REspiratory Health Effects of PM generated by Aircraft Turbine Engines (REHEATE)

an *in vitro* study for evaluating the toxicity of non-volatile particulate matter from an aircraft turbofan engine on bronchial epithelial cells

Mathilde N. Delaval[1] & Hulda R. Jonsdottir[1], Alejandro Keller[2], Benjamin Brem[3], Lukas Durdina[3], Miriam Elser[3], Prem Lobo[4], Heinz Burtscher[2], Marianne Geiser[1]

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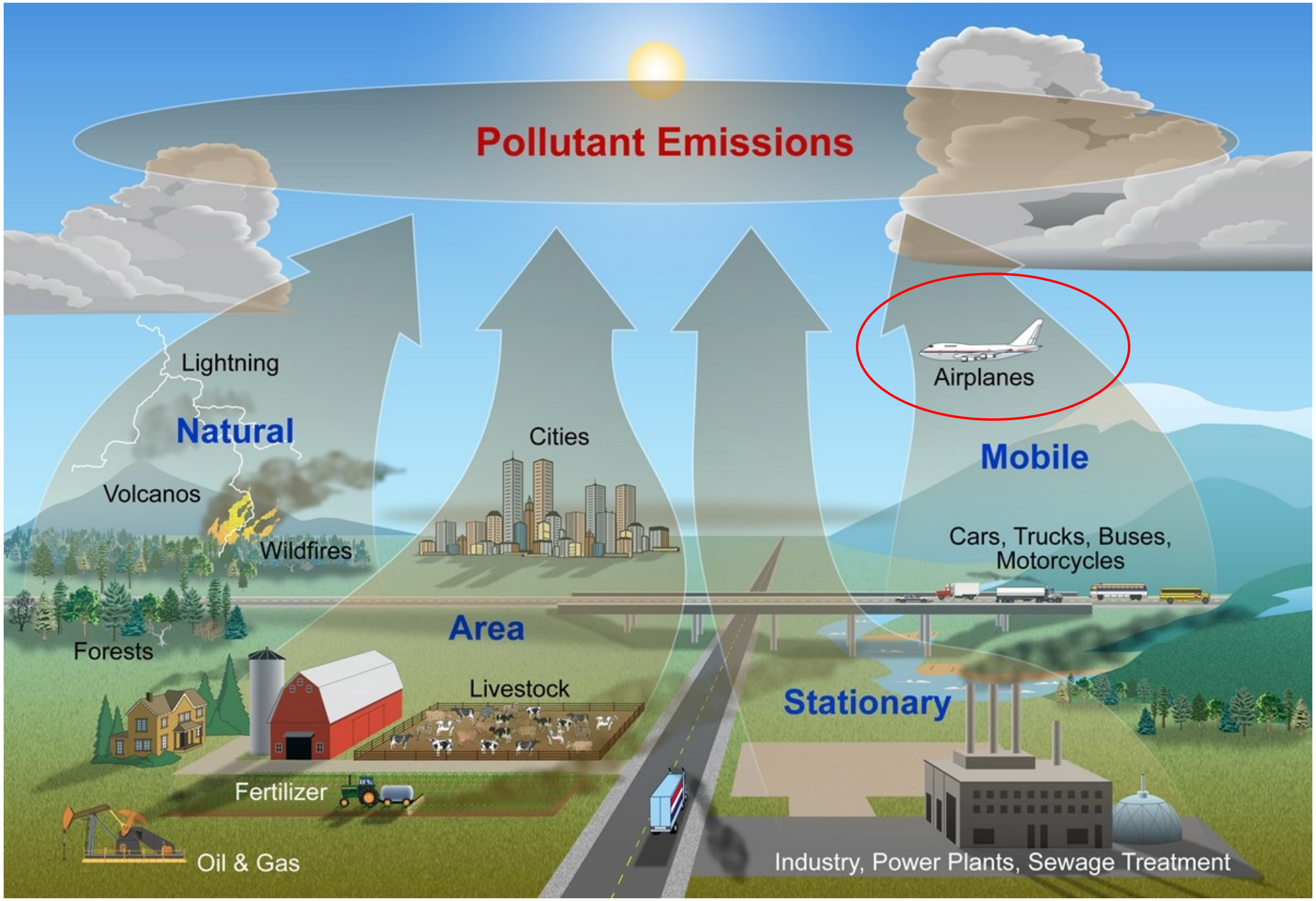
Contribution of aircraft emissions to air pollution



https://www.nps.gov/subjects/air/sources.htm

Health effects of aircraft emissions

- Aircraft emissions comprise gaseous components and particulate matter (PM)
- nvPM size are generally below 100nm

- Potential adverse health effects
    - Information derived from existing documentation on health effects of particle emissions generated from gasoline and diesel combustions
    - Traditional vs. alternative fuel
    - Engine operating conditions can change the properties of aircraft emissions

- Airport workers are especially vulnerable to ground emissions

Bendtsen, 2021, Environmental Health;
Durdina, 2021, Environ. Sci. Technol.

Aim

BAZL

- To investigate the respiratory health effects of non-volatile PM (nvPM) emitted from a run-in CFM56-7B26 turbofan
  - REspiratory Health Effects of PM generated by Aircraft Turbine Engines (REHEATE)

EMPAIREX 1

COMMUNICATIONS BIOLOGY

ARTICLE

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Non-volatile particle emissions from aircraft turbine engines at ground-idle induce oxidative stress in bronchial cells

