UFP Measurements in Aircraft

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Combustion Aerosol Conference 2019

- Cambridge University

26-28 June,2019

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Who am I?

Health and Flight Safety Implications from Exposure to Contaminated Air in Aircraft

PhD
S. Michaelis
2010

- http://handle.unsw.edu.au/1959.4/50342

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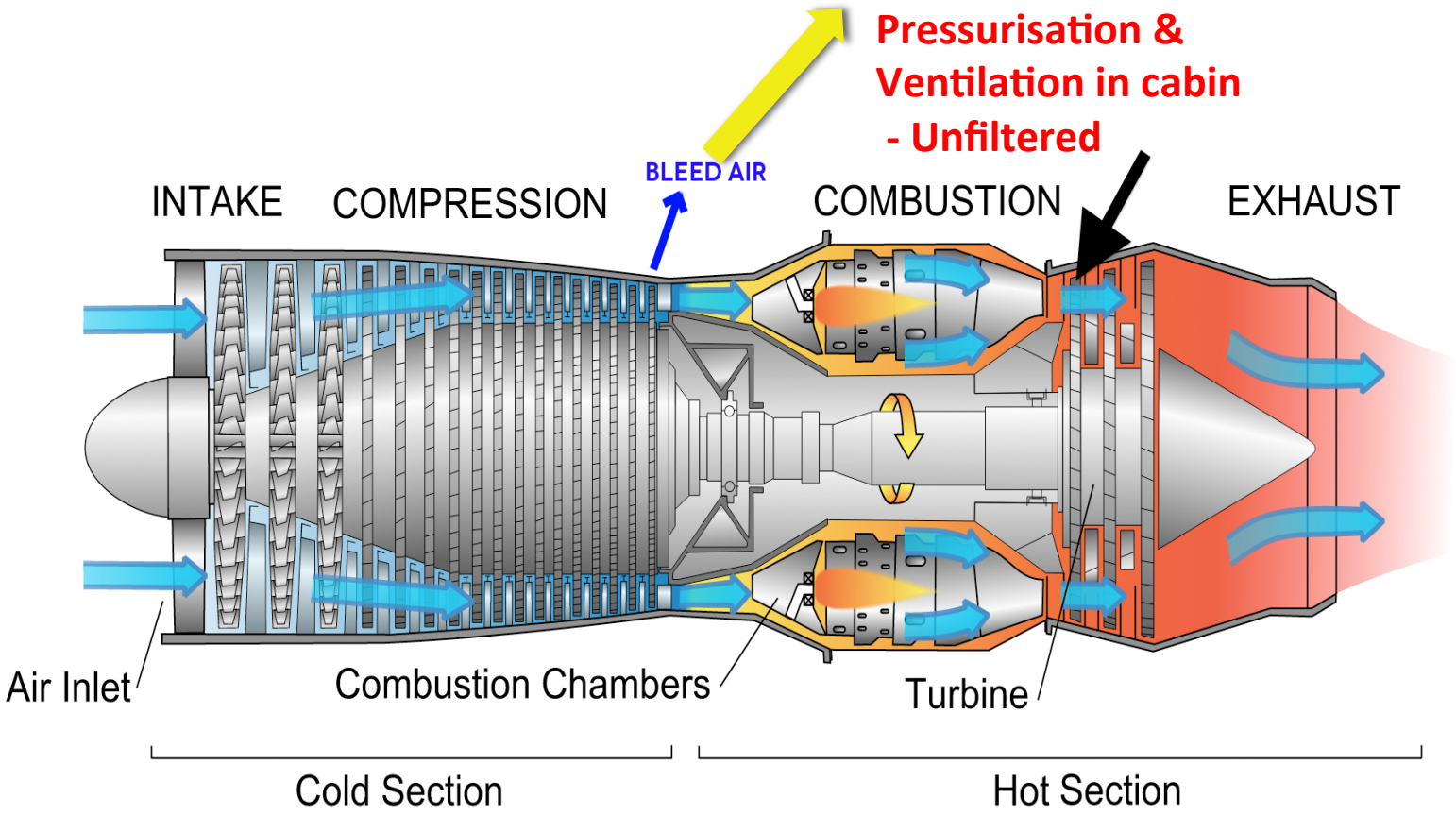
Jet engine and ‘Bleed Air’



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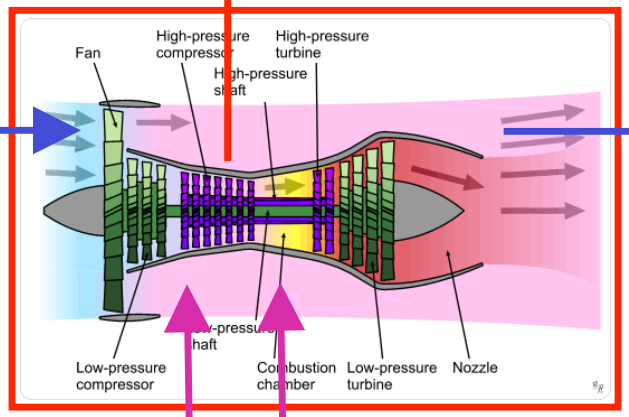
What is the problem?

- Cabin ventilation and pressurization taken from compressor = 'Bleed air'
- Unfiltered
- Oil migrates across seals in bearing chamber- entering compressor airflow → bleed air
- Synthetic jet engine oils
  - Organophosphate – TCP & other additives
  - Ester base stock
  - Complex pyrolysed mixture
- Hydraulic and other fluids can enter air supply

Aircraft cabin air and engine oil

How much Oil
Gets into the Cabin?



air

air & combustion products

oil

fuel

18 December 1953

Boeing Document D-14766-2
B-52 Decontamination Program

- Testing of a filter system
- The possible toxic effect of the contamination is still unknown.
- Smoke or haze is reported in only a few flights.
- Obvious increases in the contamination level were noted during changes in engine power conditions.

