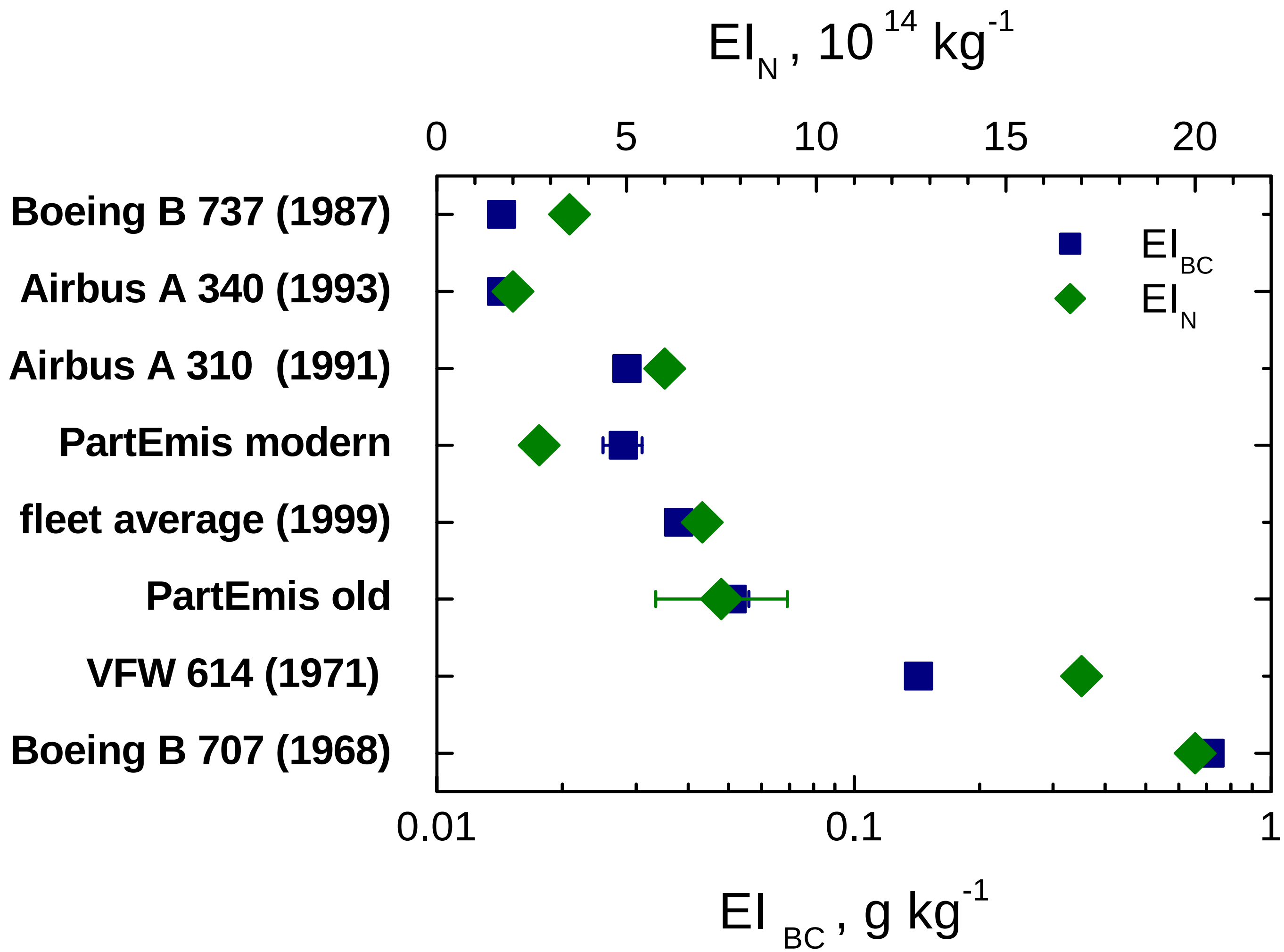
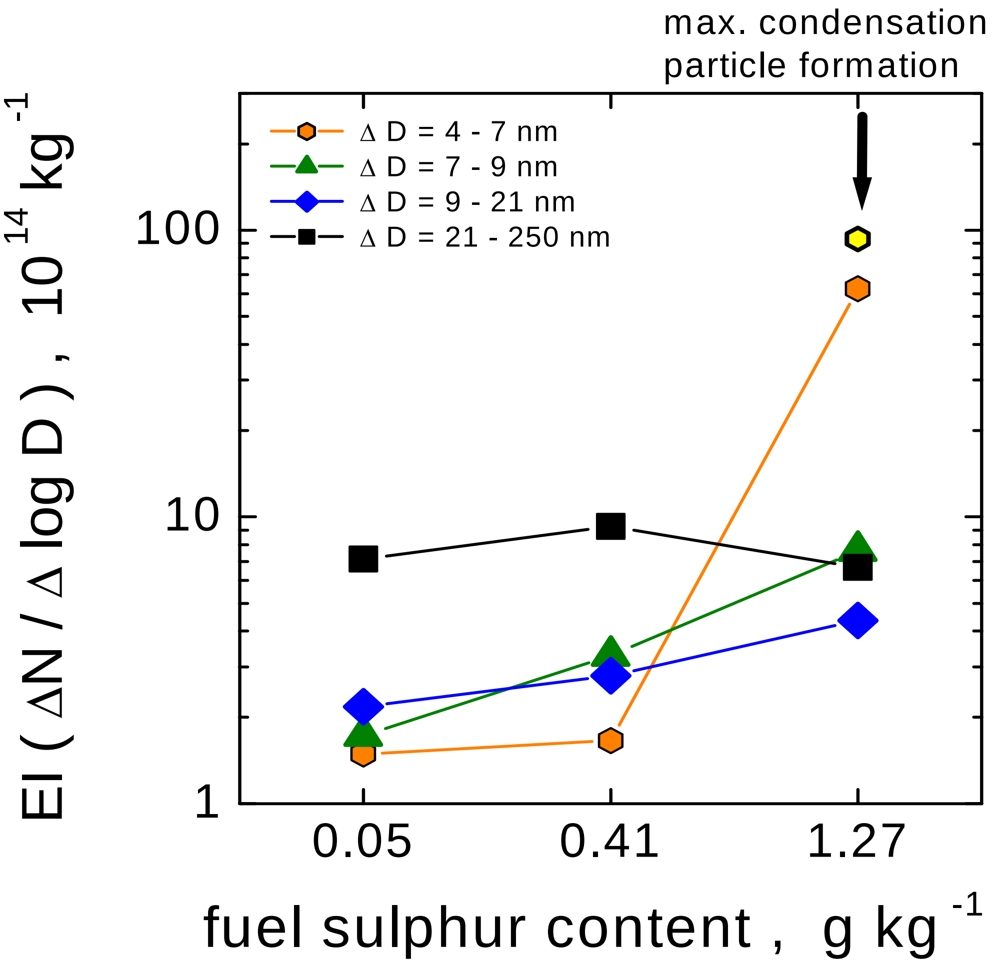
Particulate Matter Emission Properties