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EMPAIREX 2

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ELSEVIER

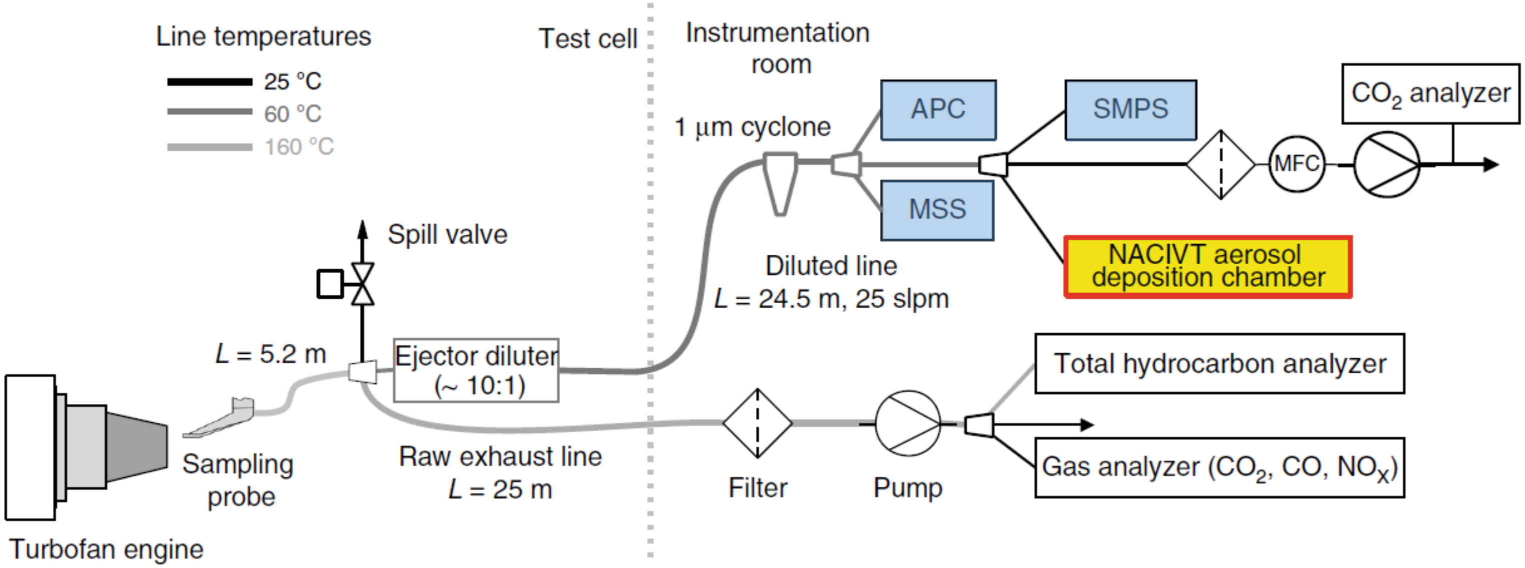
Responses of reconstituted human bronchial epithelia from normal and health-compromised donors to non-volatile particulate matter emissions from an aircraft turbofan engine☆

Mathilde N. Delaval[a,1,3], Hulda R. Jonsdottir[a,1,9], Zaira Leni[a], Alejandro Keller[b], Benjamin T. Brem[c,4], Frithjof Siegerist[d], David Schönenberger[c,5], Lukas Durdina[c,6], Miriam Elser[c,g,7], Matthias Salathe[e], Nathalie Baumlin[e], Prem Lobo[f,8], Heinz Burtscher[b], Anthi Liati[g,2], Marianne Geiser[a,*]

EMissions of Particulate and gaseous pollutants in AIRcraft engine Exhaust (EMPAIREX)

Jonsdottir, 2019, https://doi.org/10.1038/s42003-019-0332-7
Delaval & Jonsdottir, 2022 https://doi.org/10.1016/j.envpol.2022.119521

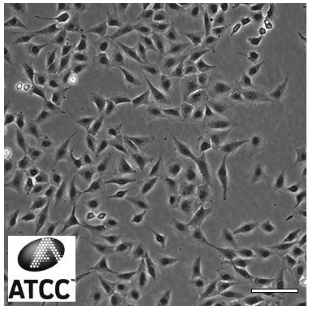
Aerosol generation, sampling and characterization



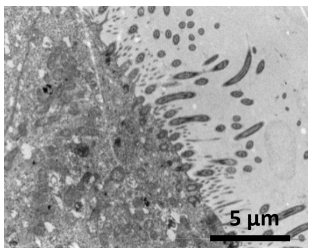
CFM56-7B26

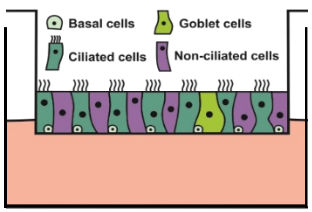
- **Aerosol generation:**
  - Two fuel types:
    - Jet A-1 base fuel
    - HEFA blend (32% v/v)
  - 3 thrust levels:
    - Ground Idle (3-4% thrust)
    - Taxi (7% thrust)
    - Climb-out (85% thrust)
- **Aerosol characterization**
  - Mass concentration (Micro Soot Sensor, MSS)
  - Number concentration (AVL particle counter APC)
  - Particle Size Distribution (SMPS)
- **Aerosol conditioning for NACIVT**
  - VOCs removal with thermodenuder
  - Diluted with dry synthetic air

Cell cultures and aerosol exposures



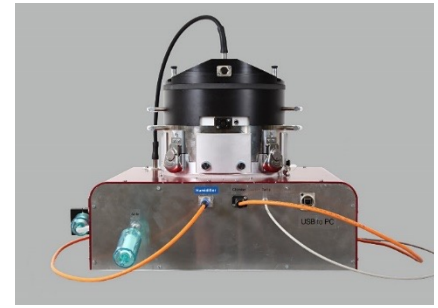
- **BEAS-2B cells**
  - Epithelial cell line
  - Derived from normal bronchial epithelium
  - Can be exposed at Air-liquid interface

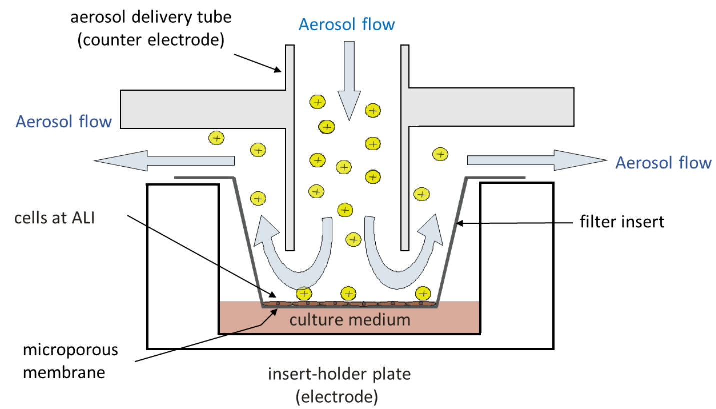




- **Human bronchial epithelia**
  - Primary cells
  - Isolated from human lungs
  - Polarized and differentiated
  - Pseudostratified containing multiple cell types
  - Resembles in vivo bronchial epithelium