BOEING AIRPLANE COMPANY
SEATTLE 14, WASHINGTON

DOCUMENT NO. D-14766-2 DATE December 18, 1953
MODEL B-52 CONTRACT NO.
TITLE DECONTAMINATION PROGRAM

ISSUE NO. TO DATE
SHORT TITLE
(For Classified Data)

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Why did the problem occur?

- More advanced engines (1950s) required synthetic engine oils
- Contamination coincided with synthetic oil use & use of bleed air
- Civilian aircraft did not use bleed air initially due to contamination concerns
- Bleed air then introduced on all aircraft except the new B787 Dreamliner
- Why bleed air?
  - Cheaper – Fan already available to compress air
  - Decided internal engine air was same as outside air quality

What are the implications?

Flight safety

- Oil: Do not breathe heated vapour/mist
- Mostly fumes

- ‘fume events may impair crew members and could potentially impact the safe operation of the aircraft’ – ICAO 2015

ICAO

https://www.local10.com/news/local/fort-lauderdale/sick-people-on-flight-fll?fbclid=IwAR15B0pni9rxu7BTh-Ggl4ZBR_V1b2cm9uptNGdc14_NfIunTTvA4-un_nU

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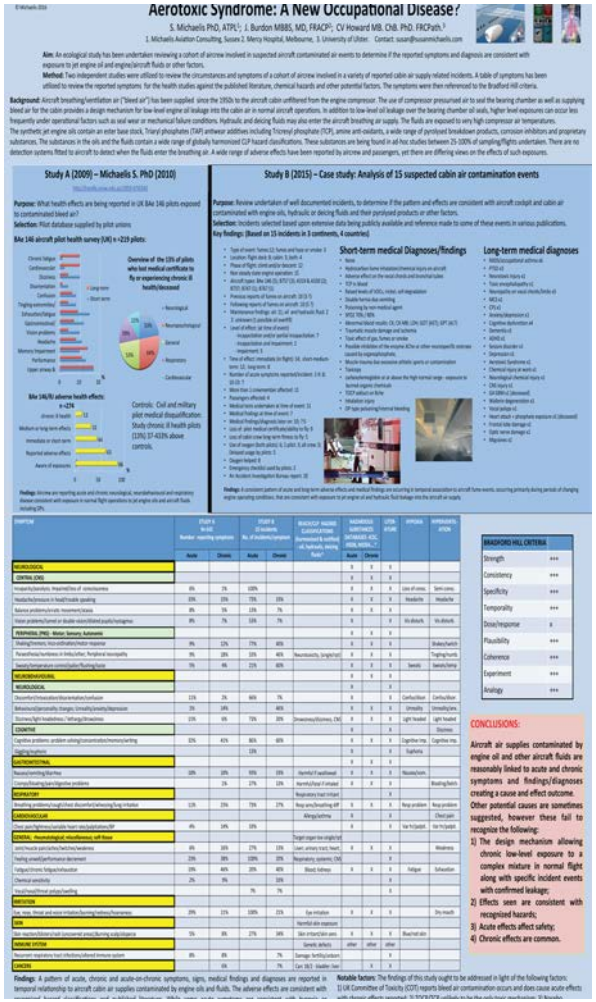
HEALTH

Aircraft air supplies contaminated by engine oil and other aircraft fluids are reasonably linked to acute and chronic symptoms and findings/diagnoses creating a cause and effect outcome.

New occupational disease?



Michaelis S, Burdon J, Howard CV. Aerotoxic Syndrome: A New 16. Occupational Disease? Public Health Panorama 2017; 3: 141-356 . http://www.euro.who.int/__data/assets/pdf_file/0019/341533/5_OriginalResearch_AerotoxicSyndrom_ENG.pdf

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MSc review of oil leakage (2016)

Permissible oil consumption: Normal

Low level oil leakage occurs in 2 ways in normal operations:

- **Continual very low level leakage across seals which limit emissions, rather than prevent them**
- **Increased leakage with changes in power/ air configuration**

Failure condition

- Bearing/seal failure….
- Worn seal
- Oil overfill……

Industry focuses on this <u>only</u>

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Gap in aviation regulations & standards/compliance

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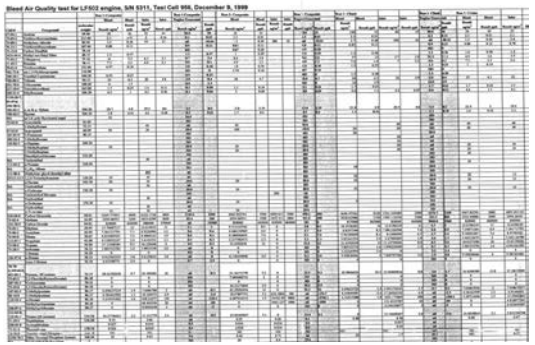
Cabin air monitoring

- Bleed air is NOT filtered
- Numerous ad-hoc air monitoring studies
- Wide range of substances identified including TCP in 25-100% of flights.
- Low levels repeatedly found
- Industry says better than houses/offices, below OELs



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Who has measured UFPs? Actual or simulated

- Cranfield (Crump et al) 2011
- Li et al. (2014)
- Jones et al. 2017
- EASA (CAQ) 2017
- Space et al 2017
- Spengler et al (ACER) 2012

- GCAQE (2018)

