EASA
European Union Aviation Safety Agency

Workshop on future Cabin Air Quality Research

30th – 31st January 2020

Stakeholder Presentation Material

Thorwald Buck
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Your safety is our mission.

An Agency of the European Union

Session #1

→ **Cabin Air Quality : State-of-the-art of research and Perspectives**

→ Presentations: ECA, BDL, Scientific Expert, Fraunhofer

ECA
European Cockpit Association

Cabin Air Quality

EASA CAQ Workshop
30-31 January 2019, Cologne

European Cockpit Association (ECA)

- Created in **1991**
- **Representative body** of European pilots at EU level
- **40.000+** pilots
- National pilot associations in **33 EU states**

ECA
European Cockpit Association

Position on Cabin Air Quality

Cabin air contamination is **a known problem**
that can cause **serious short- and long-term health effects**
which may compromise flight safety.

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European Cockpit Association

Position on Cabin Air Quality

- **Safety promotion activities by EASA** (incl. basic training for crews and operators) are needed to raise awareness and improve reporting
- Need for a clear **standardised medical protocol**
- **Need for action** by operators & manufacturers based on the current knowledge and technology (sensors, filters, oil components, etc)

Long-term = Bleed-free aircraft design

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Future Research

- Development of technology for detection & filtration
- Study of medical effects on crews involved in fume-events
- Research and development of less toxic chemicals (oils, hydraulic…)

But regardless of the topic(s), future research should NOT block taking action now!

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The next slides are for reference only and list the elements of the ECA position (2015)

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Technology

- Real-time **detection systems** and cockpit warning devices
- **Bleed-air filtration**
- **Less toxic chemicals** (oils, hydraulics…) to be certified and applied
- Long term — **Bleed-free aircraft design**

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European Cockpit Association

Training & reporting

- **Basic education for air crews and companies** on nature, effect and symptoms of fume events, as well as awareness & safety management training
- **Improved and harmonised operating procedures** for smoke / fire / fume / smell events including post-event guidance
- **Facilitate improved and systematic reporting** of fume events to the operator and by the operator to crews and competent authority

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Research

- European risk assessment to quantify the magnitude of the problem
- Robust inhalation studies (based on aircraft environment)
- Research on biomarkers specifically for fume events

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CAQ – Perspective of Airline Operations & derived Research Needs

BDL

Exchange with relevant Stakeholders

Sensitization of the Crews

Standardized reporting Procedure

Standardized medical Examination

BDL

LUFTHANSA GROUP

Condor

TUI fly

DHL

Tests of Filters

Own Investigations

Call for independent Studies

Monitoring and Support of independent Research

CAQ – Perspective of Airline Operations & derived Research Needs

Discussion on Cabin Air Quality inside an airline influences the whole airline operation even the numbers of effected flights are very low. Due to complexity of subject, integrated view is necessary to support Flight Crews, Maintenance and Flight Operation.

Required answers

- on outstanding issues before introducing comprehensive measures for airlines and/or manufacturer
- on matters concerning the crews today in their daily business
  e.g. how to detect causes of an odour, what about improved filter technology, about possible individual health risk or about alternative engine oils.

Lufthansa Group takes the issue very seriously. Further independent scientific investigations on Cabin Air Quality from EASA is appreciated.

CAQ – Perspective of Airline Operations & derived Research Needs

BDL

Who we are

- Dedicated CAQ team involving flight ops, engineering, cabin dept. and occupational safety
- Supported by responsible Mgmt. granting high degree of freedom for innovation

What we do

- Incorporation of Event Classification Matrix to allow objective and comparable classification & statistics
- Crew training to explain technical background, action strategies and reporting

TUI fly

What we have achieved

- Worldwide launch customer for Advanced Cabin Air Filters combining HEPA and activated carbon technology on Boeing 737
- Project time less than 24 months from first draft to fleet standard equipment

What lies ahead

- Active involvement in latest developments concerning filtration, sensor equipment and research
- First Boeing 787 operator in Germany (soon): a chance for direct comparison of different ECS design performance

CAQ – Perspective of Airline Operations & derived Research Needs

TECHNOLOGY

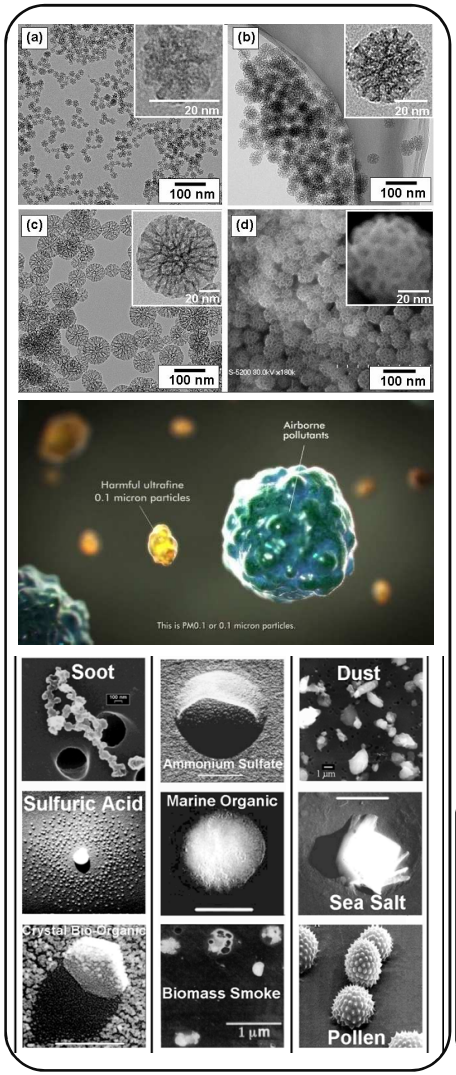
- Follow-up of the 2017 EASA Study Results
- Filters
- Detectors

