Quantifying PM emissions and assessing health impacts

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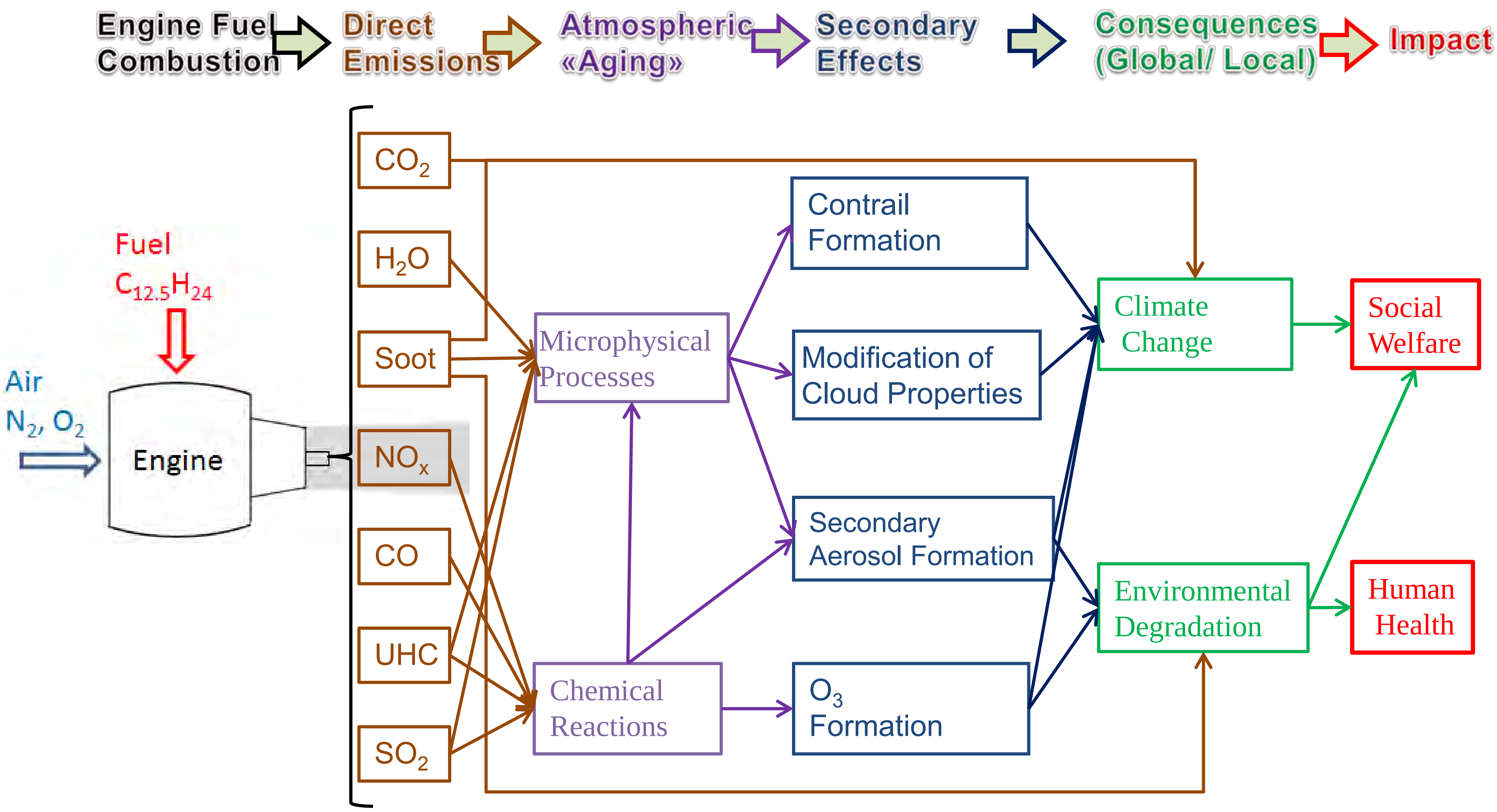
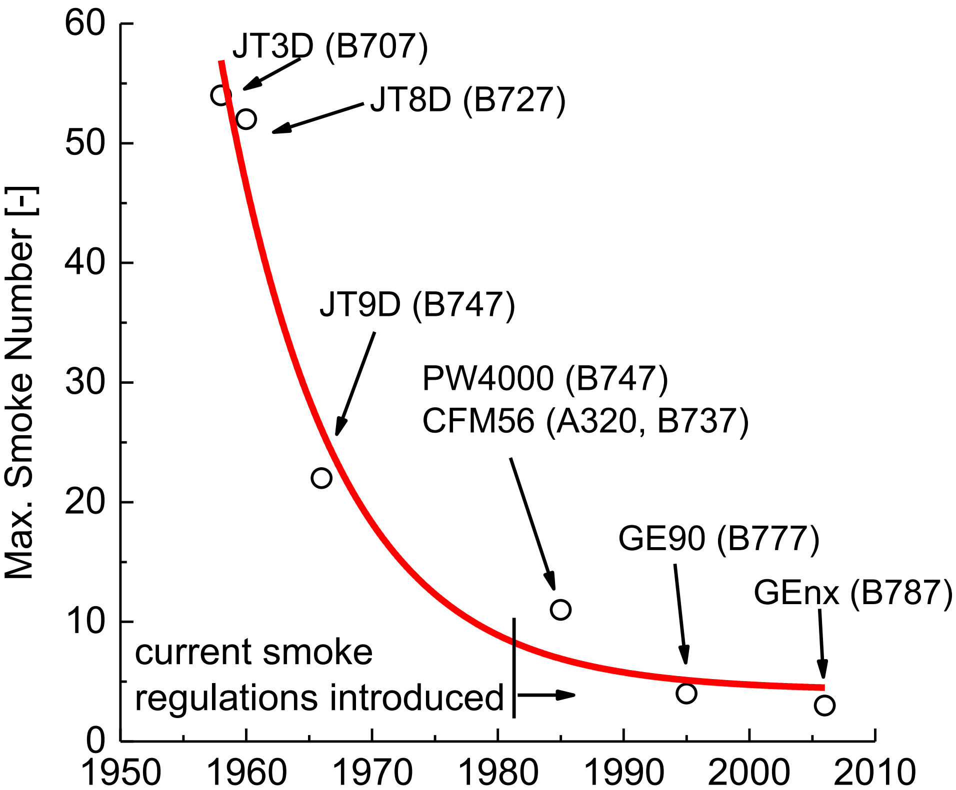
Empa
Materials Science and Technology

Aircraft Emissions and Impact



Aircraft Engine Emission Measurement



From smoke number to PM (particulate matter) number and mass.

Our project contributes significantly to a certification requirement and an international standard for aircraft engine PM emissions by the International Civil Aviation Organization (ICAO).

ICAO Standard on Particulates

- 2016/02/02: The Committee on Aviation Environmental Protection of the International Civil Aviation Organization (ICAO) approved a preliminary standard governing the emission of particulates by aircraft engines.
- 2017/03/03: Final approval of the standard by the ICAO council.
- 2020/01/01: All engine types for passenger aircrafts should be certified in accordance with the new standard.