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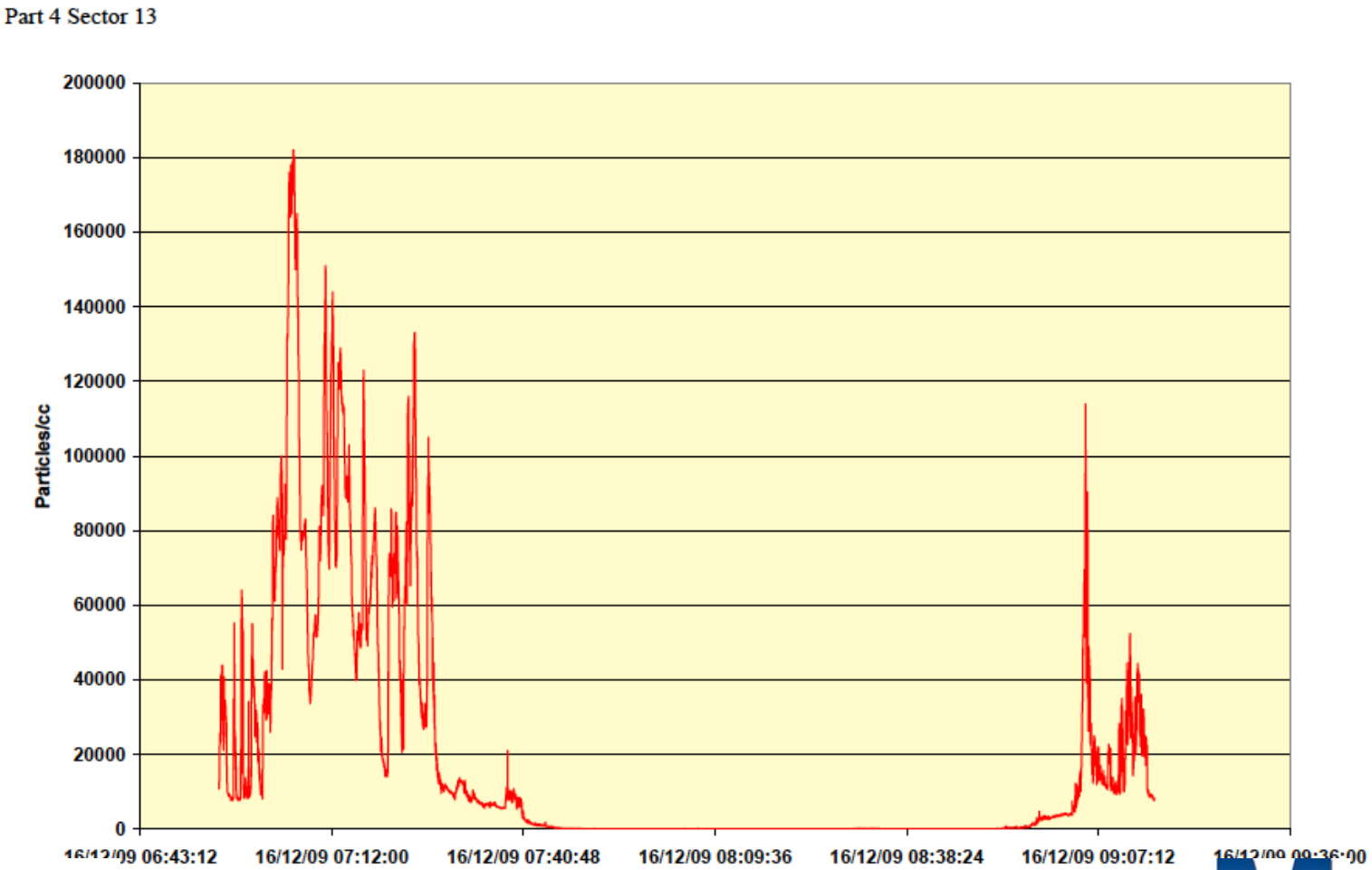
UFP:Cranfield, 2011



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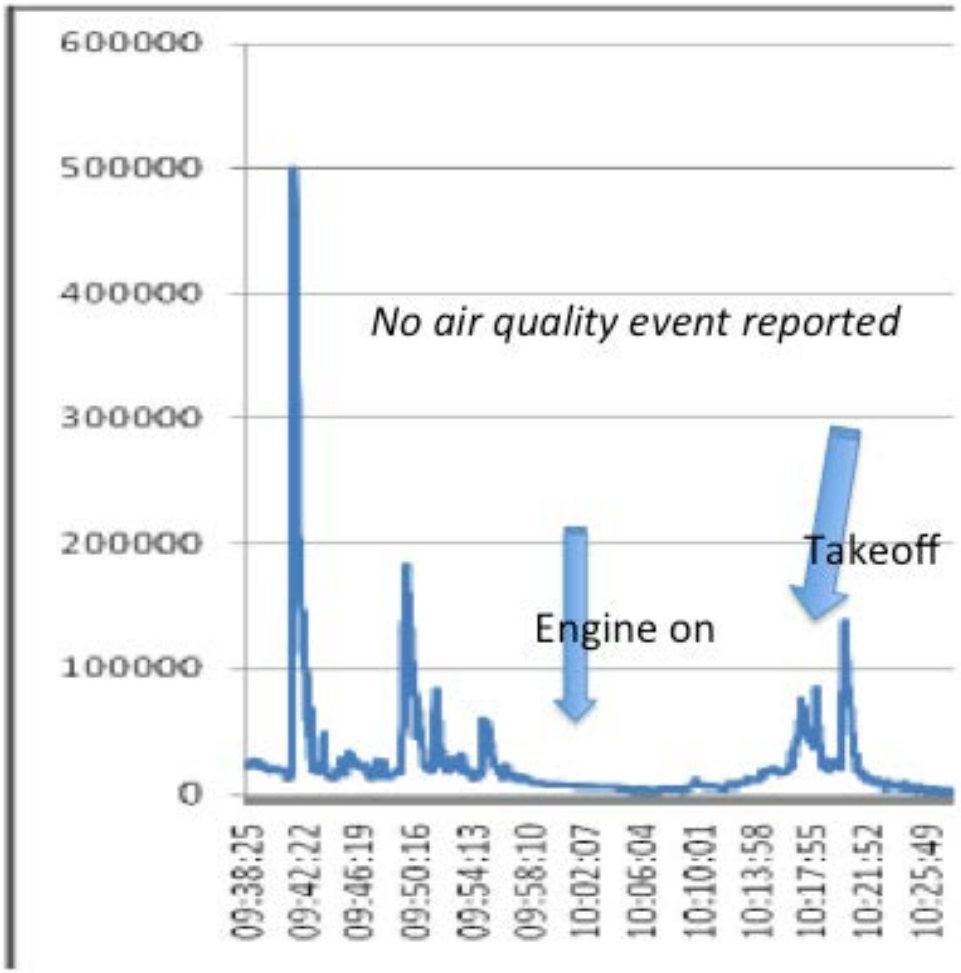
UFP:Cranfield, 2011