Volatile Particle Formation



Burning fuel with low (0.05 g kg^{-1}) or medium (0.41 g kg^{-1}) FSC:

no volatile nucleation particles observed in the size range D > 4 nm;

burning high (1.27 g kg^{-1}) FSC :

formation of volatile nucleation particles observed;

N (D < 10 nm) / N (total)

low + medium FSC	< 10%
high FSC	> 90 %

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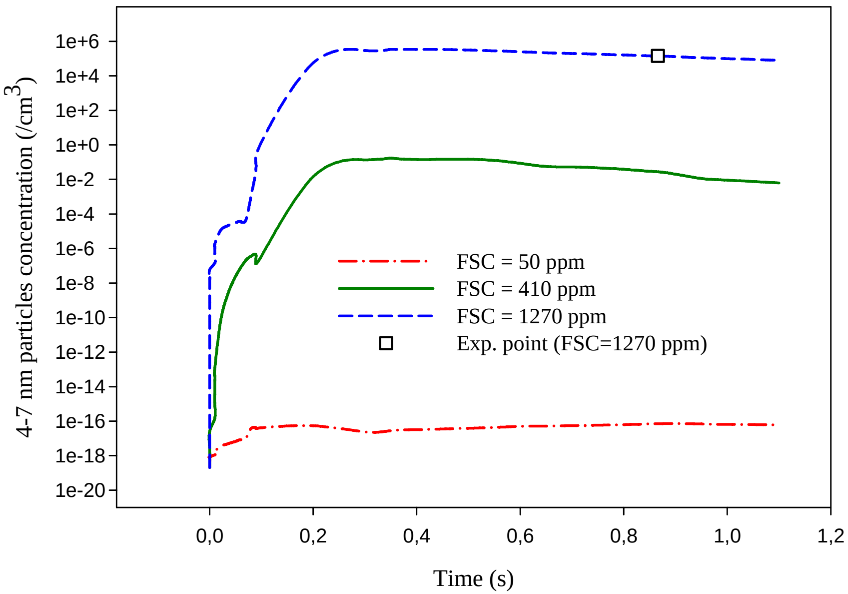

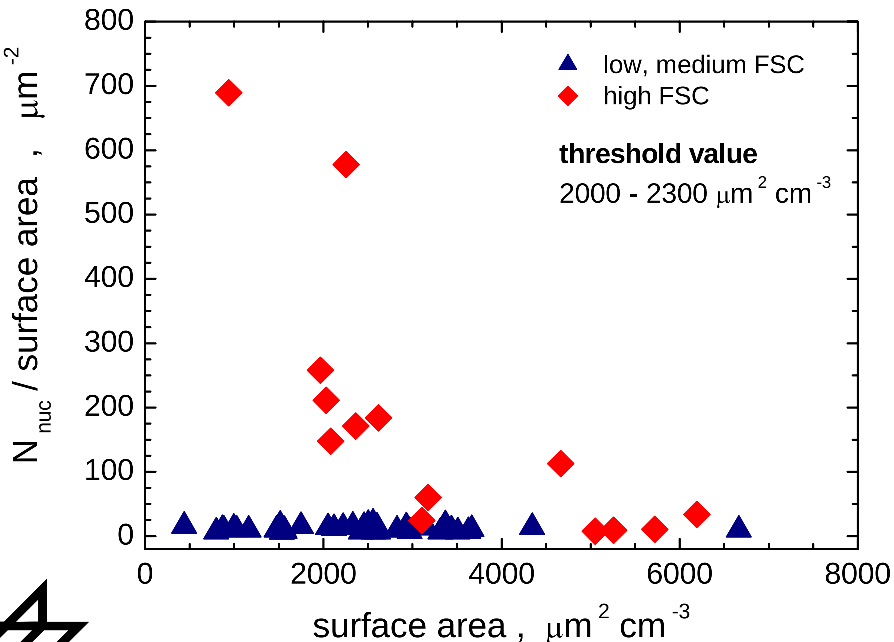

Formation Conditions

- high FSC $\Rightarrow$ high H_2SO_4

sulphuric acids reaches super-saturation in the plume which causes particle nucletaion from the gas phase: temporal evolution of condensation particles as a function of FSC (Vancassel et al., 2004)

- low surface area density of combustion aerosol

combustion particle surface acts as a sink for condensable species quenching particle nucleation; for particle nucleation the surface density threshold value has to be exceeded

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Particulate Aircraft Engine Emissions

- aircraft engines emit a considerable amount of insoluble sub-0.1 µm sized combustion aerosol particles
- volatile particles form by nucleation in the cooling exhaust plume
- the fraction of particulate organic material increases with decreasing engine load
- the emission of combustion particles and of volatile (soluble) nucleation particles during ground operation is not (well) known
- the particle emission properties of APUs are almost unknown

Emissions of aircraft engines and APUs are assumed to make a considerable contribution to the load of airport air concerning ultrafine or nanoparticles, both volatile / soluble or insoluble, **in terms of particle number** .