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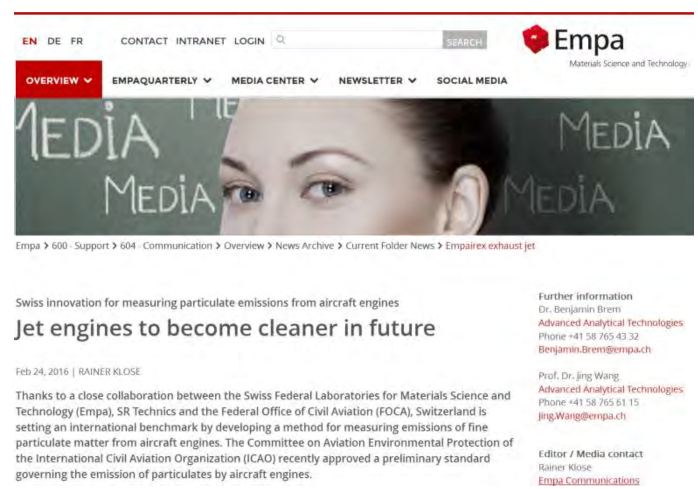
Startseite › Medien › Media Corner › Medienmitteilungen › Schweizer Innovation zur Messung von Feinstaubpartikeln aus Flugzeugtriebwerken

‹ Medien
Media Corner
Medienmitteilungen
Bilder
Häufig gestellte Fragen
Aktuelle Dokumente
Kontakt

‹ Zurück zur Übersicht

Schweizer Innovation zur Messung von Feinstaubpartikeln aus Flugzeugtriebwerken

Bern, 26.02.2016 - In enger Zusammenarbeit zwischen der Empa, der SR Technics und dem Bundesamt für Zivilluftfahrt (BAZL) hat die Schweiz ein Verfahren für die Messung von Feinstaubpartikeln aus Flugzeugtriebwerken entwickelt – und damit international Massstäbe gesetzt. Das Umweltgremium der internationalen Zivilluftfahrtorganisation (ICAO) hat vor kurzem dank dieser Arbeiten eine erste Vorschrift für die Emission von Feinstaubpartikeln aus Flugzeugtriebwerken verabschiedet.



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Swiss innovation for measuring particulate emissions from aircraft engines

Jet engines to become cleaner in future

Feb 24, 2016 | RAINER KLOSE

Thanks to a close collaboration between the Swiss Federal Laboratories for Materials Science and Technology (Empa), SR Technics and the Federal Office of Civil Aviation (FOCA), Switzerland is setting an international benchmark by developing a method for measuring emissions of fine particulate matter from aircraft engines. The Committee on Aviation Environmental Protection of the International Civil Aviation Organization (ICAO) recently approved a preliminary standard governing the emission of particulates by aircraft engines.

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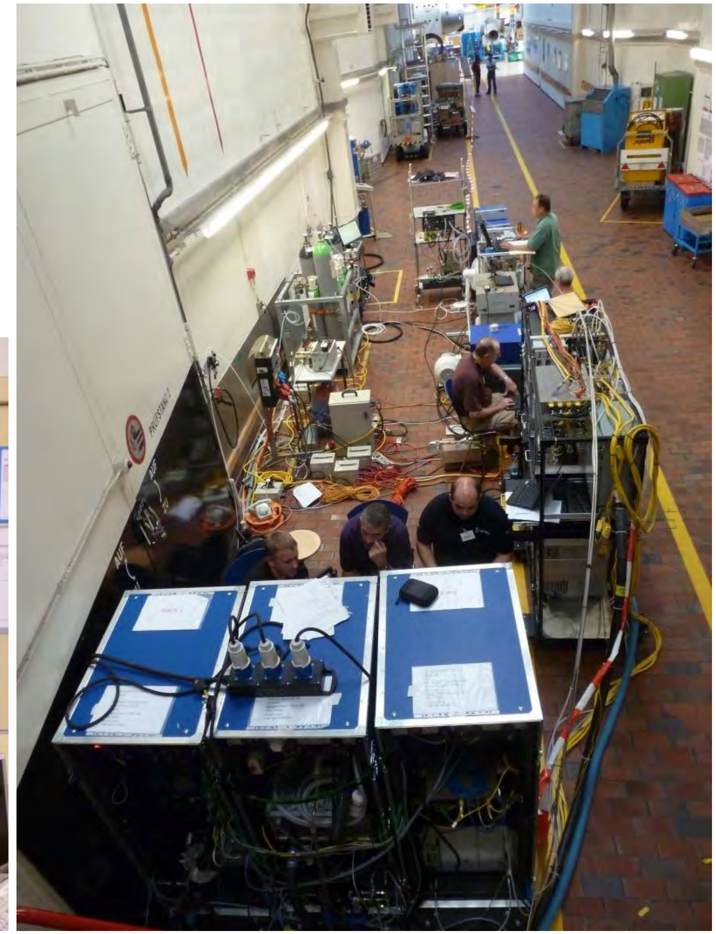
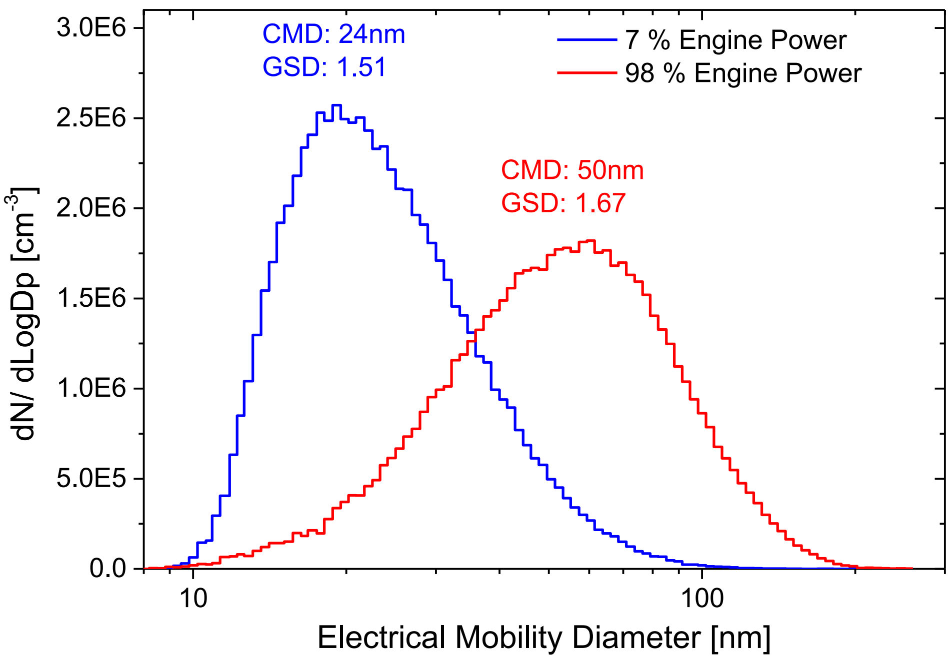
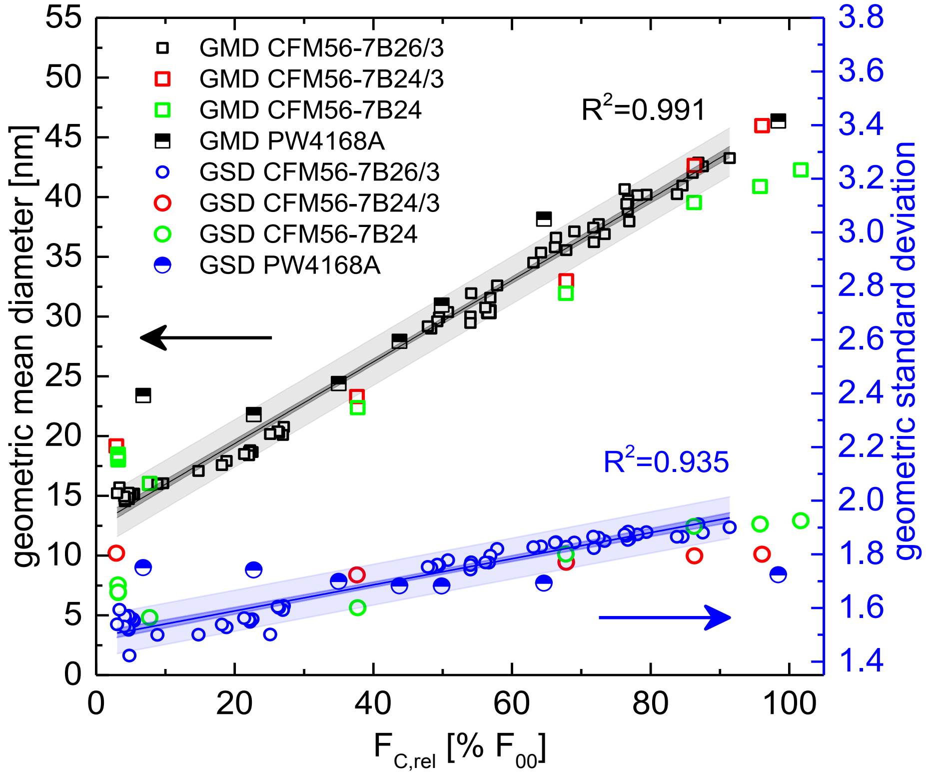