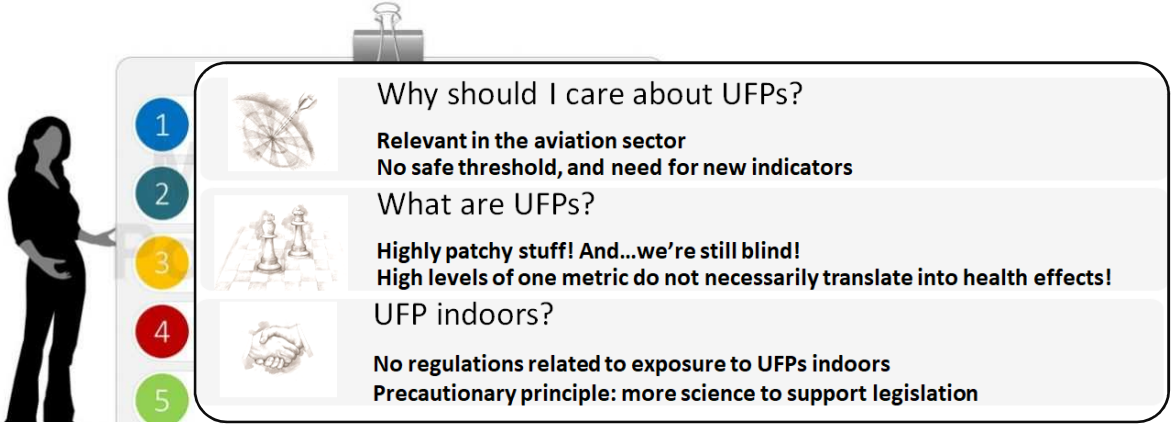
HUMAN

- Odour Explanations
- Medical Examinations on Persons concerned by Smell/Fume Events
- Metabolization
- Combination of several Substances

Francesca Costabile 30.01.2020

Combustion-derived Ultrafine Particles Challenges ahead





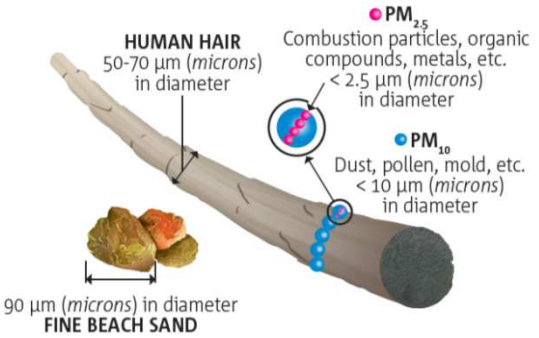
Core message

- It will take long **to obtain robust scientifically-sound evidences** on how to protect human population from health effects **possibly** deriving from exposure to combustion-generated UFPs. The **scientific complexity** is clear; the governing factors, processes, sources, mechanisms, relationships, endpoints, exposure, doses, compounds, molecules involved are not.
- The key point is to start early. As scientists, we are obligated to put on the table relevant questions like: **what** can pose a human health **risk**? **How** can this be avoided? **Who** may be affected? And **how**, **where** and **when**? And finally, **what do we need to do to get better at this?**

Why should we care about UFPs?

Particulate matter (PM)

Particulate matter is a general term used to describe very small solid or liquid particles. Emissions from aviation related activities, in a similar manner to other sources using carbon-based fuels, contain PM_{10} and $PM_{2.5}$ emissions[22], as well as ultrafine particles (PM_1, $PM_{0.1}$) that have very small diameters [91]. Such small particles, irrespective of the combustion source, can deposit in the human lung, pass natural barriers in human cells and enter the bloodstream. Solid ultrafine particles can trigger inflammation and act as carriers for toxic substances that damage the genetic information in cells. The EU Ambient Air Quality Directives [14] contain regulatory limits for PM_{10} and $PM_{2.5}$ in ambient air, but not for ultrafine particles. However, $PM_{2.5}$ is considered to be a good indicator of general risk associated with exposure to particulate matter. As the mass of the ultrafine particle emissions is so low, measurements of aircraft engine emissions have also focused on the number of emitted particles.



there remain knowledge gaps (e.g. impact of ultrafine particles)

Why should we care about UFPs?

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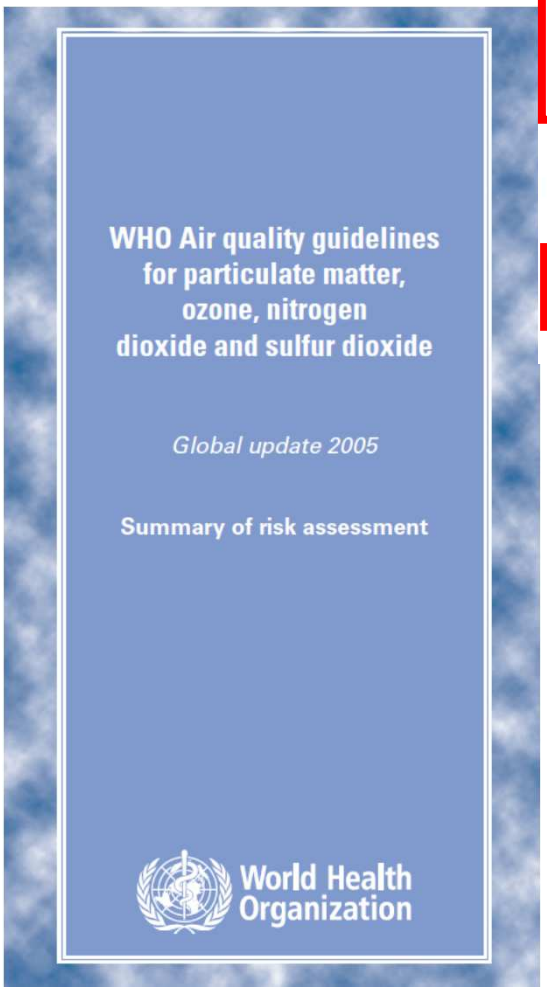


to the pollution may vary with health or age. The risk for various outcomes has been shown to increase with exposure and there is little evidence to suggest a threshold below which no adverse health effects would be anticipated. In fact, the low end of the range of concentrations at which adverse health effects has been demonstrated is not greatly above the background concentration, which for particles smaller than 2.5 μm ($PM_{2.5}$) has been estimated to be 3–5 μg/m³ in both the United States and western Europe. The epidemiological

ticular guideline value. Both the United States Environmental Protection Agency and the European Commission have recently used this approach to revise their air quality standards for PM. Countr

Particulate matter

Guidelines

$PM_{2.5}$:	10 μg/m³ annual mean 25 μg/m³ 24-hour mean
PM_{10}:	20 μg/m³ annual mean 50 μg/m³ 24-hour mean

As thresholds have not been identified, and given that there is substantial inter-individual variability in exposure and in the response in a given exposure, it is unlikely that any standard or guideline value will lead to complete protection for every individual against all possible adverse health effects of particulate matter. Rather, the standard-set-

The choice of indicator for particulate matter also requires consideration. At present, most routine

Ultrafine particles (UF), i.e. particles smaller than 0.1 μm in diameter, have recently attracted significant scientific and medical attention. These are usually measured as a number concentration. While there is considerable toxicological evidence of potential detrimental effects of UF particles on human health, the existing body of epidemiological evidence is insufficient to reach a conclusion on the exposure–response relationship of UF particles. Therefore no recommendations can be provided as to guideline concentrations of UF particles at this point in time.