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UFP:Cranfield, 2011

- TSI P-Trak® Ultrafine Particle Counter (UPC) 8525
- 100 flights measured
- 5 flights- > 500,000 particles/cm3 - No air quality events
- 65 flights – 100,001 -500,000 particles/cm3
- 25 flights reported minor air quality
  - 19 were 100,001 -500,000 particles/cm3
- Suggested to be related to phases of flight & engine operation other than cruise.

Crump D, Harrison P, Walton C. *Aircraft Cabin Air Sampling Study; Part 1 and 2 of The Final Report*. Cranfield: Institute of Environment and Health, Cranfield University, 2011.
*Crump D. Air quality in aircraft: A continuing debate. *Indoor Built Environ* 2016; 25: 725–727.

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Li et al., 2014

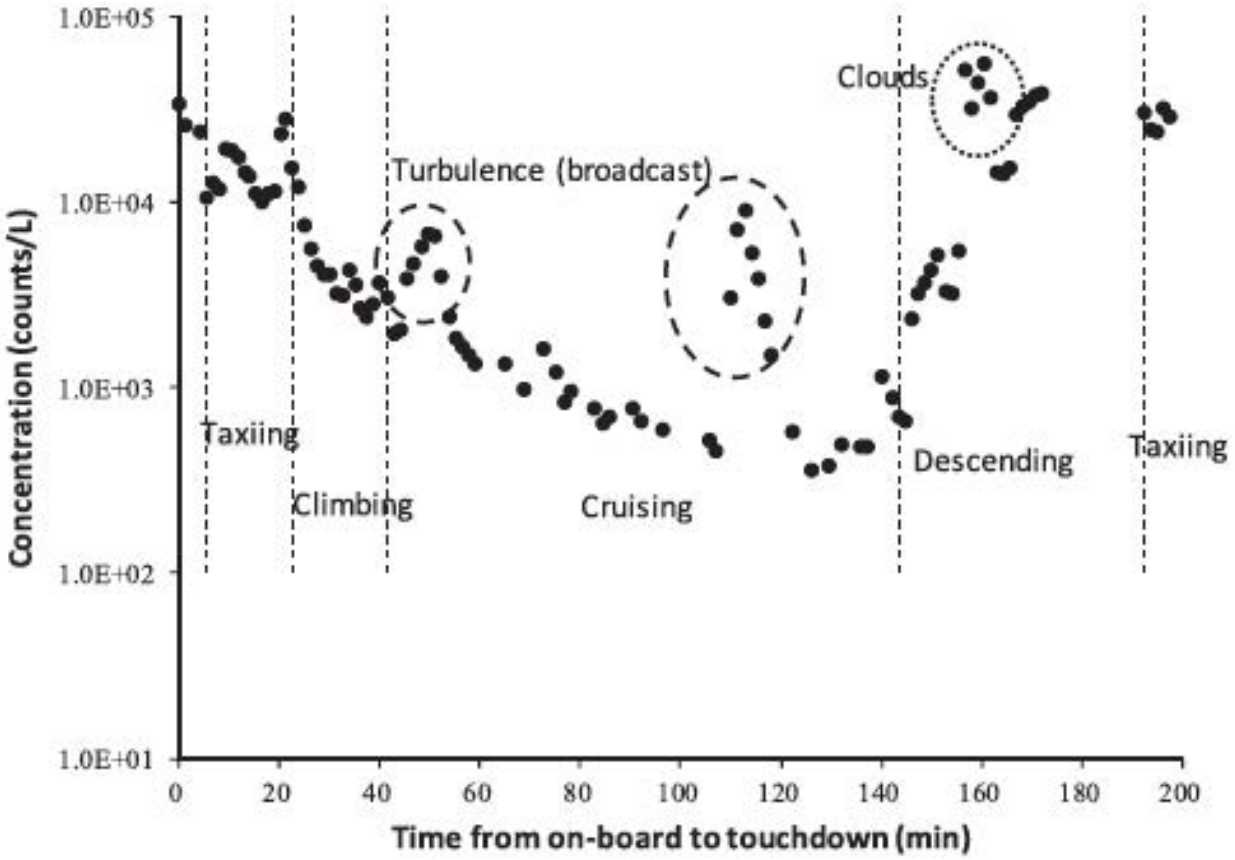

Fig. 7. Concentration of $PM_{>0.3}$ in supply air in flight 8.