- **NACIVT**
  - All-in-one portable exposure chamber
  - Can be connected to any aerosol source
  - Mimics particle deposition in the lungs





Exposure conditions

25 mL / min-1

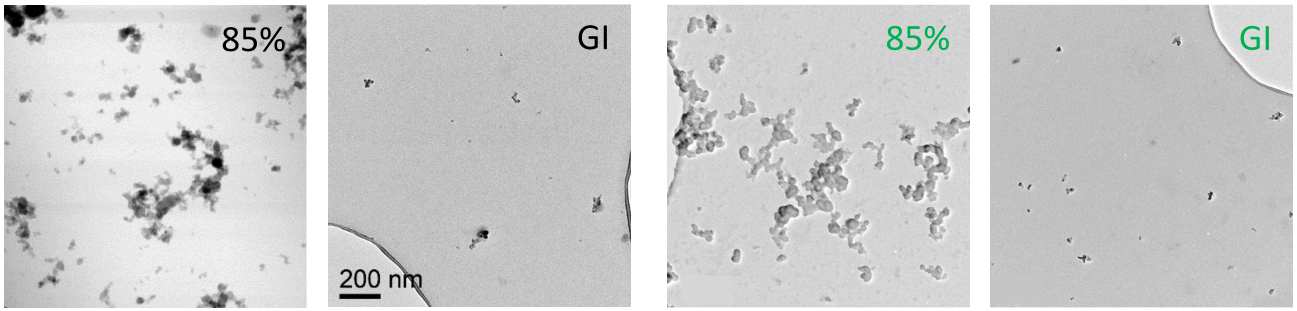
37°C, 85% rH, 5% CO_2

Air-liquid interface

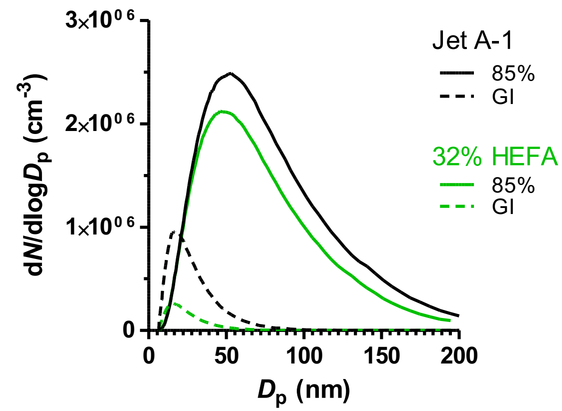
1 hour exposure

Physical properties of nvPM

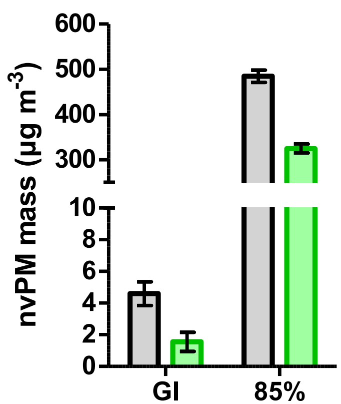
Jet A-1 | 32% HEFA



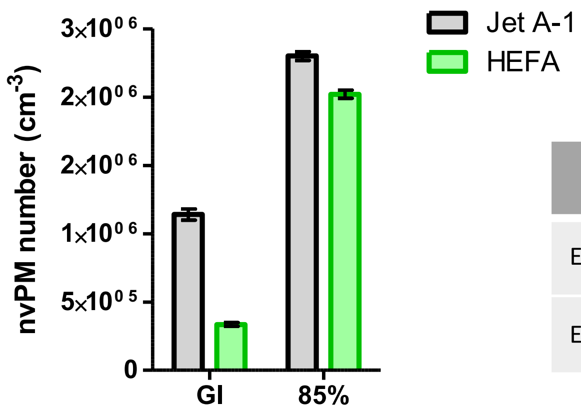
Size distribution



Mass concentration



Number concentration



	Jet A-1		HEFA	
Particle deposition	**GI**	**85%**	**GI**	**85%**
Estimated deposited mass (ng cm^{-2})	6,9	432	2,1	311
Estimated deposited number (x10^9 cm^{-2})	2,1	3,2	0,6	2,9