Lobo et al. *AS&T*, 2015.
Kilic et al. *ES&T* 2017.

Particle Size Distribution

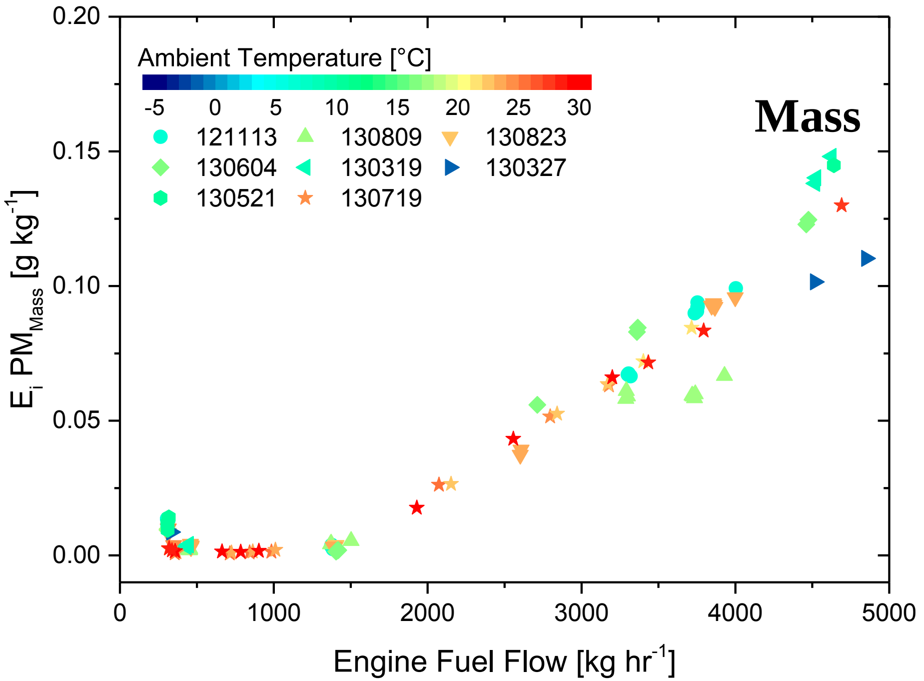


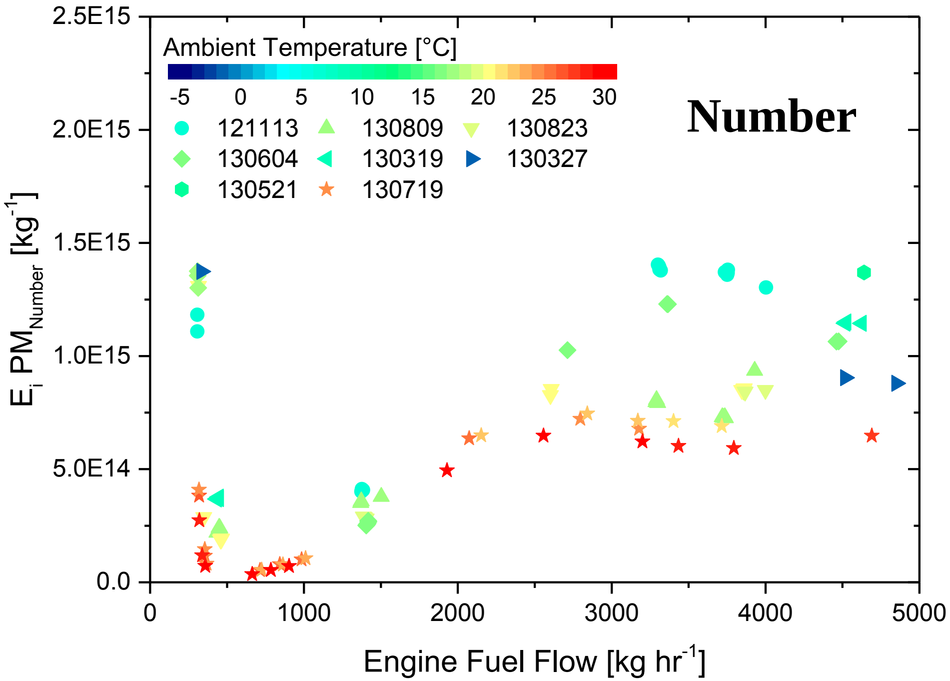


Durdina et al, *Atmospheric Environment*, 2014.
Liati et al. *ES&T*, 2014.
Johnson et al, *J. Propulsion & Power*, 2015.
Abegglen et al, *J. Aerosol Sci,* 2015.
Boies et al, *AS&T,* 2015.
Abegglen et al, *Atmospheric Environment*, 2016.