Peaks/ smaller particles > bleed/supply air

Li et al.,(2014)

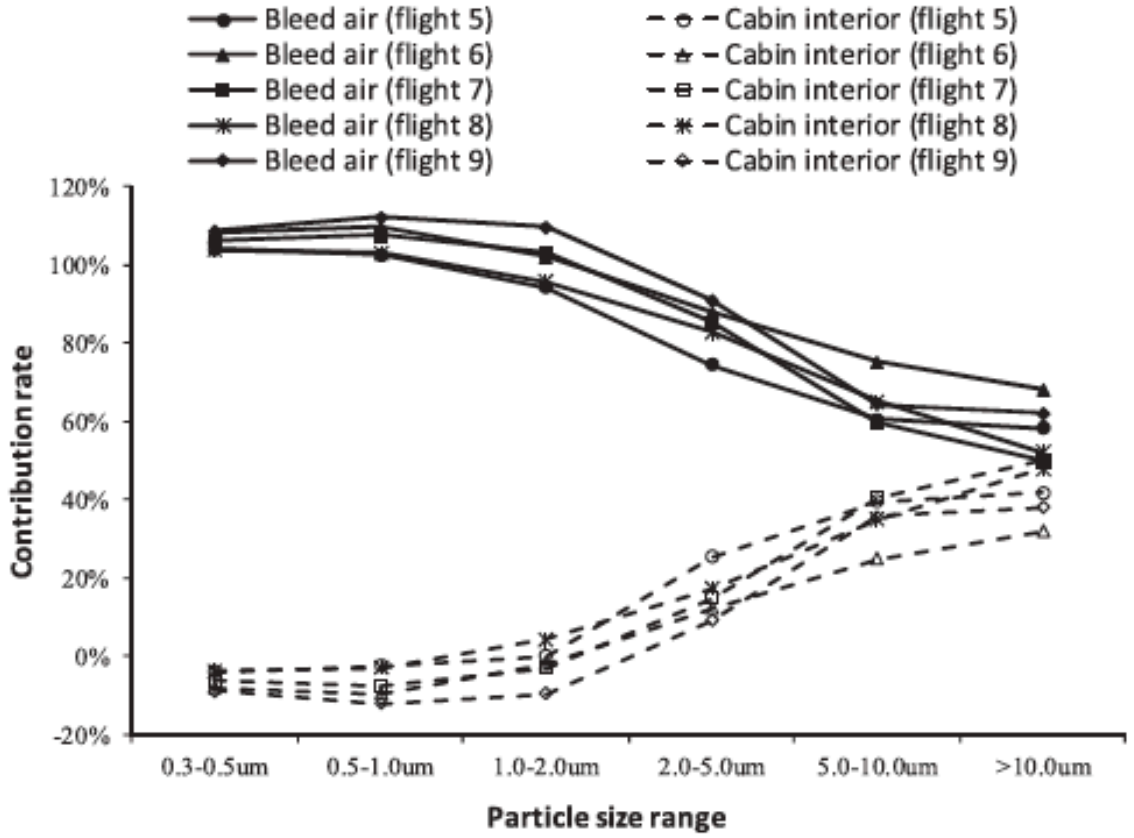

Fig. 13. Percentages of breathing zone particle concentration contributed by bleed air and cabin interior in selected flights.

Smaller size particles most likely – bleed air source

Jones et al., 2017 - simulation

- C-17 aircraft (equivalent to B757 engine) - Cruise
- *"The measurements showed that oil contamination in the compressor will result in a fog of very fine droplets in the bleed air under most operating conditions. Typically these droplets are in the 10-150 nanometer range. With very low contamination rates, it appears that many of the droplets may be even smaller than 10 nanometers."*
- Peak concentrations- 50-70nm size
- No oil injected in -1 x 10^3 particles/cm^3
- Oil injected in - 2 x 10^7 particles/cm^3 (2 orders of magnitude higher)

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Jones et al., 2017

- *"oil contamination leads to a large number of particles in the bleed air."*
- Most are in small size range 10-70. Maybe even smaller
- Measure UFPs

" This research shows that development of sensors for detecting oil contamination in aircraft bleed air should focus on ultrafine particle detection and sensing of low contamination levels may require sensitivity to extreme ultrafine particles 10 nanometers and smaller."

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EASA CAQ, 2017

- “Detection of concentration peaks of submicron aerosols in the bleed air could therefore be a hint on oil leaks in the engine.”
- Aerosols in UFP range can be differentiated
- Internal aerosol sources “cannot be ruled out”
- B787 shows different pattern − early in flight only

EASA (2017) Research project: CAQ -Preliminary cabin air quality measurement campaign

➢Information difficult to interpret regarding phase of flight

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GCAQE - 2018

- Basic initial study
- 4 flights
- A320
- TSI P-Trak® Ultrafine Particle Counter (UPC) 8525
- Particles/cm3 (20-1000nm) – most assumed to be UFP range

Results :

- Peaks associated with:
  - Engine power changes
  - Introduction/change of air supply from engines or APU
- Ground emissions of UFPs are also evident
- Age of aircraft not relevant. Need to look at engine/APU age
- Cannot say all related to passengers boarding