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Particle Measurement Harmonisation

- There is general consensus that the regulations regarding the emission of visible smoke for aircraft engines, which have been in place for decades, do not address and are not relevant to the measurement of particles responsible for health effects and environmental impacts.
- Working Group 3 of the ICAO Committee on Aviation Environmental Protection (CAEP) has asked the SAE E-31 committee and the European Commission AERONET Group for technical assistance in developing appropriate particulate characterisation techniques for routine certification of aircraft turbine engines.
- US EPA requests the consideration of both volatile and nonvolatile particles in the process of establishing Aerospace Recommended Practices (ARP) for the measurement of particle emissions from aircraft engines.
- The European Network of Excellence ECATS (Environmentally Compatible Air Transport System) will put one focus on the role of aircraft emissions on local air quality.

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Current Status of Regulations

- Emissions from aircraft gas turbines are presently regulated for emissions of:
  - Oxides of nitrogen (NO and NO_2)
  - Carbon monoxide
  - Total unburned hydrocarbons
  - Carbonaceous particulates (soot) as correlated to visible smoke.
- As a result of the control of smoke, soot and any aerosols resulting from condensed hydrocarbons or sulphur that are quantified by a smoke number are currently regulated.
- There is general consensus that the regulations regarding the emission of visible smoke for aircraft engines, which have been in place for decades, do not address and are not relevant to the measurement of particles responsible for health effects and environmental impacts.
- Control of particles in the range of D = 10 -100 nm is becoming a requirement.

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Defining What to Measure

- Principal aerosol parameters are mass, number, and size distribution. An agreement is required to determine which fraction of the exhaust aerosol becomes subject to regulatory rule. This agreement is important if a size distribution measurement is considered.
- From recent scientific investigations, it is known that refractory carbonaceous particles make up the most stable fraction of the exhaust aerosol.
- The volatile nanoparticle mode is highly variable and depends strongly on the sampling conditions and the fuel used.
- When setting up a new regulatory standard for the measurement of particulate emissions from aircraft turbine engines, the conditions for sampling and considered particle size ranges have to be described very carefully to define the object of measurement unambiguously.

Aerospace Information Report 5892

Non-volatile Particle Measurement Techniques

The process of developing recommendations for particle measurements is being initiated in response to expressed interest from a variety of regulatory and certification agencies. The scope of these recommendations includes:

Measurements at the engine exit plane

Characterisation of non-volatile particles

Exclusion of the characterisation of volatile particles

Volatile aerosols have not yet formed when the exhaust leaves the engine and depend sensitively on ambient environmental conditions. Measurement of condensable precursor gases that contribute to volatile aerosol formation and particle growth is a separate and distinct measurement issue and will be treated separately.

Summary

Aircraft engines and most likely APU's as well are emitting volatile and nonvolatile particles in the nanometer size range which are highly relevant concerning air quality issues.

The emission of nonvolatile combustion particles is a property of the engine itself while the emission of volatile particles depends on fuel composition and sample treatment.

The process of developing recommendations for particle measure-ments in the exhaust of gas turbines is being initiated.

Emission properties of aircraft engines concerning volatile and nonvolatile particles are characterised; similar information for APU's is not available.

Concerning the effect of particle emissions from aircraft engines and APU's on airport air quality, particularly with respect to source apportionment, **dedicated field experiments are required**.