Why should we care about UFPs?

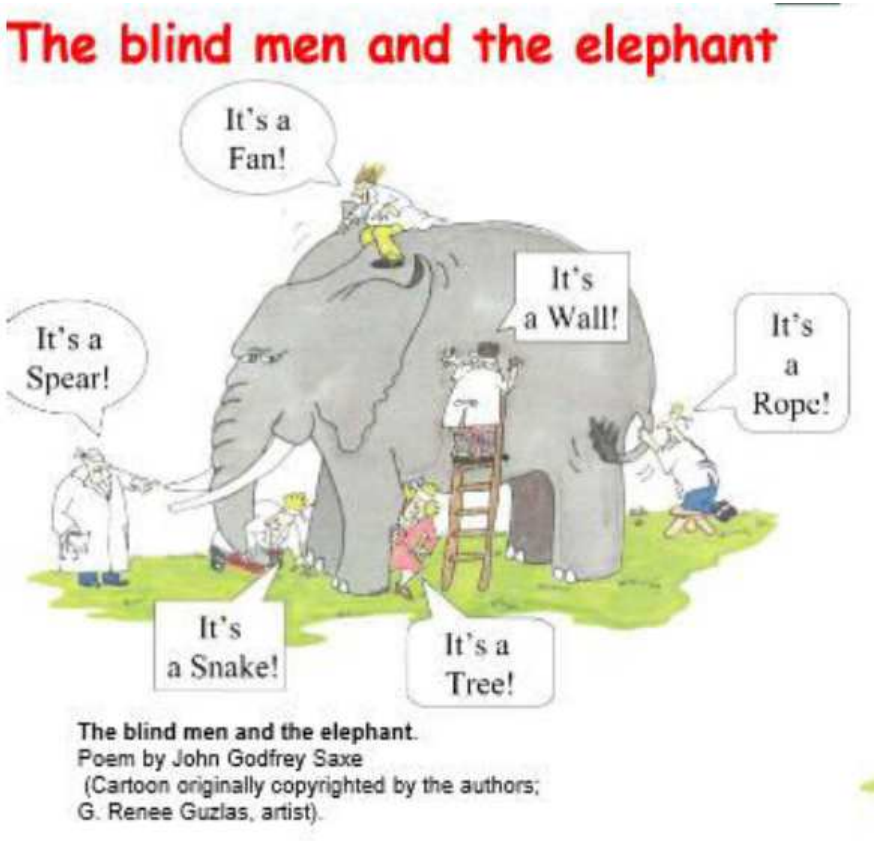
Suspected health effects for UFPs
Mortality, lung cancer, cardiopulmonary toxicity, DNA damage, neurological disorders such as severe cognitive deficits, Alzheimer's and Parkinson's disease, suicide and dementia [e.g., *WHO, 2010; IARC, 2016; Lancet Neurol. , 2017; Burnett et al., 2018; Calderón-Garcidueñas et al. 2019*]

Epidemiological evidence of health effects for UFPs
The research is still at the beginning.

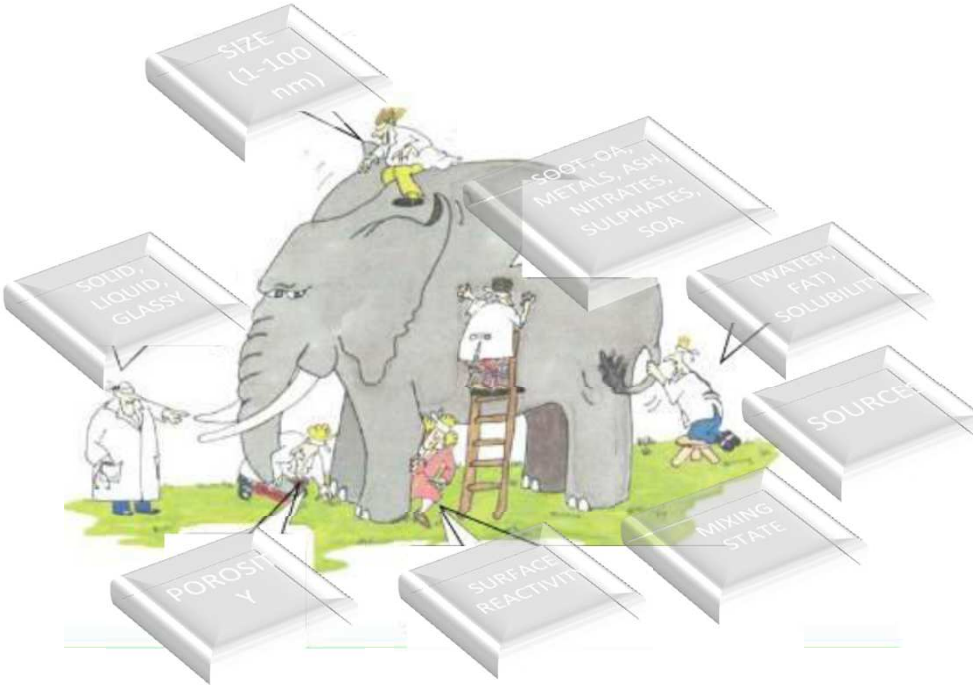
According to a recent systematic literature review update [*Ohlwein et al., 2019*] updating review of the Health Effects Institute [*HEI, 2013: Understanding the health effects of ambient UFPs*]:

- Epidemiological evidence for UFPs is still scarce and too often based on daily data, and one single (PNC) metric; only few epidemiological studies for UFPs integrated metrics (PNC, PLC, PSC) at hourly resolution [e.g., *Chen et al., 2020*]
- inconsistent evidence on long-term health effects for UFPs
- Insufficient overall evidence for UFP health effects independent from co-founding factors (e.g., co-emitted pollutants, ambient conditions)
- Insufficient evidence to derive conclusions for neurocognitive function or birth outcomes
- there is evidence for short-term health effects linked to UFP exposure (pulmonary and systemic inflammation, autonomic tone and blood pressure), which may be at least partly independent of other pollutants

What are UFPs?