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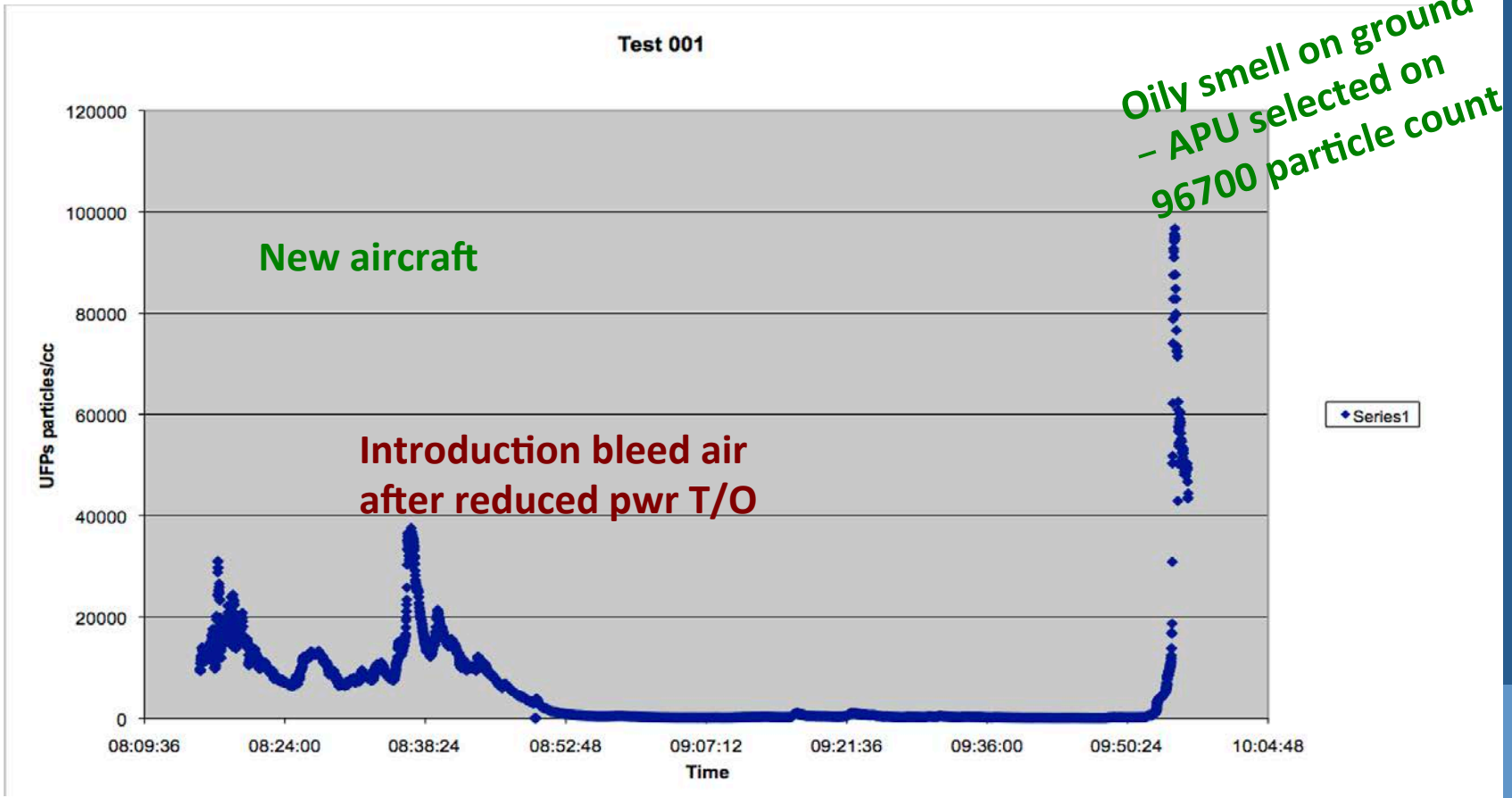
GCAQE – Flight 1



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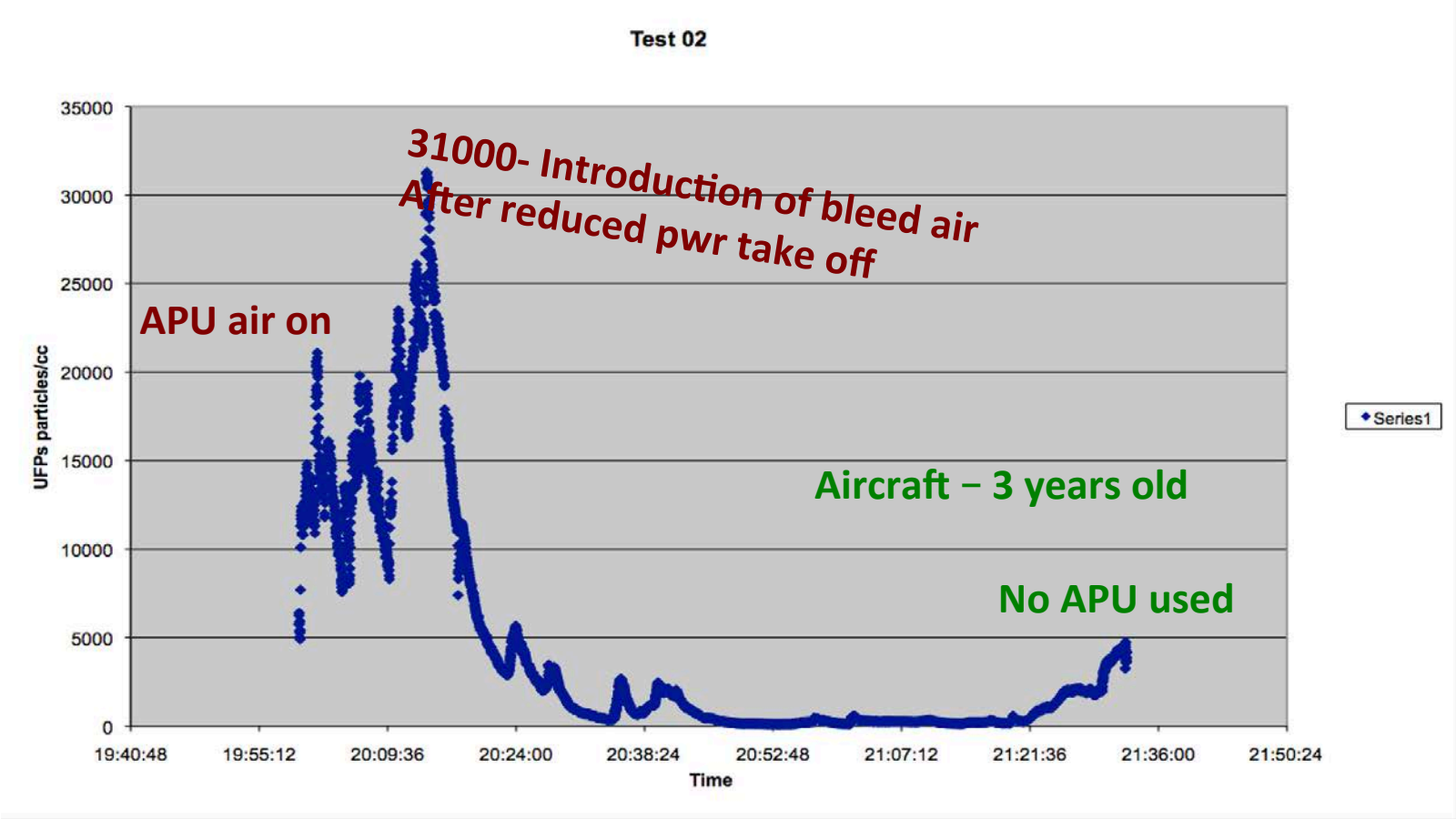
GCAQE – Flight 2