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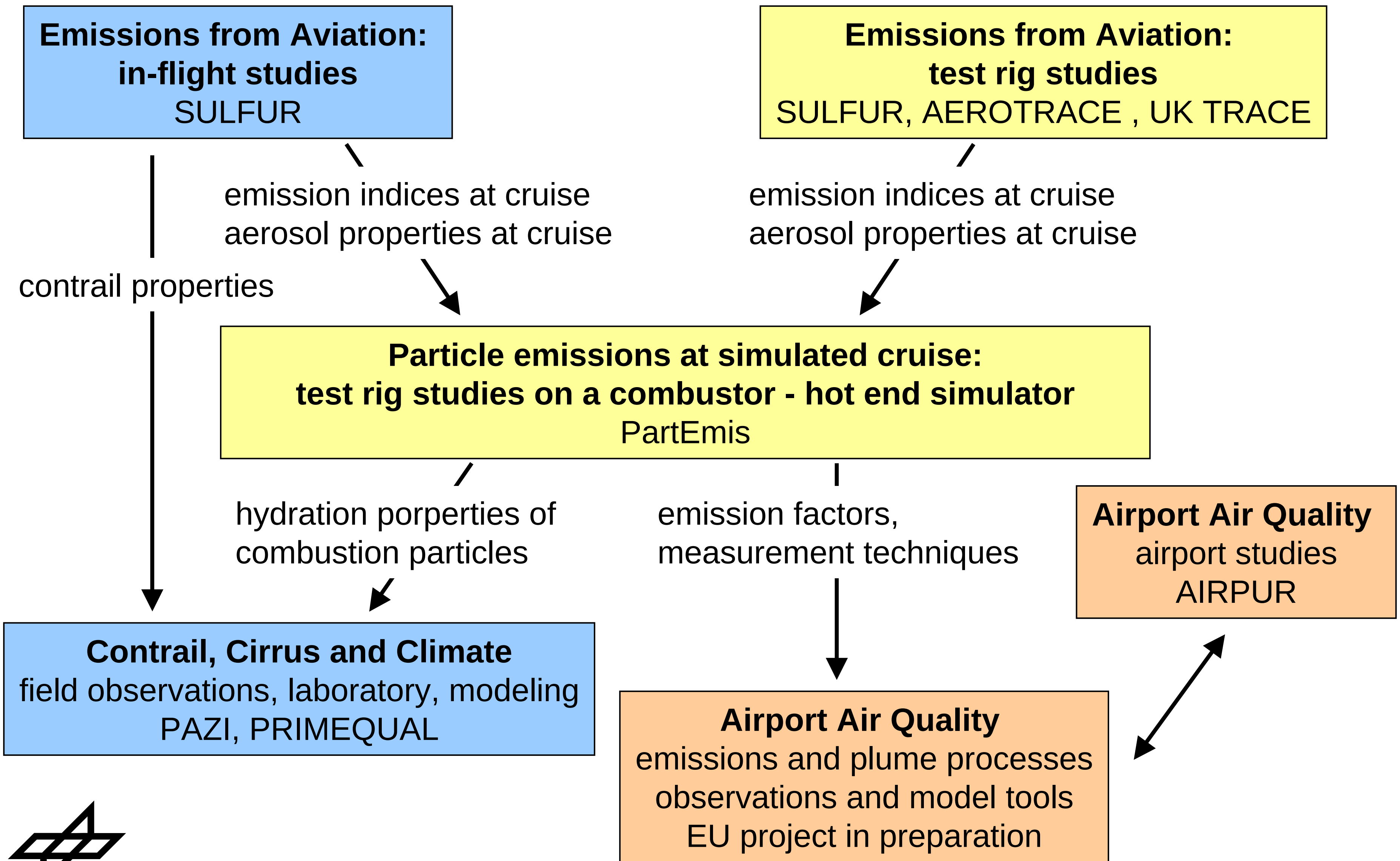
Relationships of European Research Programmes