Non-volatile PM Emission Indices

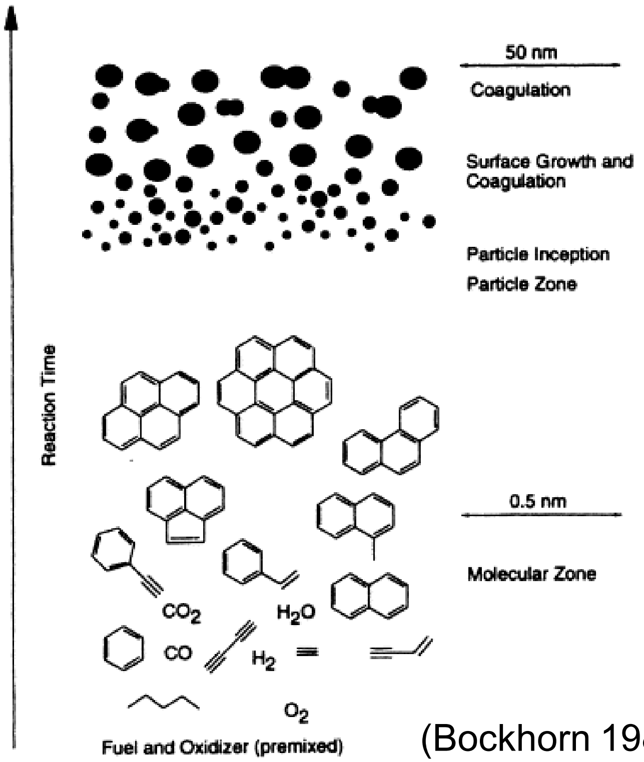
- CFM56-7B, 90's technology mid-size turbofan: used on Boeing 737; one of the most common aircraft engines worldwide, more than 20,000 units built



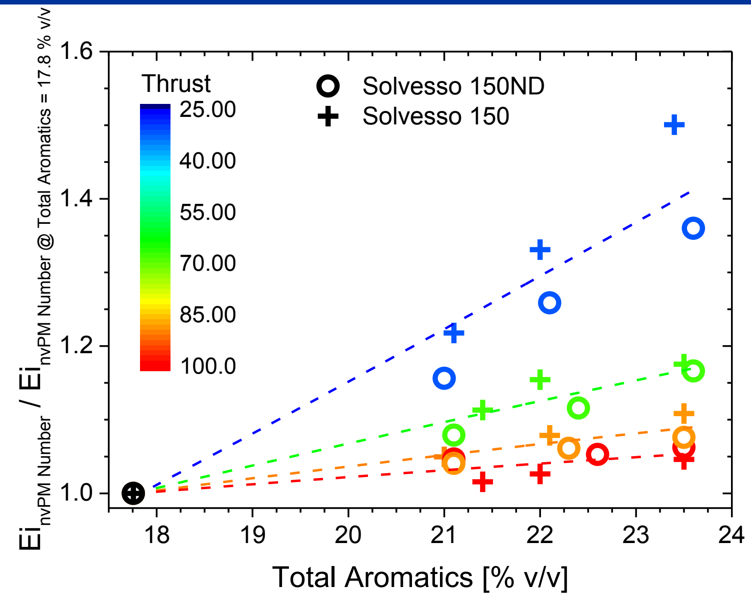


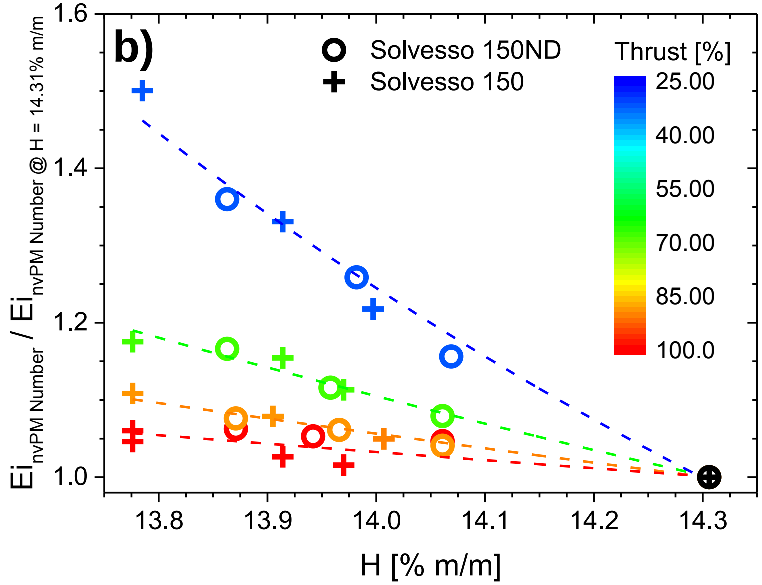
- High number emissions at low engine fuel flow that do not correlate with mass emissions
- Engine maintenance status and temperature effects visible in the number emissions

Fuel Aromatics and Emissions



(Bockhorn 1983)