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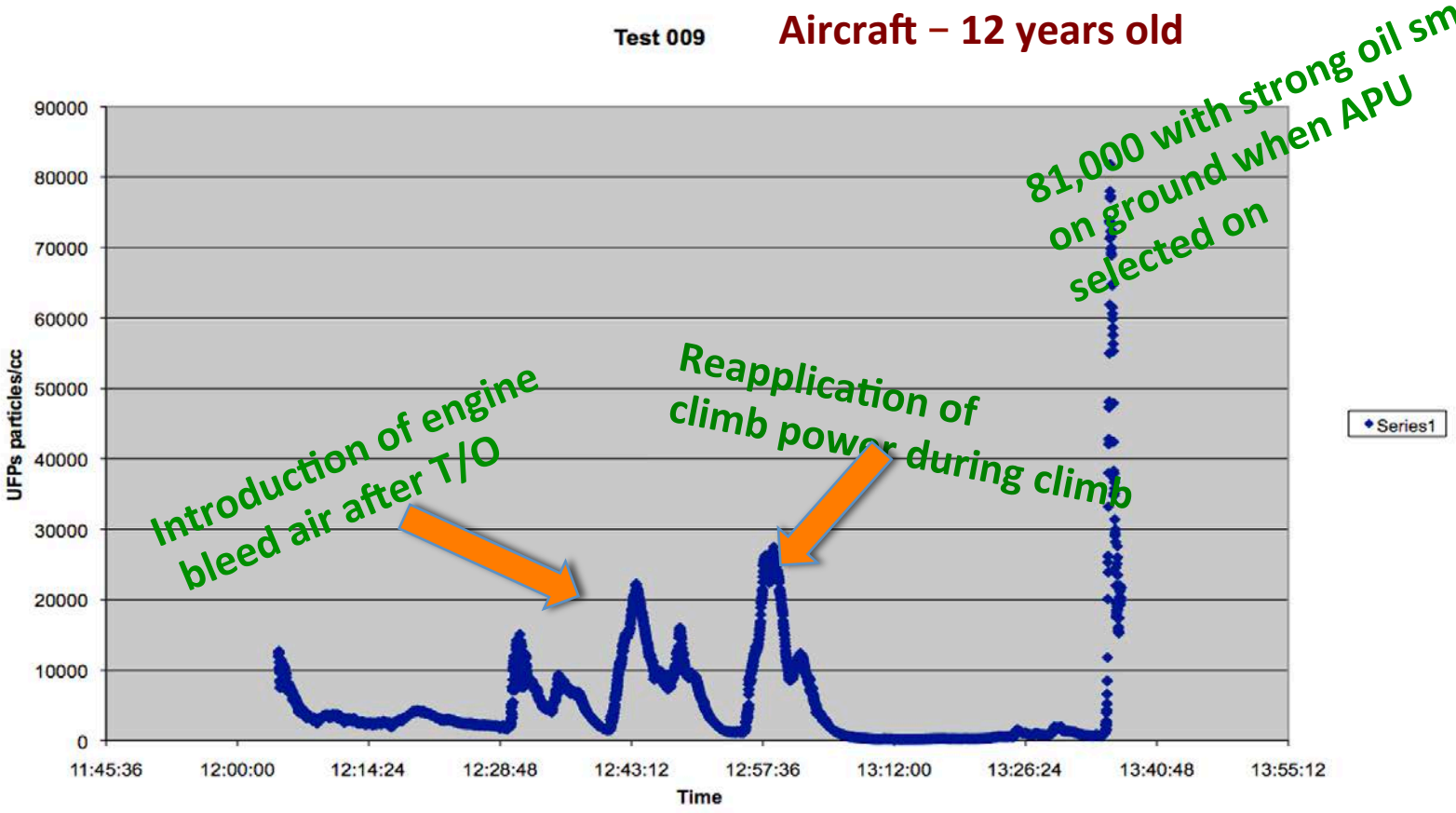
GCAQE – Flight 3