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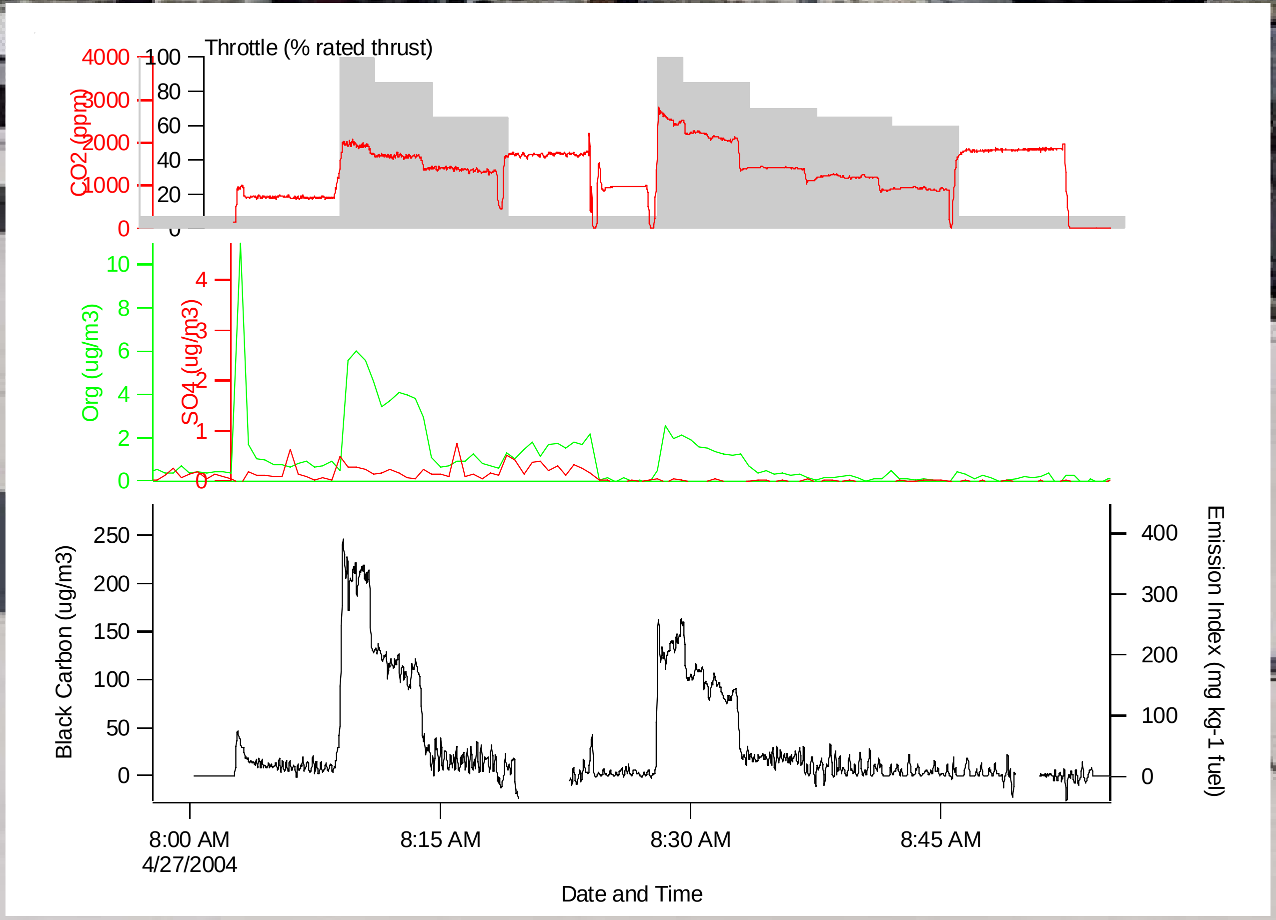
NASA Aircraft Particle Emissions Experiment