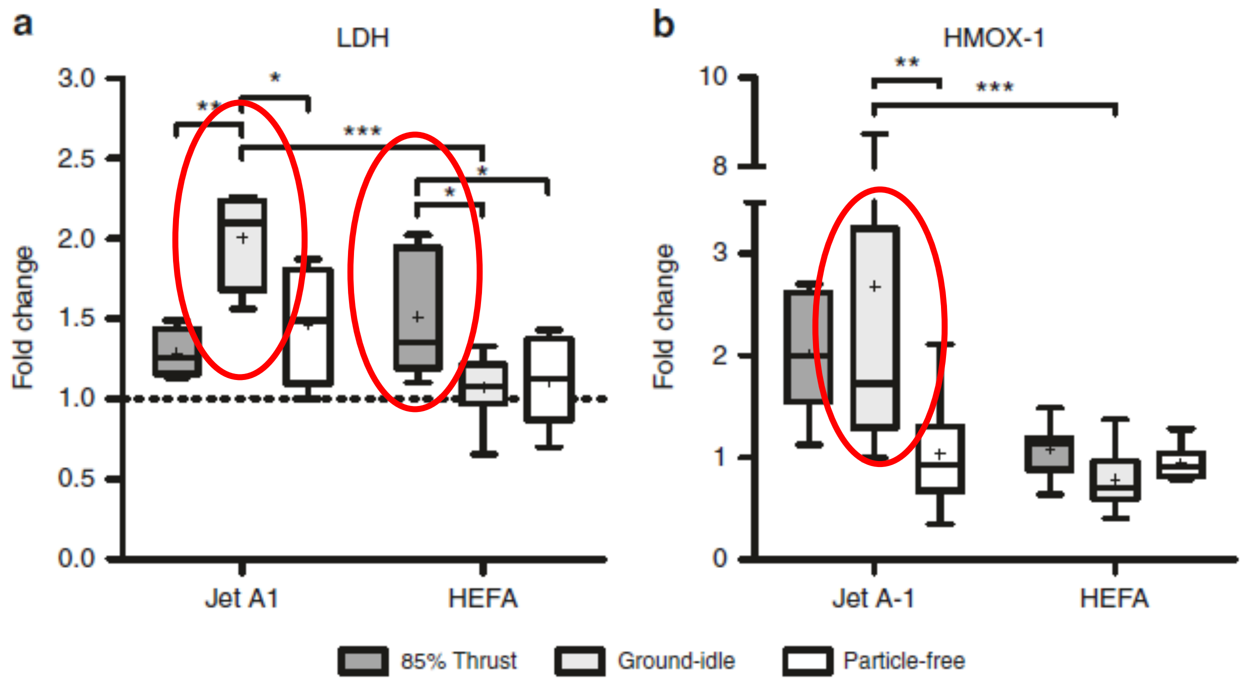
Jonsdottir, 2019, Comms bio

nvPM from Jet A-1 cause cytotoxicity and oxidative stress

BEAS-2B cells
1 hour exposure

Cytotoxicity

Oxidative stress



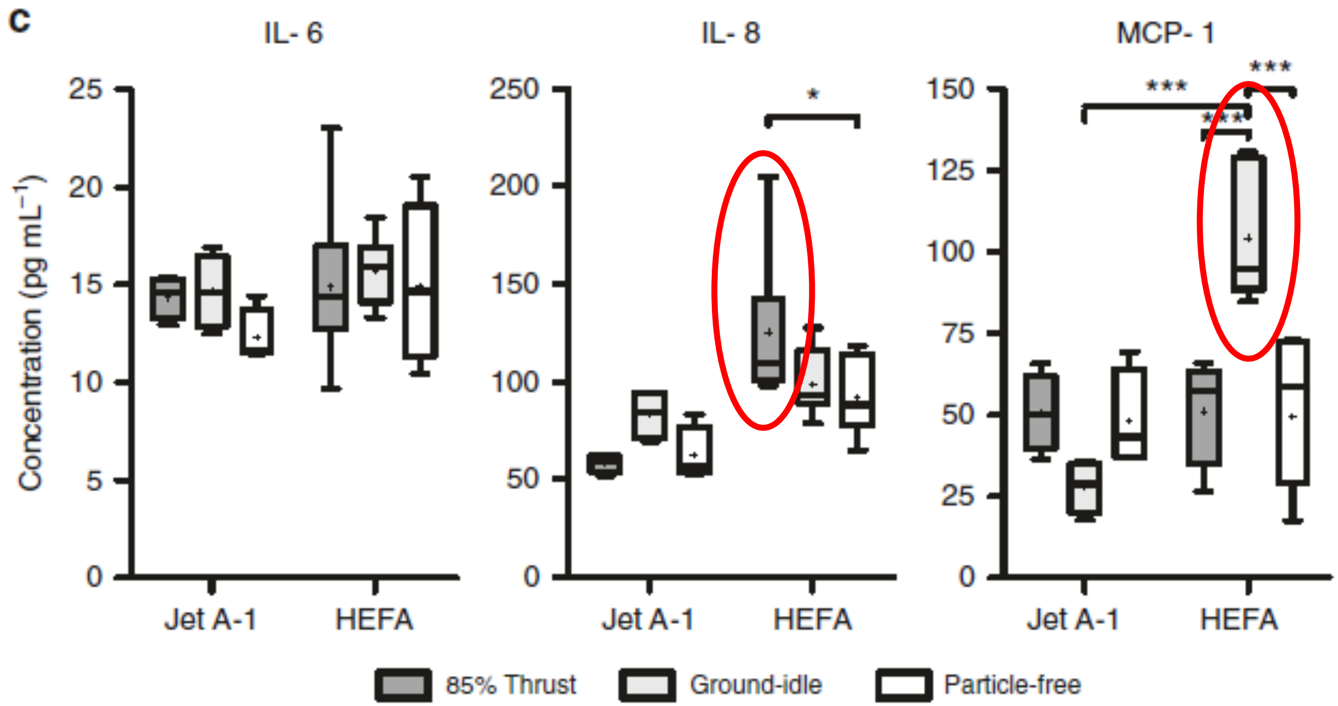
(n= 2–4 cultures for Jet A-1, n = 4–8 cultures for HEFA blend).
non-matching two-way analysis of variance (ANOVA) with Bonferroni posttests: *$p < 0.05$, ** $p < 0.01$, and ***$p < 0.001$

Jonsdottir, 2019, Comms bio

nvPM from HEFA blend cause moderate inflammation

BEAS-2B cells
1 hour exposure

Cytokine release analysis



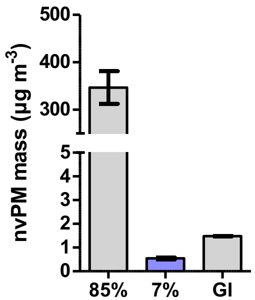
(n= 2–4 cultures for Jet A-1, n = 4–8 cultures for HEFA blend).
non-matching two-way analysis of variance (ANOVA) with Bonferroni posttests: *p < 0.05, ** p < 0.01, and ***p < 0.001

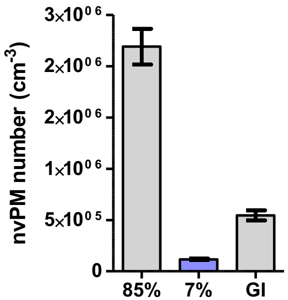
Jonsdottir, 2019, Comms bio

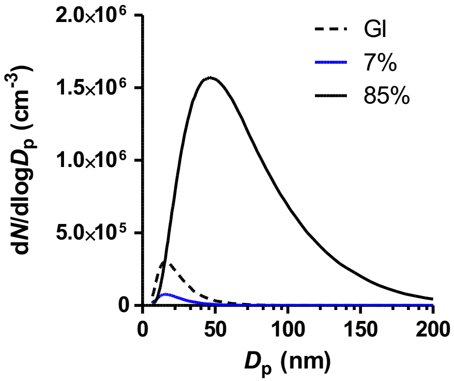
nvPM from low thrust levels cause cytotoxicity