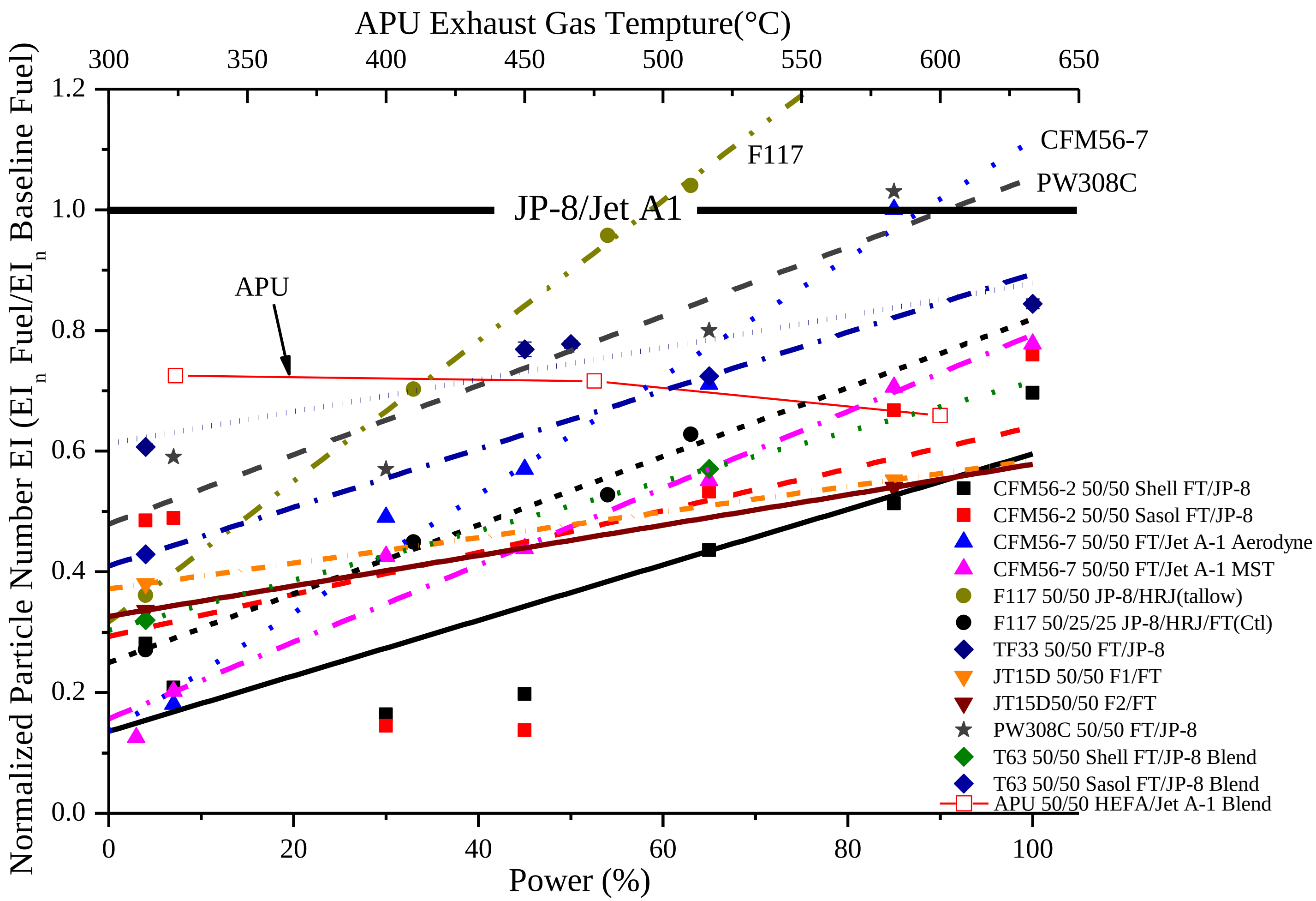




Fuel rich pockets within the flame promote reactions that form heavy PAHs which subsequently pyrolyze and form soot particles.

Brem et al. *ES&T*, 2015.
Durdina et al. *ES&T*, 2017.

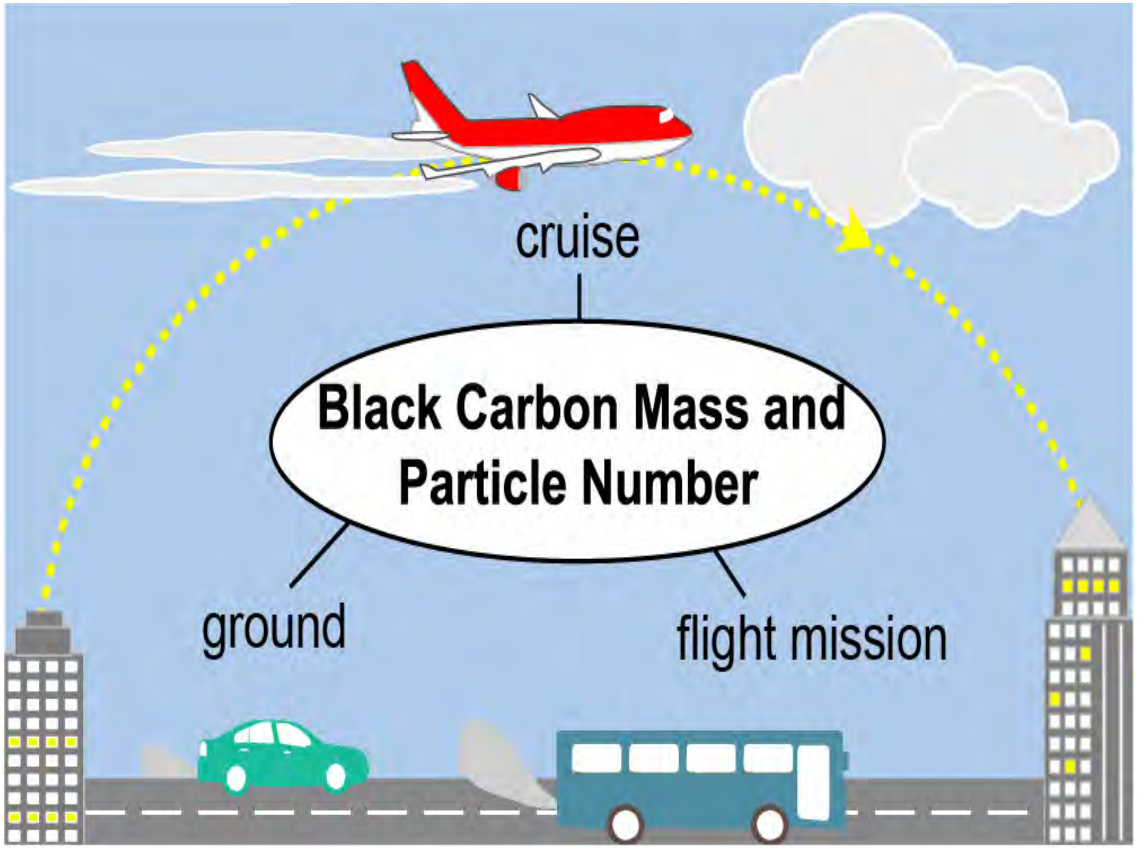
Alternative Aviation Fuel Effect



The low aromatic content levels of AAFs lead to significant reduction of particle emissions at low engine power settings.