APEX April 2004



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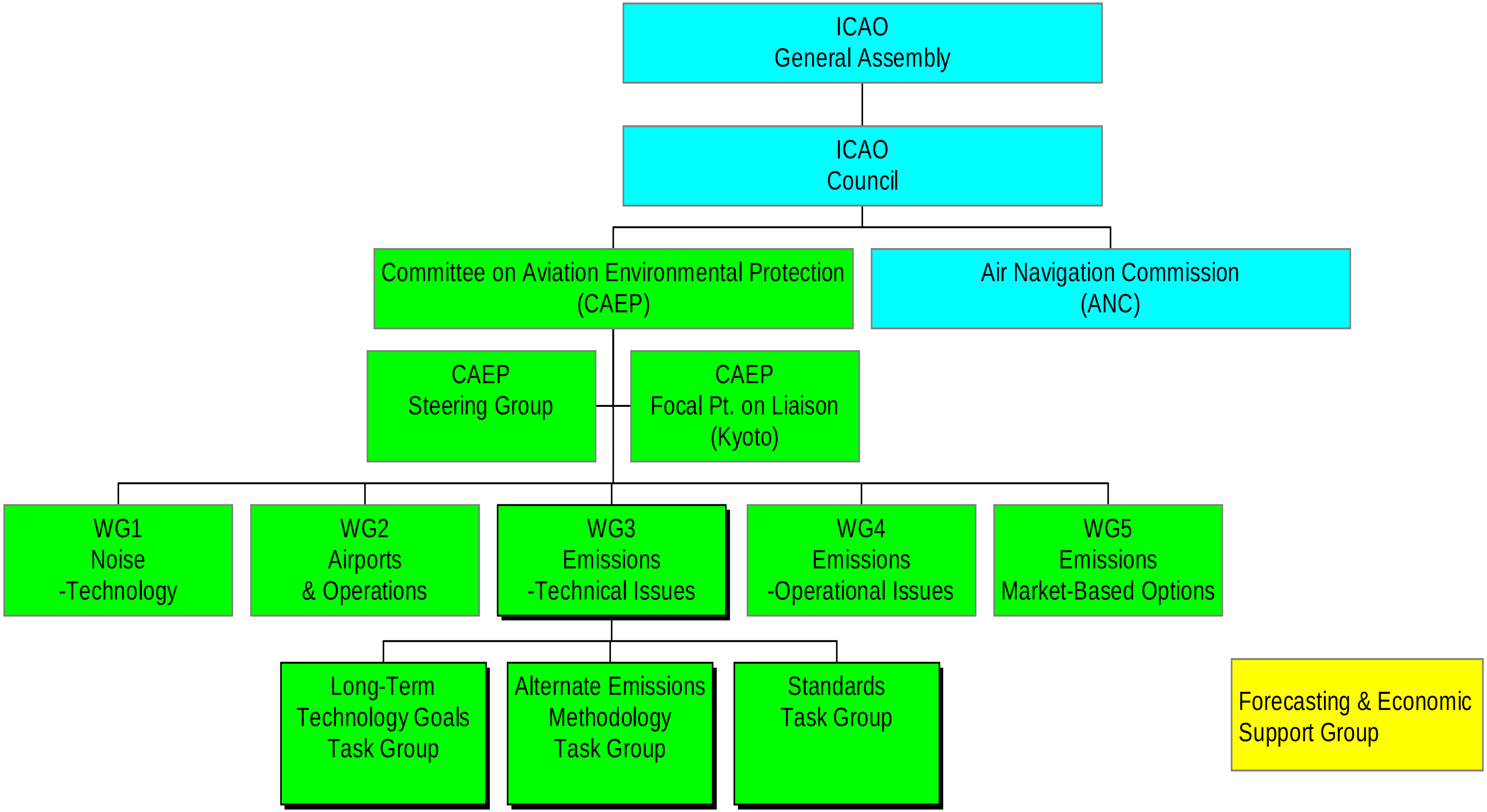
A2: International Civil Aviation Organization ICAO



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A3: Current Aerosol Measurement Methods

Mass

Measurement Method	Subject of Measurement	Comments
Gravimetric analysis	Total particulate matter, total mass	off line, filter samples
Combustion of filter samples and CO_2 detection	Total carbonaceous mass, TC	off line, filter samples
Combustion analysis including OC/EC separation	Organic carbon (OC), elemental carbon (EC) OC + EC = TC	off line, filter samples
Optical absorption photometry	Black carbon (BC) BC ≅ EC	on-line, filter samples time resolution ≥ 1 min
Laser induced incandescence	Black carbon (BC)	on-line, *in situ*

Number and Size

Condensation Particle Counter - provides on-line integral number concentration data from a certain lower particle threshold diameter ≥ 5 nm

SMPS - provides particle size distributions in the diameter range 0.01 - 1 µm, no on-line data, no operational device

Optical Particle Counter - provides on-line size distributions in the diameter range > 0.1 (0.3) µm

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A4: ICAO landing and take-off cycle (LTO)

1. Taxi /idle	7% Take off thrust	26 minutes
2. Take off	100 % Std Day Take off thrust	0.7 minutes
3. Climb	85% Take off thrust	2.2 minutes
4. Approach	30% Take off thrust	4.0 minutes