- Normal human bronchial epithelia exposed for 1hour to nvPM from aircraft engines operated at 3 operating conditions (Jet A-1 fuel)

nvPM characterization

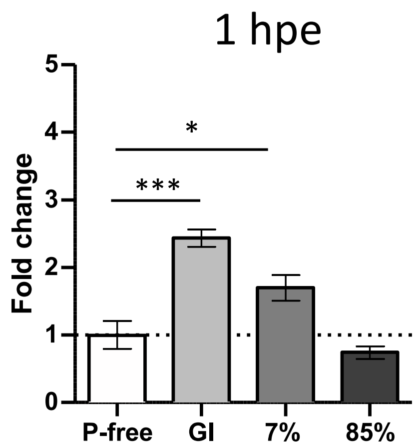


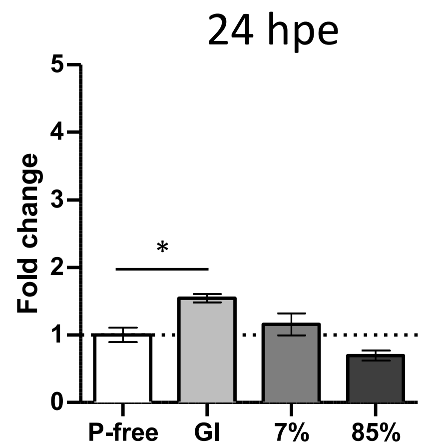




Delaval & Jonsdottir, 2022, Env Pol

Cytotoxicity measurement (AK release)





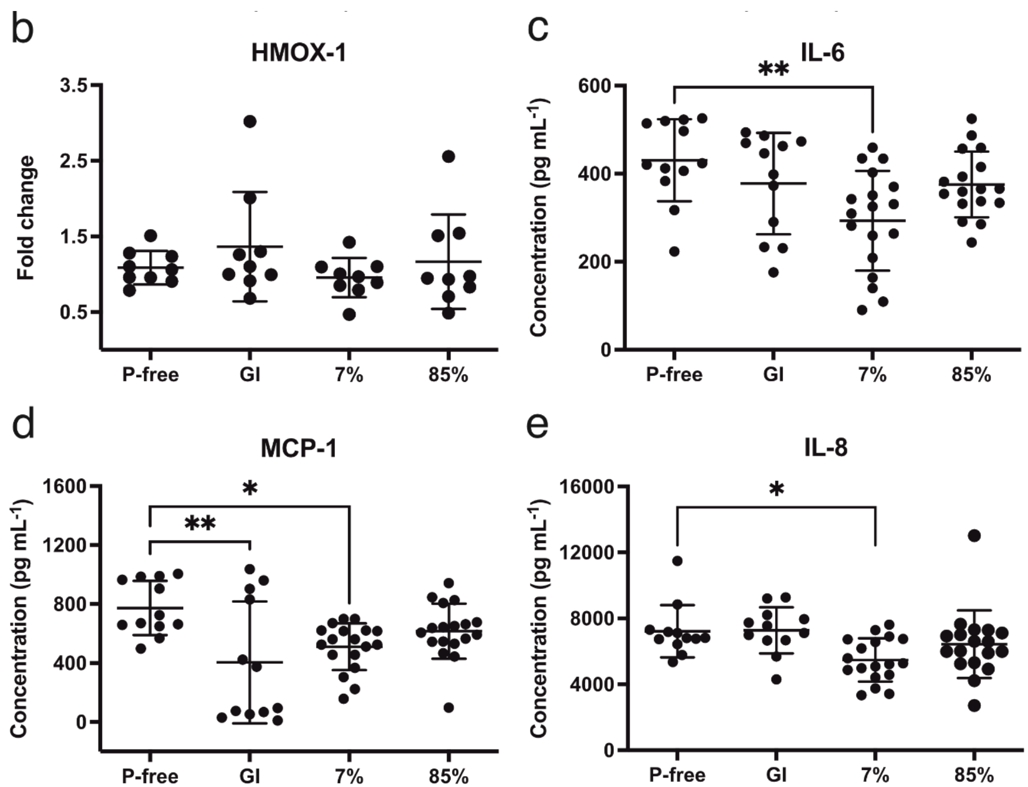
➢ **nvPM from low thrust levels cause transient cytotoxicity in normal airway epithelia**

(n= 12-18 cultures, 2-3 independant aerosol exposures).
non-matching one-way analysis of variance (ANOVA) with Tukey post test: $*p < 0.05$, $** p < 0.01$, and $***p < 0.001$

nvPM from low thrust levels cause slight inflammation

HBE cells
1 hour exposure

Oxidative stress and cytokine release analysis



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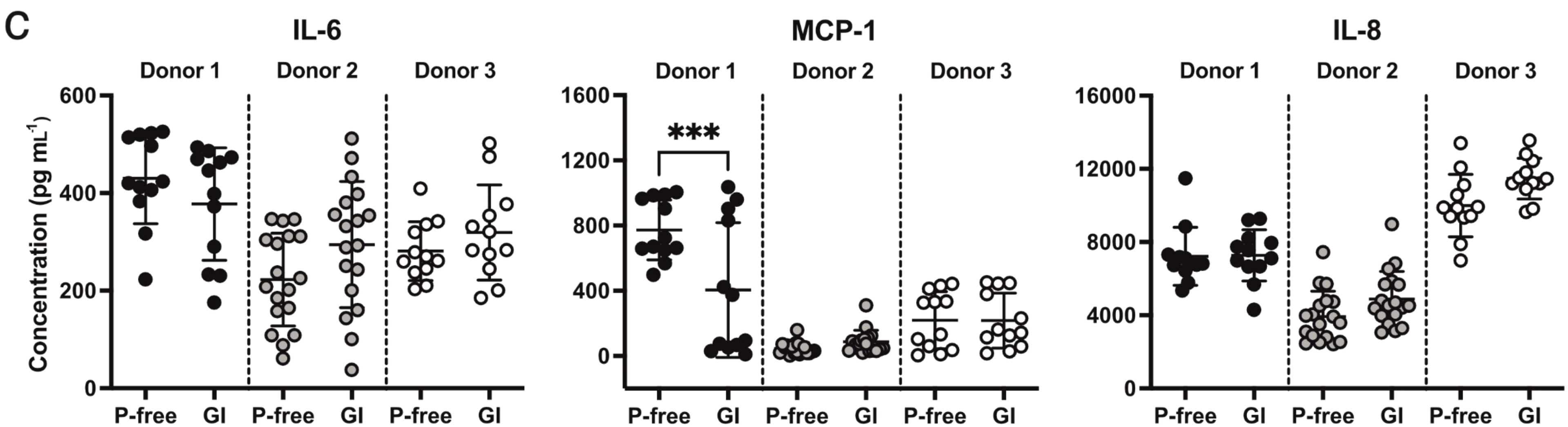
Differential responses of normal and health-compromised epithelia