The blind men and the UFPs



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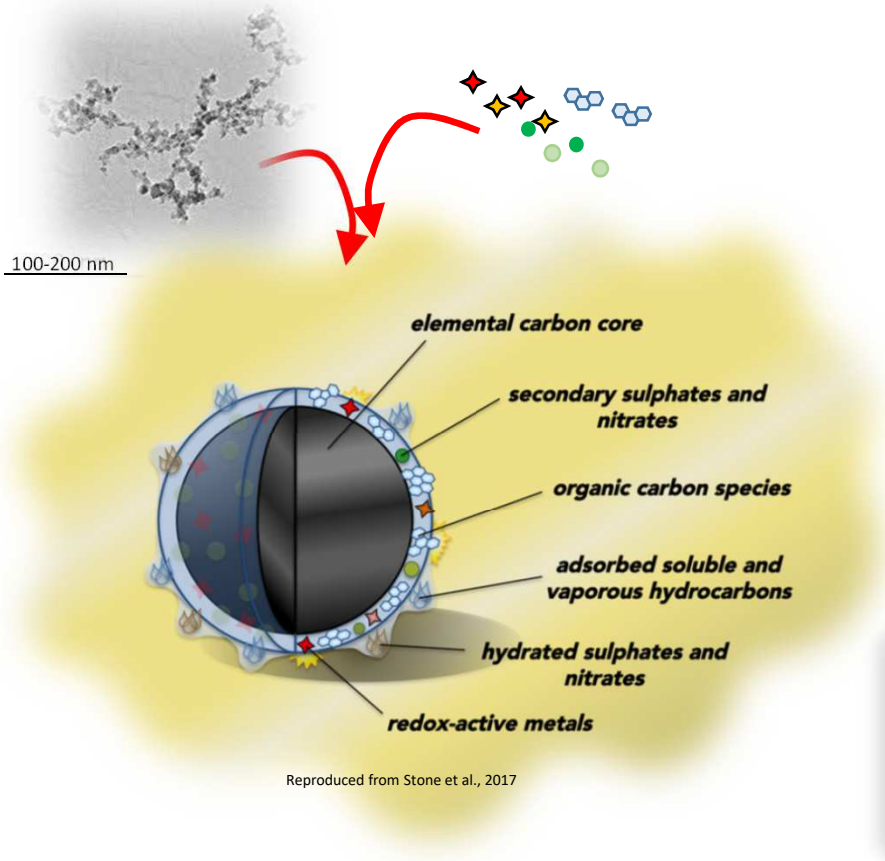
What are UFPs?

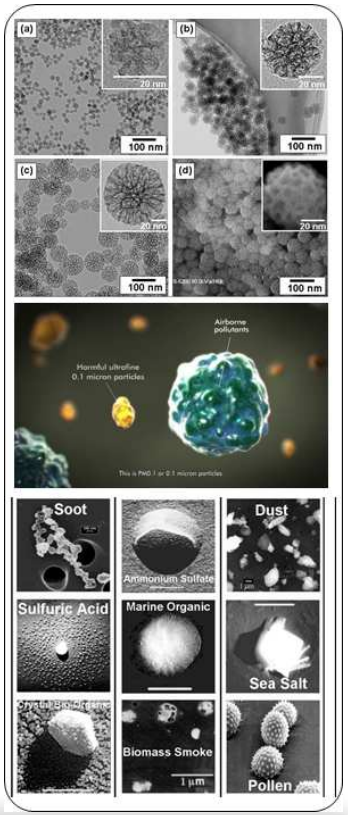
From Bémer et al., 2015



Reproduced from Stone et al., 2017

- **not a homogeneous** substance
- **different sources** (formed in atmosphere or combustion emitted)
- **processing** in air **dramatically** change physicochemical properties
- **high spatiotemporal variability**
- **cannot be described by one variable**
- **size span from a few tens to dozens nm**
- **nucleation mode particles**, **Aitken mode particles**,ì, **soot-mode**, **accumulation mode particles**
- **organic molecules (e.g., PAH), transition metals, EC/BC, SOA, OA, ashes** (e.g., Ca, S, P, Fe, O from lubricating oil)
- vapours + **solid, liquid, and glassy material**
- **smaller** than **the visible waveleghts**

[e.g., Hinds, 1999; Costabile et al., 2009; Brines et al., 2015; Seinfield and Pandis, 2016; Baldauf et al., 2016; Ruckerl et al., 2016; HEI, 2013; Stone et al., 2017; Gualtieri et al., 2018; Costabile et al., 2017, 2019; Lowther et al., 2019; Ruckerl et al., 2019]



- → **COME IN ALL FORMS AND SHAPES**
- → **HIGHLY INHOMOGENEOUS PROPERTIES – more metrics are needed!**
- → **NOT VISIBLE (no fume)**
- → **HIGH SPATIOTEMPORAL VARIABILITY – high space/time resolution msmt**
- → **CANNOT BE COMPLETELY CHARACTERIZED – new equipment**

UFPs indoors?

Compared to outdoors:

- **Less understanding** for IAQ (e.g., epidemiological results usually based on data from outdoors)
- **No regulations** → indicators and metrics, guidelines and proposal for standards are needed
- **Lower levels, but rapidly increasing in time/space**, resulting in much more variable levels in time and space → equipment has to measure over a larger range of UFPs values, and with high time resolution
- **Higher accumulation, lower removal, different sources**, outdoor/indoor infiltration and penetration, air exchange rate indoors, air mass ageing indoors → need for modeling (computational fluid dynamics) to assess measurement site representativeness
- **Constraints of power, authorization, size, noisiness, intrusiveness for equipment** → need for highly accurate, but simple, battery operated, small sensors

WHO, 2010 (Guidelines for Indoor Air Quality); ISO, 2014 (Indoor Air-Part 1: General Aspects of Sampling Strategy); Lowther et al., 2019;

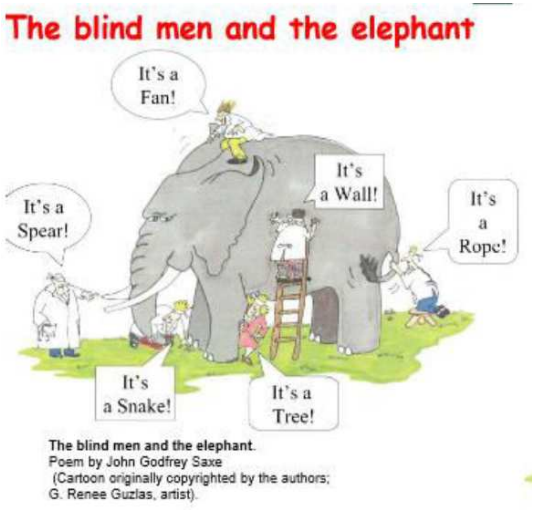
Concluding: ask about

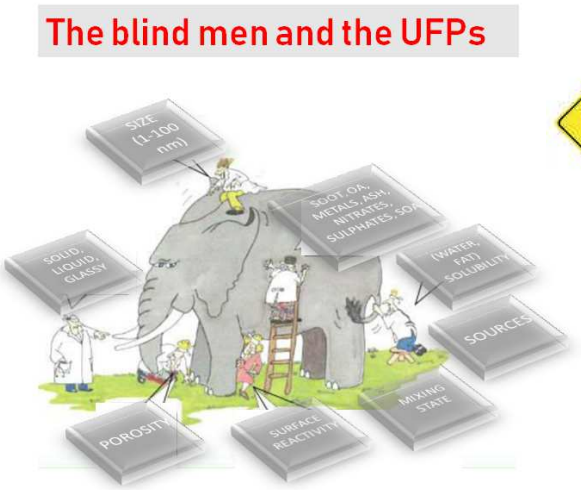
KNOWLEDGE GAPS (TO START WITH)