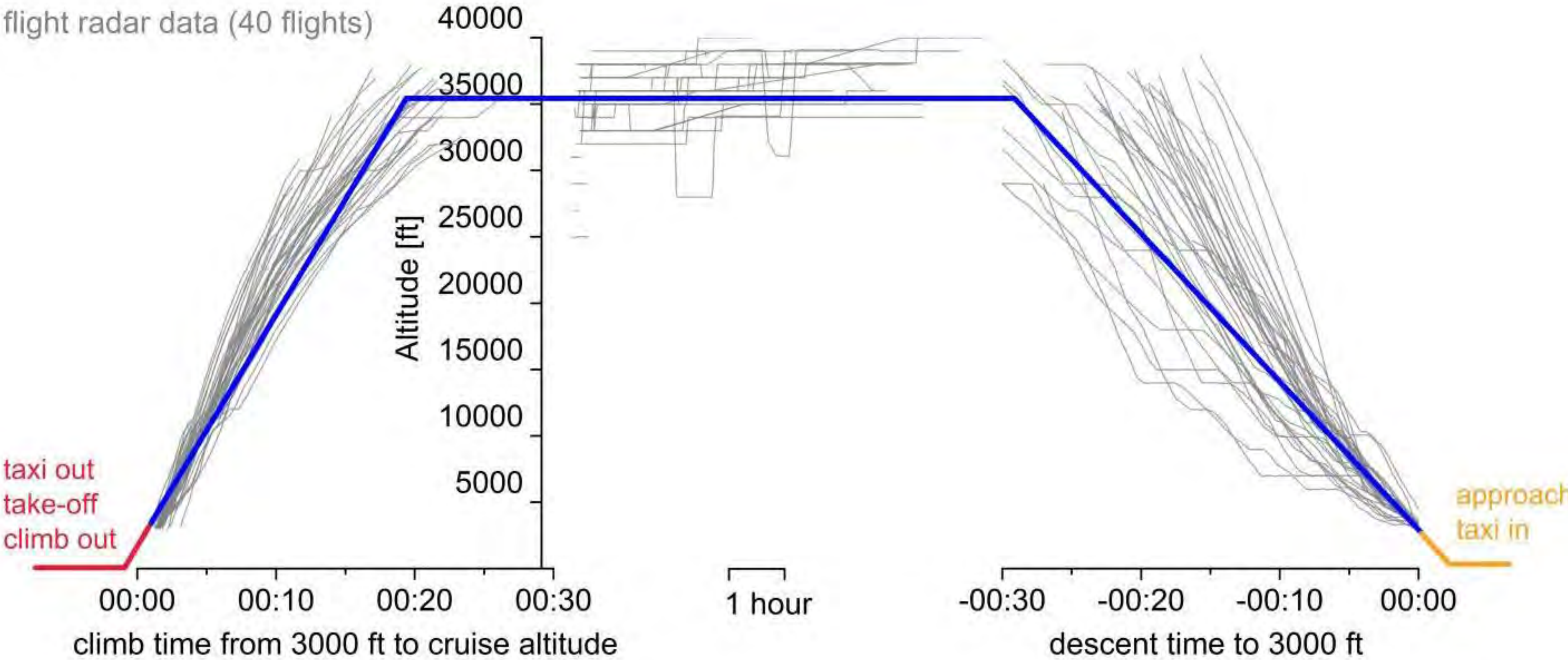
Comparing Airplane and Vehicle Emissoins

- Model plane: Boeing 737NG (~30% of all 100+ seater airliners)



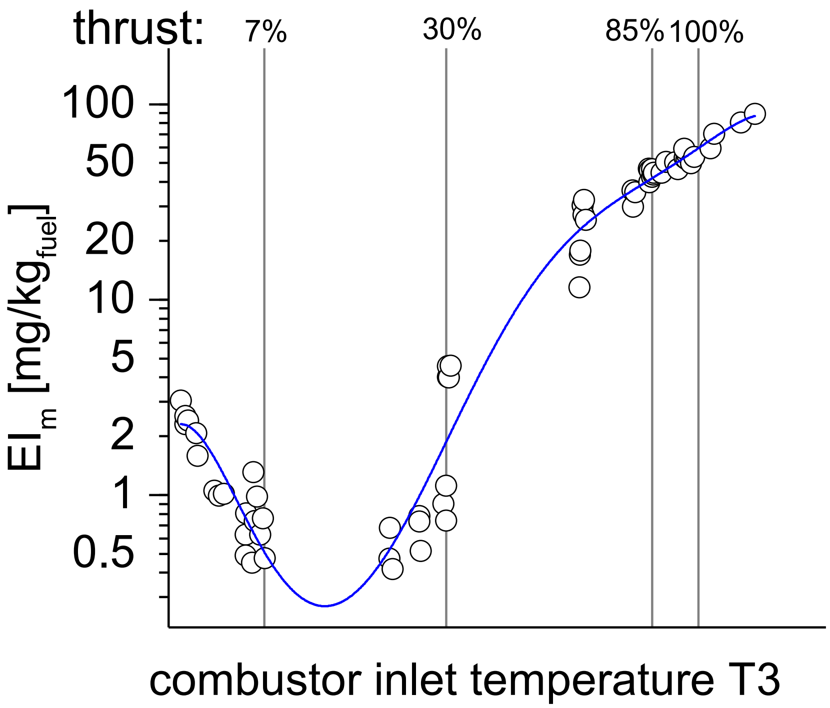
Durdina et al. *ES&T*, 2017.

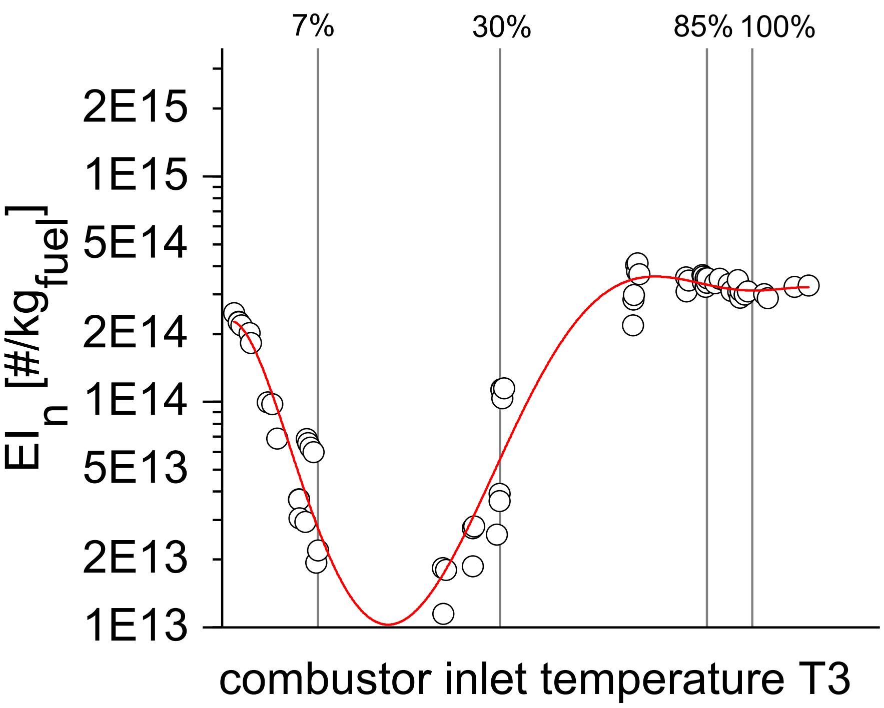
Flight Profiles



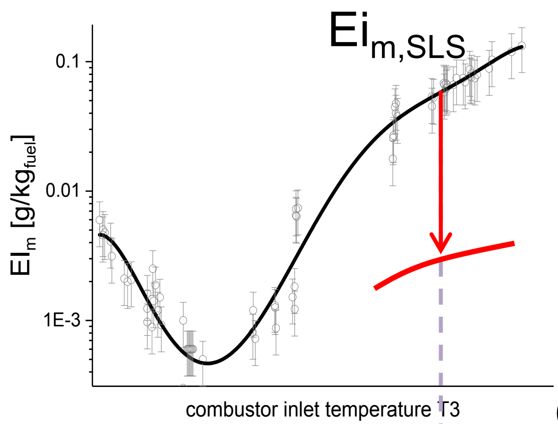
Flight profile used in the model (blue line) based on flight radar data (gray lines). Note the different time scale for the cruise data.