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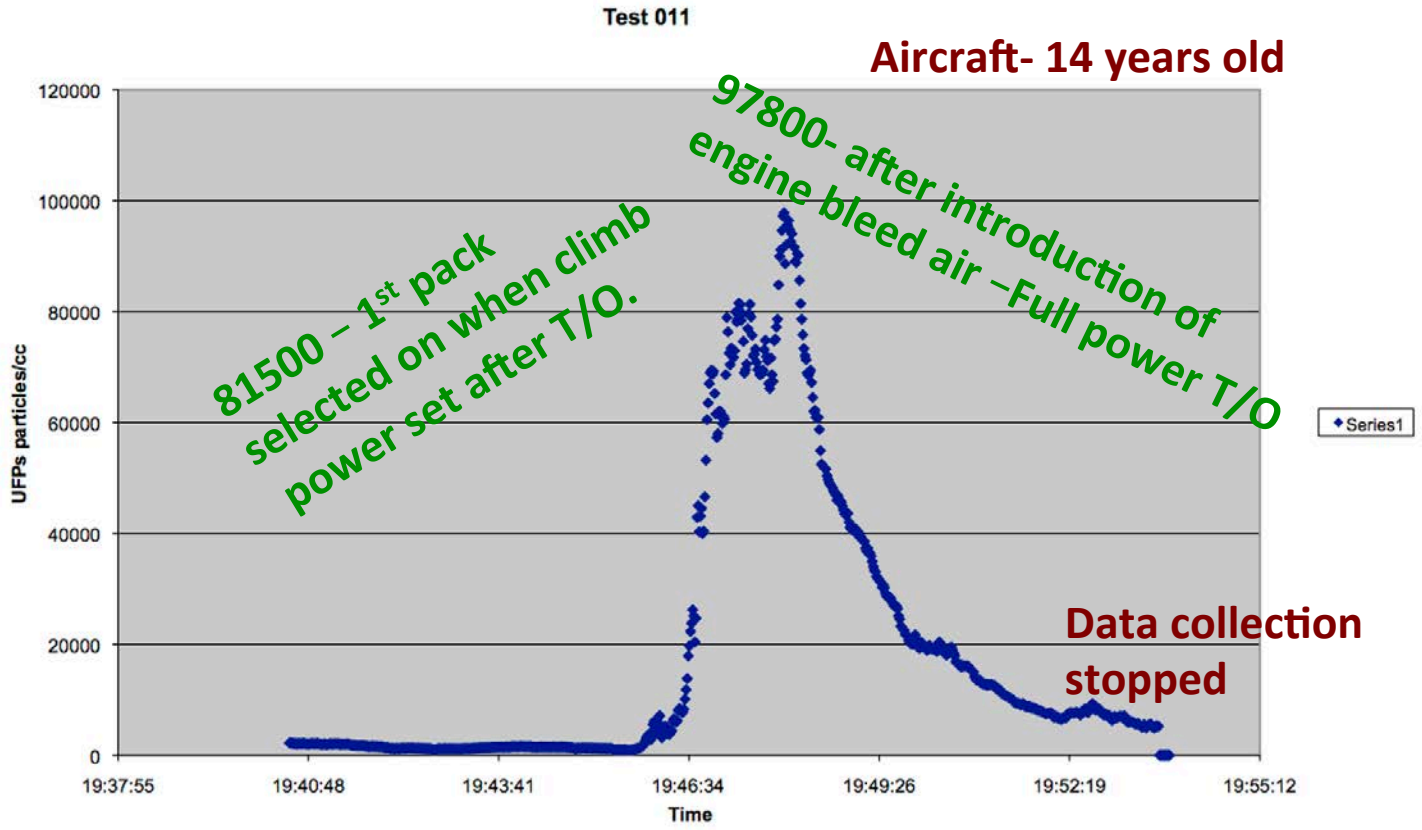
GCAQE – Flight 4



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Compared to other locations

LOCATION	AVREAGE LEVELS RECORDED: Particles/CM3
Beach- beside water- English channel	2428
Train compartment – moving train	3242
Household kitchen – Not cooking	3661
Street outside Victoria station, London	24428

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Science

Howard et al (2018)

- UFPs + complex mixture
- UFPs enter the blood stream >> travel to most organs in body
- UFPs act like trojan horses carrying other chemicals over BBB – TAPs….in vapor phase condense onto UFP surface – remain there.

- "A consideration of the toxicology of Nano-particles concludes that their continual presence over a typical working lifetime of up to 20,000 hours in aircrew will predispose them to chronic respiratory problems and will exacerbate the translocation of neurotoxic substances across the blood brain barrier."

- Smaller size are more chemically reactive

Howard CV, Johnson DW, Morton J, Michaelis S, Supplee D, et al. (2018) Is a Cumulative Exposure to a Background Aerosol of Nanoparticles Part of the Causal Mechanism of Aerotoxic Syndrome? J Nanomed Nanosci: JNAN-139. DOI: 10.29011/JNAN-139. 100039

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Conclusion

- UFPs are generated from engine oil use in jet engines under normal operating conditions (continual)
- UFPs increase with engine/APU power changes & changes in air supply configuration
- UFP concentration far higher than other environments
- UFPs are very suitable candidate to measure presence of engine oil in air supply
- UFPs predominantly smaller size range (50-70 nm)
- Continual UFP exposure for aircrew predisposes them to respiratory & neurological and other conditions
- Need for further UFP measurements with engine power & bleed configuration changes identified….
- Characterize bleed air supply aerosol/particulate emissions for oil

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https://www.aircraftcabinair.com/
Imperial College London
17-18 Sept. 2019

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