1. What UFPs indicator/metric (or combination of) is(are) the best suited to measuring health risk?
   e.g., mass, number, PNSD, lung deposited surface area, particle length/diameter, source-apportioned, chemical components, size ranges
2. What methods are the best suited to assess exposure to UFPs
   (sampling and conditioning systems do generate artefacts for particles <23 nm and for (semi)volatile fraction and (semi)liquid particles → nvPM? No sampling?
3. What equipment is the best suited to assess exposure to UFPs /how to fill technological gaps?
   e.g., chemistry, LDSA, diameter, solid vs liquid, solubility
4. Which evidence we have that high values of one single metric (e.g., particle number) are indicative of health effects?

"While humans may be the problem, with better understanding we can also be the solution"

[Let's work together. Nat Rev Earth Environ 1, 1 (2020)]





Thank you for this opportunity to share ideas

QUESTIONS?

Workshop on future Cabin Air Quality Research **Cologne 30.-31.01.2020**

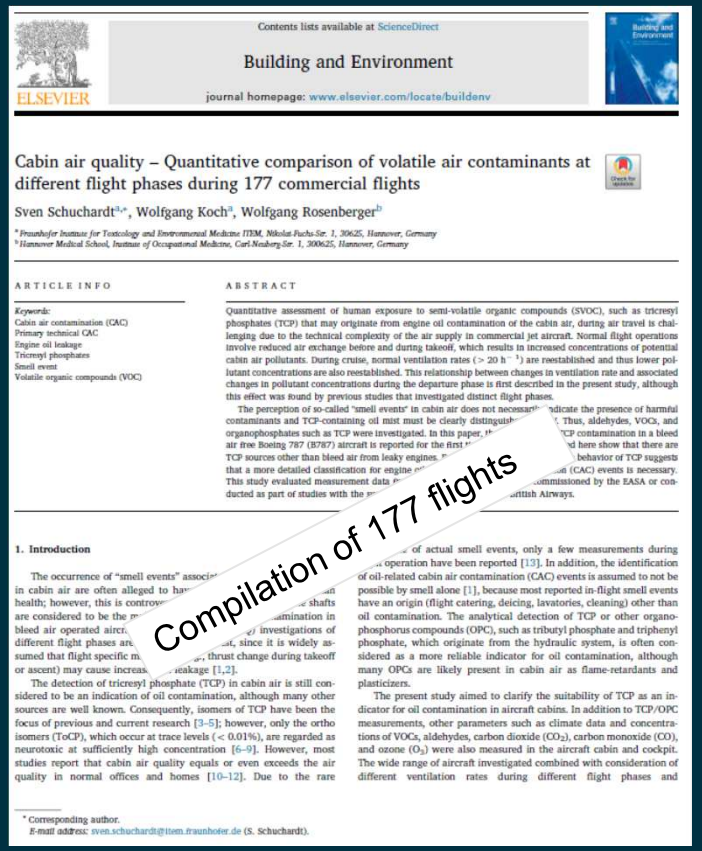
“Recommendation for a large scale project plan”

(Chapter 8, Final Report EASA CAQ Campaign)

Dr. Sven Schuchardt
Fraunhofer ITEM, Hannover

Fraunhofer ITEM

Recommendation for a large scale project plan

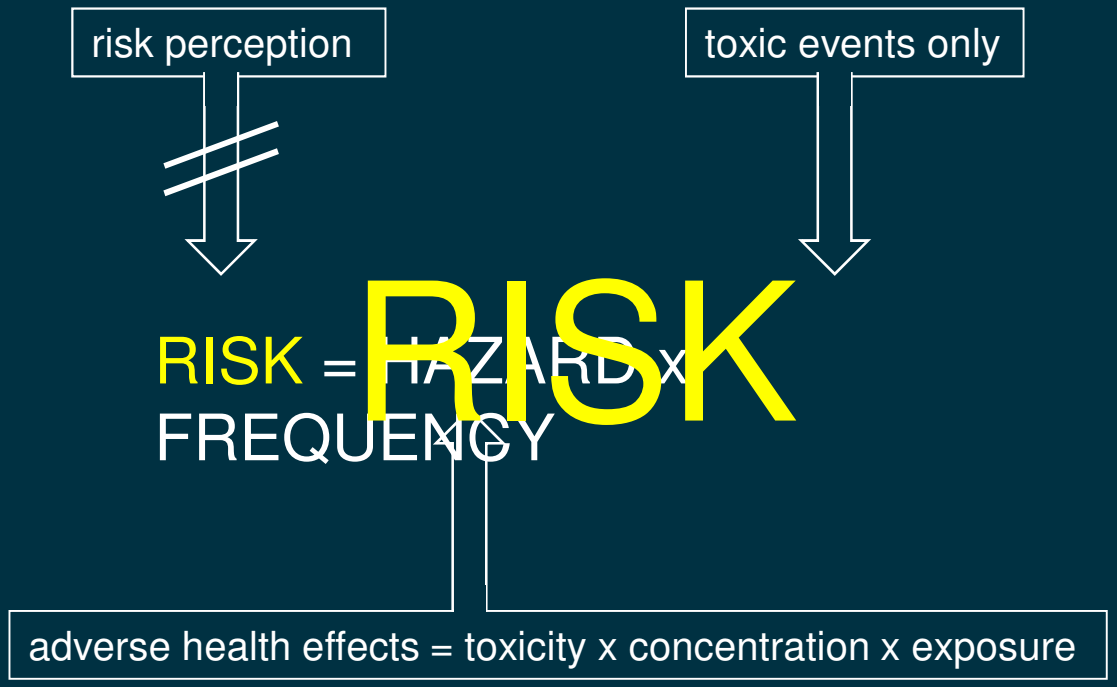


Fraunhofer ITEM

RISK

Q: Is oil contaminated cabin air toxic?