Emission Depends on Engine Power





Ground Data to Flight Conditions

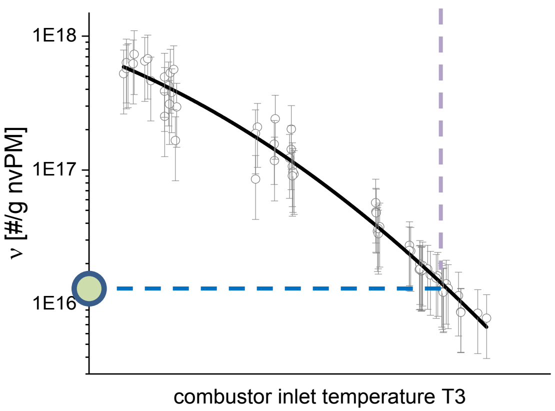


$$EI_m = EI_{m,SLS} \times K_{P3} \times K_{AFR} \times K_{TFL}$$

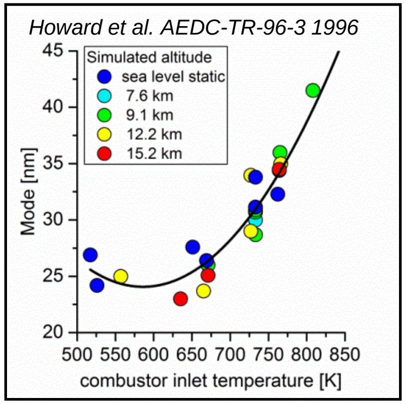
Adiabatic flame temperature effect ≈1

Combustor inlet pressure effect

Air-fuel ratio effect



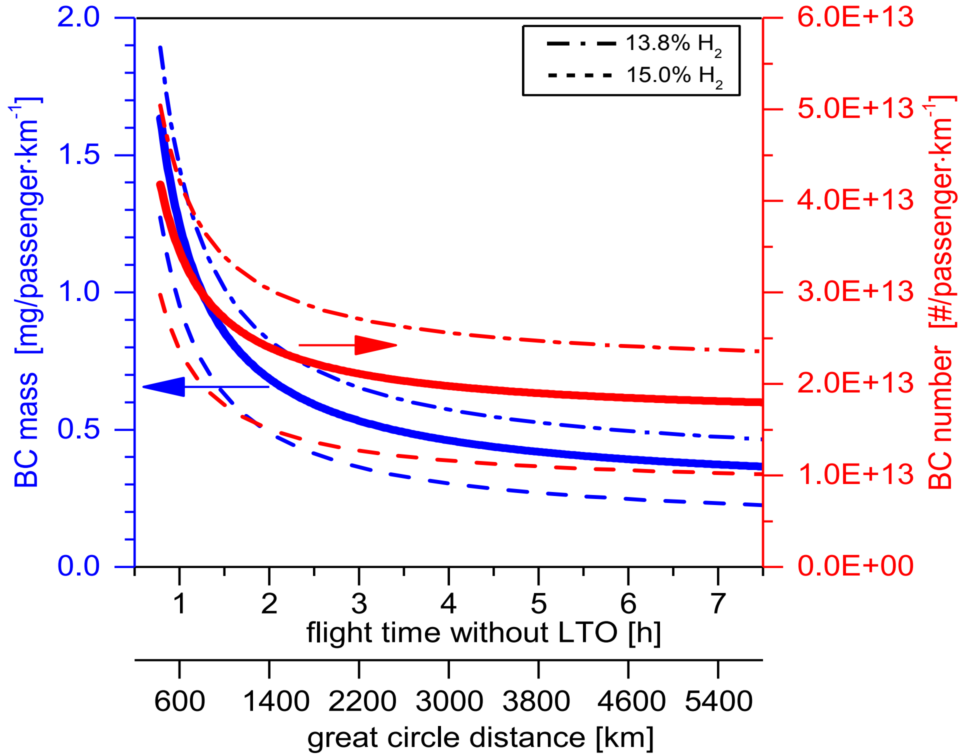
$$EI_n = \nu(T3) \times EI_m$$



Assumption: GMD is a function of T3 independent of altitude

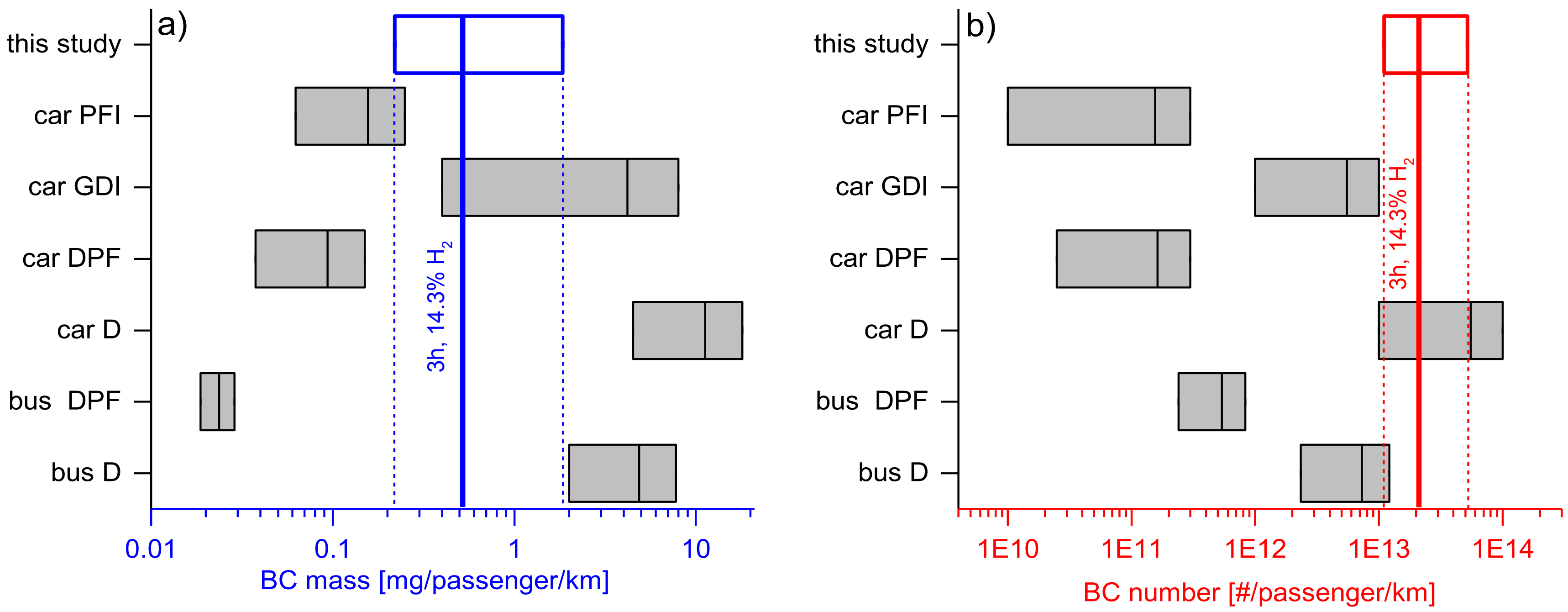
Emission Dependence on Flight Time

- Flight profile (climb, descent) based on flight radar data for Boeing 737 flights
- LTO and climb emissions are dominant for short flights



Emissions Comparison

- Assumed plane occupancy 80% (130 pass.), 30 bus passengers, and 2 car passengers
- Mass emissions comparable with gasoline vehicles
- **Number emissions relatively high, comparable with old diesel cars**



PM Health Impacts

- Vehicle emissions

There exist strong evidence that exposure to diesel exhaust particles is associated with an increased risk of lung cancer.