HBE cells
1 hour exposure

Cytokine release analysis



Donor 1: Healthy donor
Donor 2 and 3: Asthmatic smokers donors

Delaval & Jonsdottir, 2022, Env Pol

Conclusions

- Fuel type and operating conditions influences particle properties
  - Increasing engine thrust leads to increased particle number, mass and size
  - Use of biofuel (32% HEFA blend) reduces nvPM emissions especially at Ground Idle

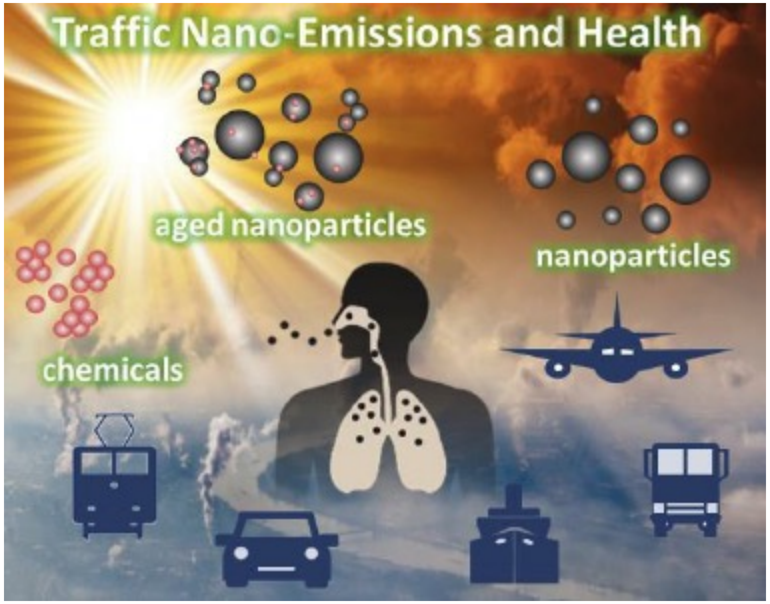
- Fuel type and operating conditions influences biological responses of bronchial epithelial cells
  - nvPM from Jet A-1 at ground-idle conditions is the most hazardous
  - nvPM from alternative fuel caused inflammation but no cytotoxicity or oxidative stress

- Simple bronchial cell culture model is more sensitive than complex reconstituted airway epithelium
  - nvPM induced stronger toxicological responses in BEAS-2B cells than in primary cells
  - Epithelia from health-compromised donors are less sensitive than epithelia from normal donors

- **Fuel type, thrust level, and size of generated particles are important factors for the impairment of epithelial cells lining the upper conducting airways**
- **Cell models and experimental set up are important factors for the detection of potential adverse effects of aircraft emissions, and combustion generated particles in general**

ULTRHAS

ULtrafine particles from TRansportation - Health Assessment of Sources



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https://www.fhi.no/en/studies/ultrhas/
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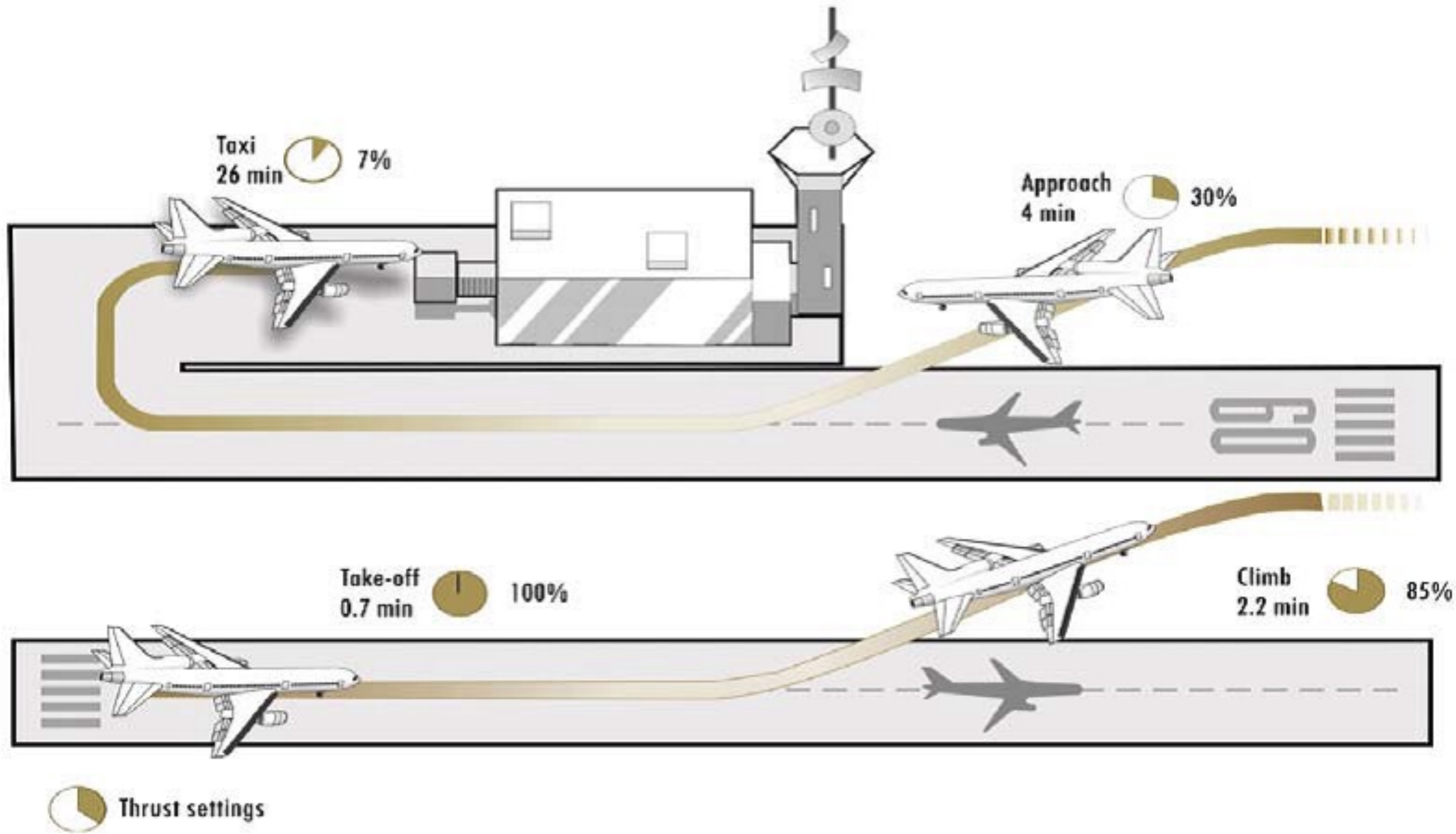
Thank you!