Metrics of Risk Assessment

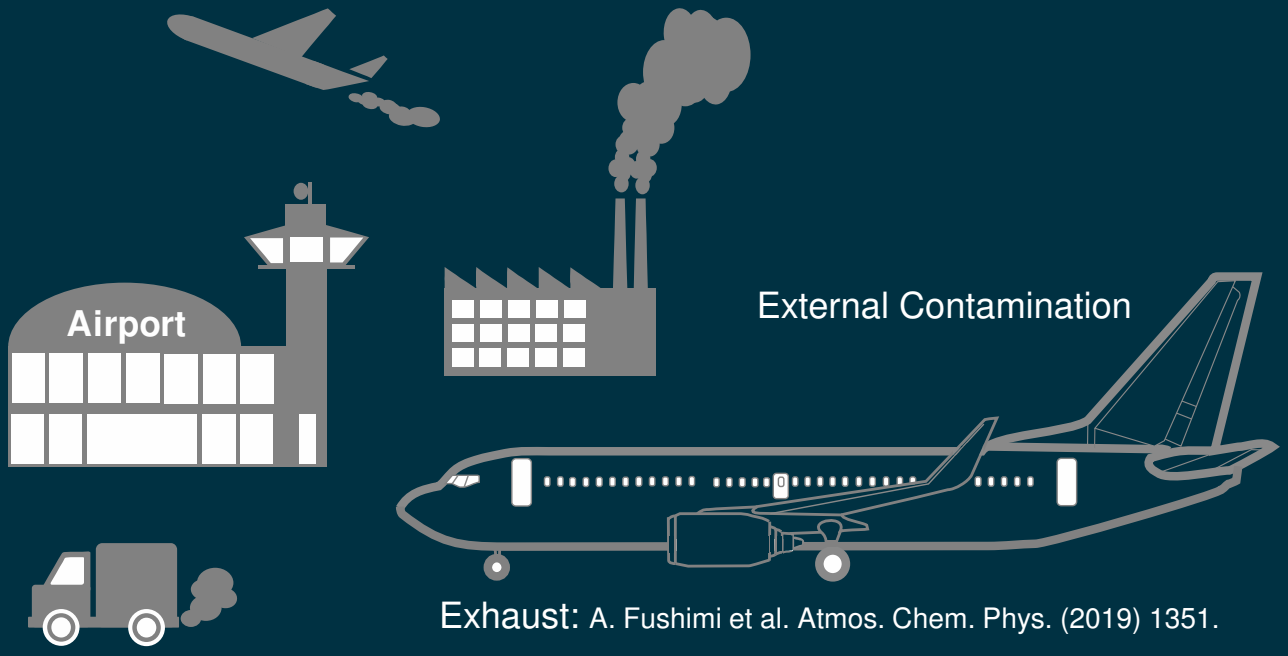


Re.: Use only scientific data for risk assessment.

Disturbing factor I: External Sources of Cabin Air Contaminations (CAC)

Particle deposition **HEPA** filter:

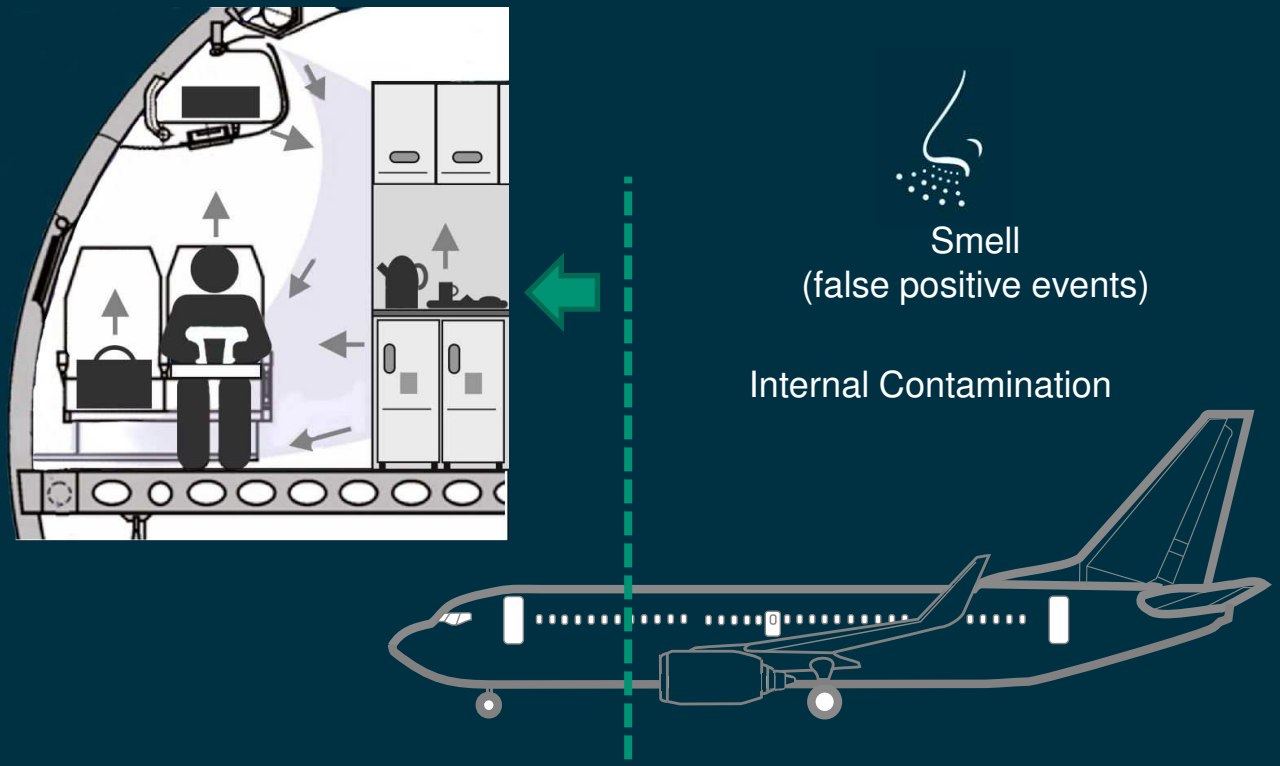
Q. Cao et al. Atmos. Environ. 154 (2017) 118–128.
Q. Cao et al. Indoor Air. 28 (2018) 852-865.