International Agency for Research on Cancer classified diesel engine exhaust as carcinogenic to humans (Group 1) (IARC, 2012).

The exhaust of gasoline engines is also suspected as carcinogenic (Group 2B) (IARC, 2012).

- Aircraft emissions

Only a few studies have established a specific link between exposure to pollution in an airport work environment and respiratory problems.

The link is weak and there are not enough data to demonstrate a cause-effect relationship.

Reported Respiratory Symptoms

People exposed	Respiratory symptoms	References
Airport vicinity exposure	Coughing, shortness of breath, wheezing onset and decreased lung function	Staatsen et al. 1994; Schiphol Airport, Amsterdam.
	Exacerbation of pre-existing respiratory diseases	Health Council of the Netherlands, 1999.
Airport occupational exposure	A runny nose and a cough with phlegm	Tunnicliffe et al. 1999; Birmingham Airport
	Chest illnesses	Whelan et al. 2003; flight attendants.
	Exacerbation of pre-existing respiratory diseases	LaPuma et al. 1999; aircraft painting operation.

Health Impact on Airport Workers

Occupational exposure of Birmingham International Airport workers and respiratory disorders.

Exposure group	Workers	Subjects n	Comments	Median time in aircraft taxiing area h/day	Crude prevalence of respiratory problems			
					Running nose	Cough with phlegm	Shortness of breath	Wheezing
High	Baggage handlers; Airport hands; Marshalers; Operational Engineers	53	Considerable proportion of working day in close proximity to in-service aircrafts	8	58%	36%	25%	13%
Medium	Security staff; Fire fighters; Airfield operation managers	83	Some of working time on the airport apron, in reasonable proximity of aircrafts	1	42%	16%	22%	17%
Low	Terminal and office workers	86		0	45%	36%	24%	20%

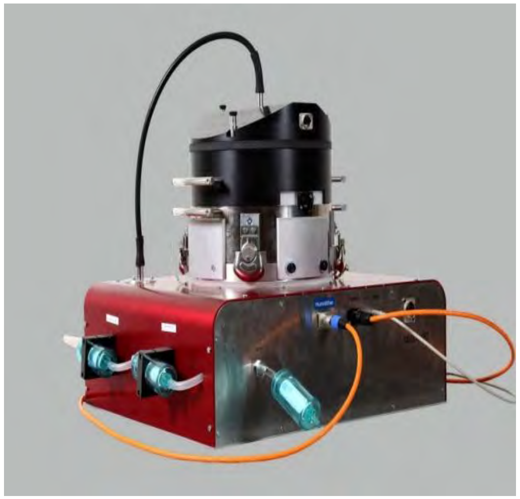
Tunnicliffe et al. *Occup Environ Med* 1999; Touri et al. *Eur Respir Rev* 2013.

PM Based Modeling for Health Impact

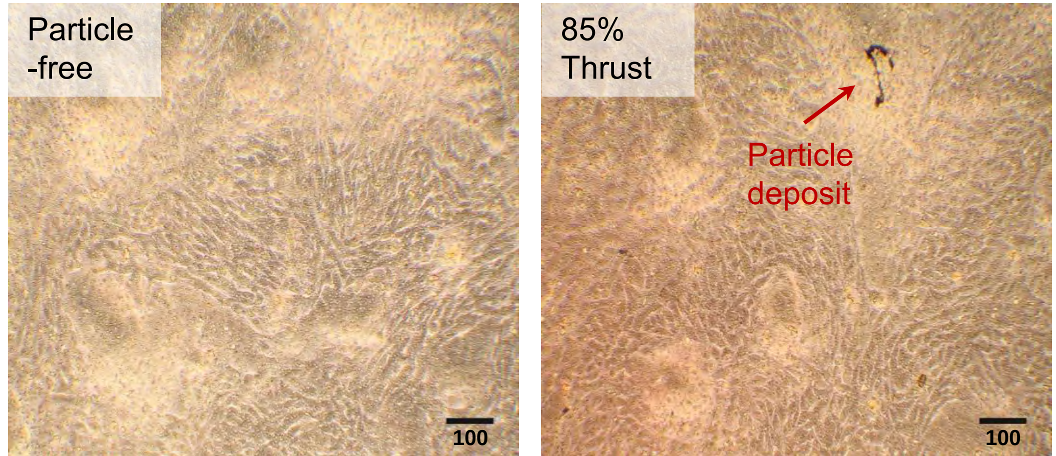
Barrett group used concentration-response functions to estimate premature deaths due to population exposure to aviation-attributable emissions:

- It is reported that global aircraft emissions of PM2.5 caused ~10 000 premature deaths per year globally, with 80% due to cruise emissions (Barrett et al. *ES&T* 2010).
- The current UK aviation emissions caused ~110 premature deaths per year (Yim et al. *Atmos. Environ*. 2013).
- Aviation emissions of PM2.5 and ozone cause~16 000 (90% CI: 8300–24 000) premature deaths per year, costs of ~$21 bn per year (Yim et al. *Environ. Res. Lett*. 2015).

Exposure of Lung Cells to Jet Engine Exhaust



Nano Aerosol Chamber for In-Vitro Toxicity (NACIVT, http://www.nacivt.ch)



Human bronchial epithelial cells (BEAS-2B) exposed to particle-free exhaust (filtered 50% thrust) or to exhaust at different thrust levels (up to 85%) for 60 min at 37°C and 85% RH

- NACIVT allows the deposition of nanoparticles from jet engine exhaust on lung cell cultures in a controlled, realistic manner
- A single, short exposure of lung epithelial cells to jet engine exhaust at different thrust levels does not lead to severe morphological changes (e.g. massive cell death or detachment)

REHEATE Project - University of Bern - M. Geiser/H.R. Jonsdottir

Summary

- Mass and number based particle emission indices depend on engine type, conditions, and are sensitive to fuel composition.
- The emission particle sizes are small, generally the peak size is below 50 nm. The size is smaller at lower thrust.
- Higher fuel aromatic contents lead to higher particle emissions. Alternative aviation fuels can reduce the emissions.
- PM from Boeing 737NG is comparable with gasoline vehicles in terms of mass, and higher in terms of number.
- The aircraft emissions have been shown related to respiratory symptom for airport workers and nearby residents in limited studies, however, no cause-effect relationship is demonstrated.