BAZL

In memory of Dr. Anthi Liati

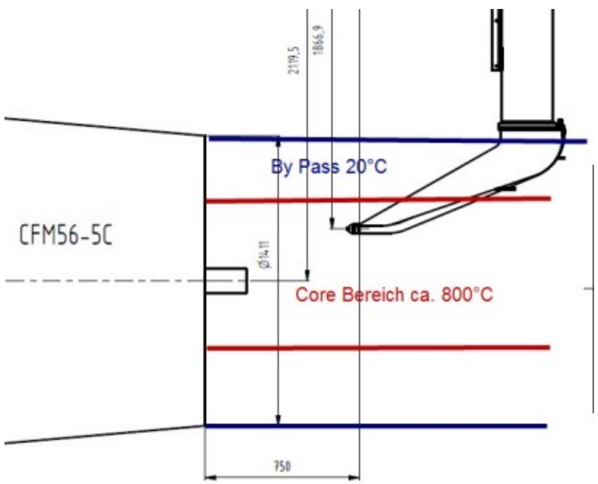
Landing and Take-off (LTO) cycle



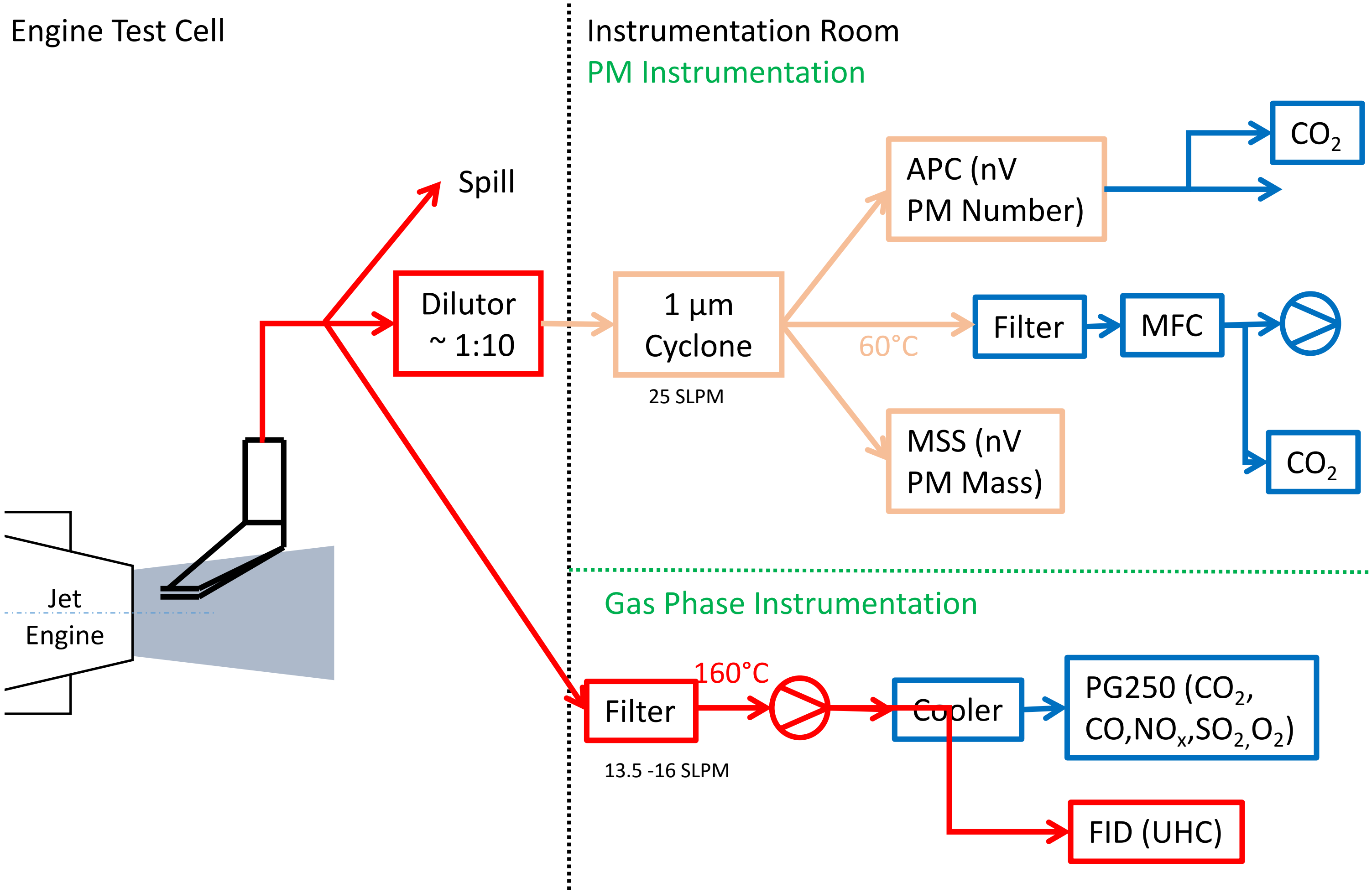
ICAO emissions certification procedure

Sampling Probe

- Single point probe
- Probe position can be changed in the vertical and horizontal direction
- Probe is retracted for engine starting and shut down
- Probe made of Inconel
  - Temperatures up to 750°C
  - Velocities near Mach 1