Exhaust: A. Fushimi et al. Atmos. Chem. Phys. (2019) 1351.

Re.: External contamination must be taken into account.

Disturbing factor II: Internal Sources of Cabin Air Contaminations (CAC)

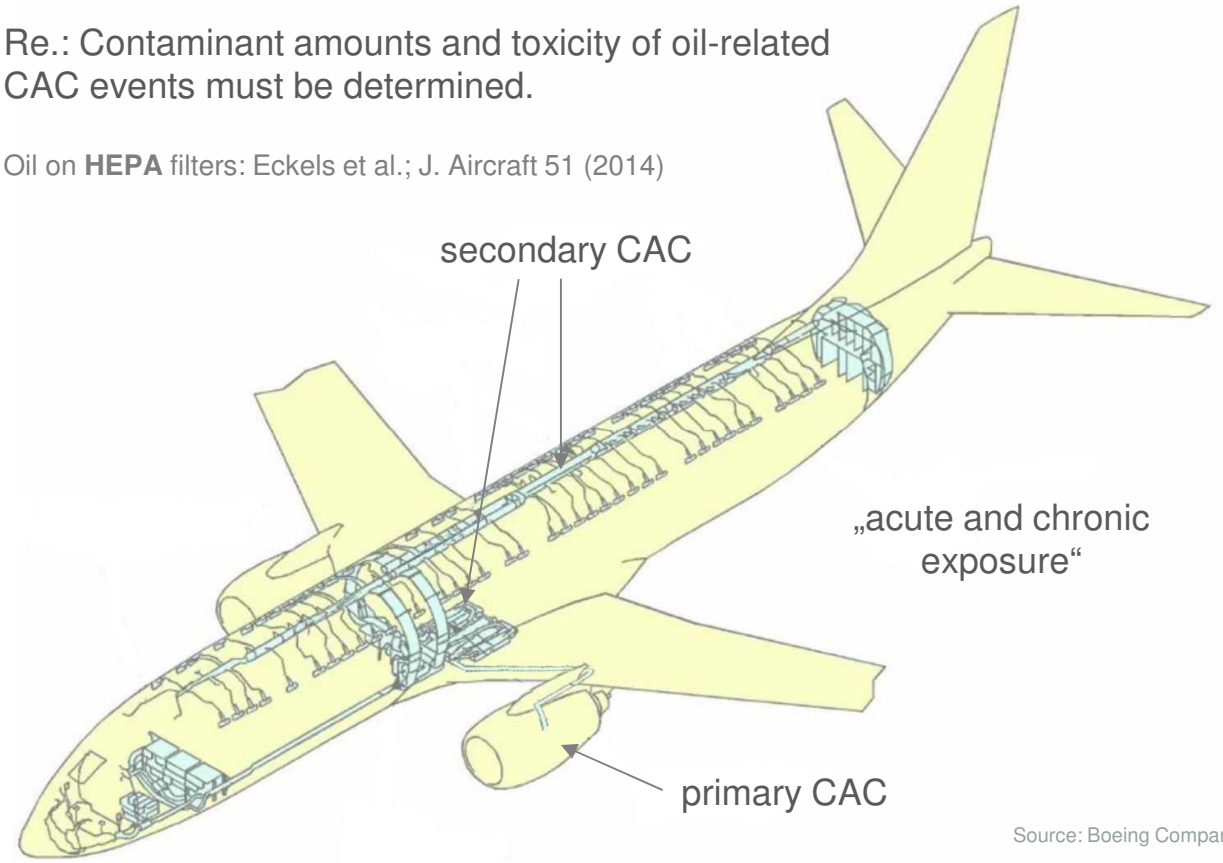


Re.: Internal contamination and smell needs to be investigated.

Main contamination factor : Oil-related Cabin Air Contaminations (CAC)

Re.: Contaminant amounts and toxicity of oil-related CAC events must be determined.

Oil on **HEPA** filters: Eckels et al.; J. Aircraft 51 (2014)



Source: Boeing Company

Recommendation for a large scale project plan – Summary -

- Use only scientific data for risk assessment...
- Consideration of external and internal contaminants / smell.
- Investigations on primary and secondary CAC events.
- Investigations on acute and chronic exposure.
- Determination of worst-case CAC toxicity.
- Determination of toxic CAC events frequency.
- …
- Validation of biomonitoring methods (blood & urine).
- …
- Investigations on psychosocial and medical effects.

Last remarks on risk perception…

„Journalists report plane crashes and plains that take off.“

Steven Pinker 2015

EASA Workshop 2020

Thank you for your attention!

Session #2

→ **Diagnosis, Toxicological Assessment, Health Risk Assessment**

→ Presentations: Air France, ESAM, IfADo, DLR, University of Stirling

ONBOARD FUME EVENTS: SHORT TERM HEALTH CONSEQUENCES IN AIRCREW

Vincent FEUILLIE, MD – Michel KLERLEIN, MD – Maxime LOIZEAU, MD

Air France Medical Department, Occupational Health Services

EASA Workshop, Cologne, 30th 31th January 2020

AIRFRANCE

I have the following financial relationships to disclose:

Employee of: AIR FRANCE

I will not discuss off-label use and/or investigational use in my presentation

Onboard Fume Event : so what ?...

Questions about air quality

- Presence of neurotoxic compounds ? (TCP isomers – ToCP – Carbon Monoxyde…)

Questions about immediate health effects

- Should I seek medical advice, even without symptom ?