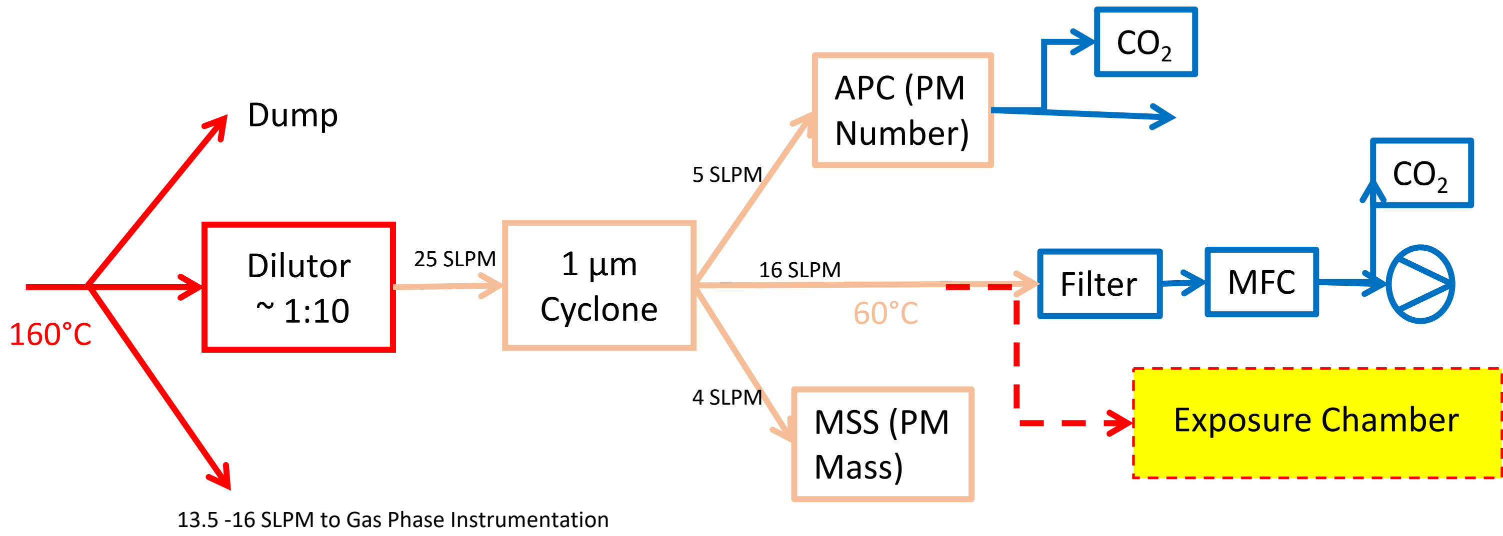


Courtesy of Dr. Benjamin T. Brem, Empa



Courtesy of Dr. Benjamin T. Brem, Empa

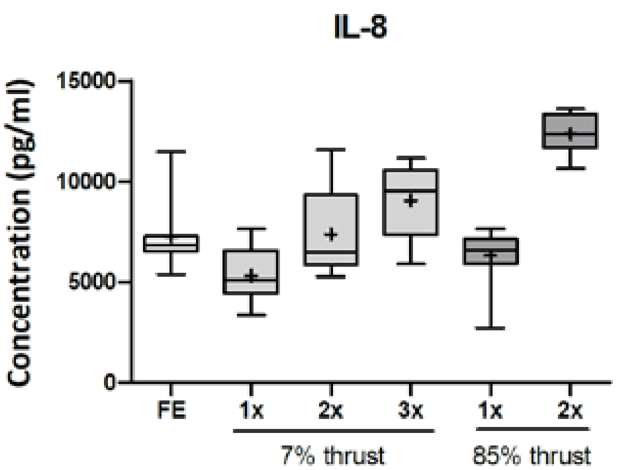
PM Line Instrumentation

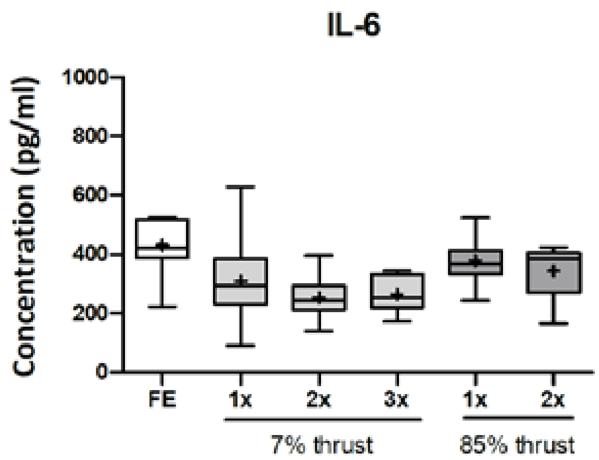


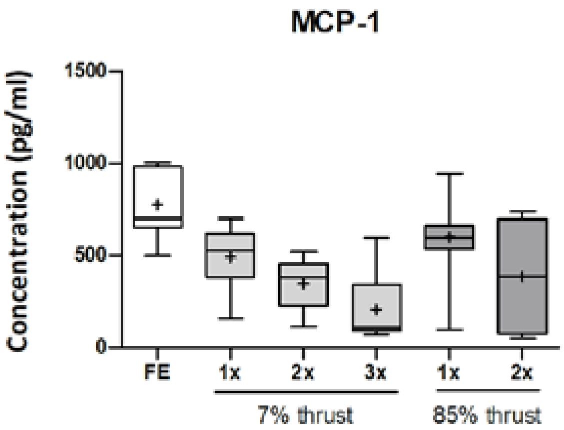
- Line is heated to 60°C and diluted with synthetic air
- Downstream CO_2 measurements are used to infer the dilution factor
- Non-volatile PM number concentrations are measured with an AVL Particle Counter (APC)
- Non-volatile PM (soot) mass is measured with a Micro Soot Sensor (MSS)

Courtesy of Dr. Benjamin T. Brem, Empa

EMPAIREX 2 campaign: Multiple exposures







➢ Multiple, short exposures (over a few days) are well tolerated by the airway epithelium