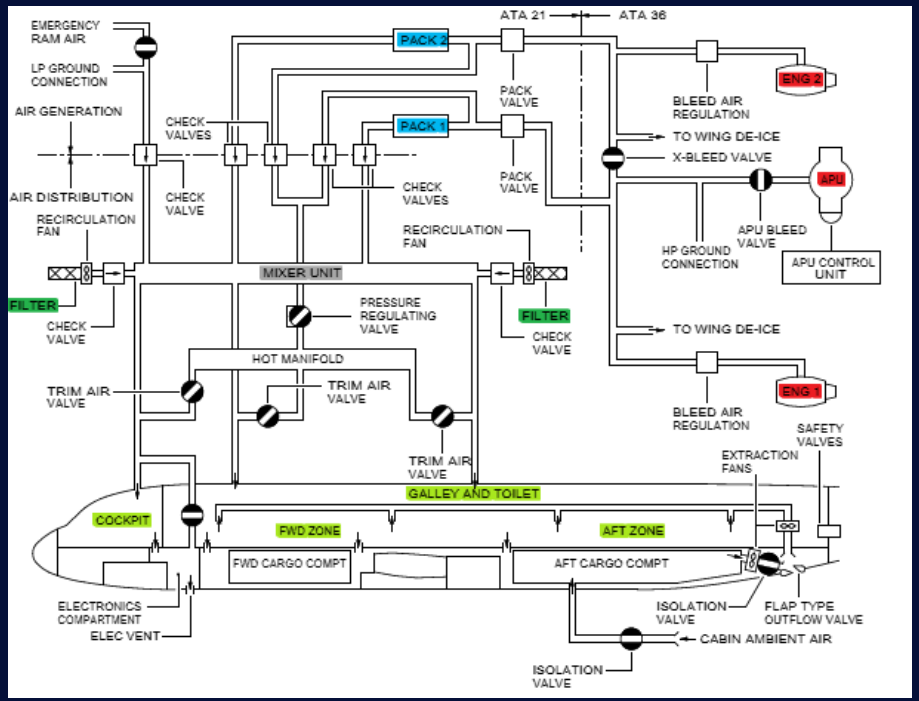
Questions about delayed effects

- Delayed neuropathy ?

What are we talking about ?

Bleed air technology : the outside fresh air is compressed in the engines, then processed by the packs, before being distributed to passengers and crews

Oil and Chemical contamination : theoretically possible to have oil or hydraulic fluid leaks from the engines to the fresh air, explaining very low levels of cabin air pollution



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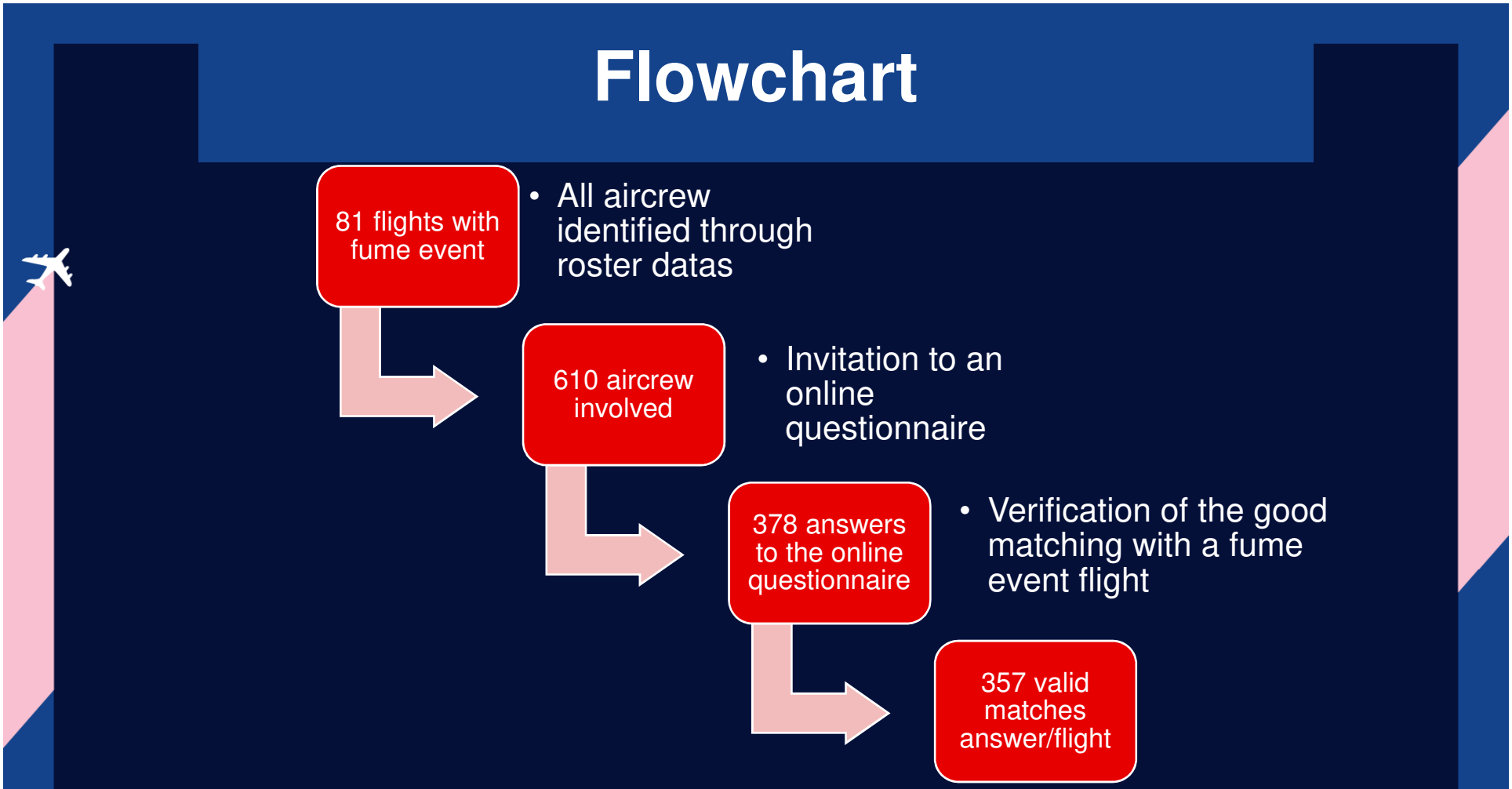
Objectives of our study

- **Understanding the feeling of the aircrew**
  during and immediately after a fume event exposure
- **Identifying the main symptoms associated with a fume event,** immediately and secundary
- **Mapping out all the mitigation means, including medical help**

Methods

- **Identify all the reported fume events in one year:**
  - through analysis of the pilot reports, cabin safety reports, occupational injury reports…
- **Send an online questionnaire to every crewmember involved in the fume event**
- **Classic statistical analysis**
  - Breakdown
  - Multilevel logistic regression in order to look for features associated with seeking medical care

Flowchart



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Who was exposed ?
(and receive the online questionnaire invitation)

	GENDER		AIRCRAFT		AGE
	F	M	Narrow	Wide	Mean (IQR) [95 % CI Mean]
PILOTS	13 (8.1 %)	147 (91.9 %)	108 (67.5 %)	52 (32.5 %)	47.5 (13.5) [46.2 – 48.8]
CABIN CREW	289 (68.2 %)	135 (31.8 %)	206 (48.6 %)	218 (51.4 %)	45.7 (8.0) [45.0 – 46.3]
TOTAL	302 (51.7 %)	282 (48.3 %)	314 (53.8 %)	270 (46.2 %)	46.2 (9) [45.6 – 46.8]

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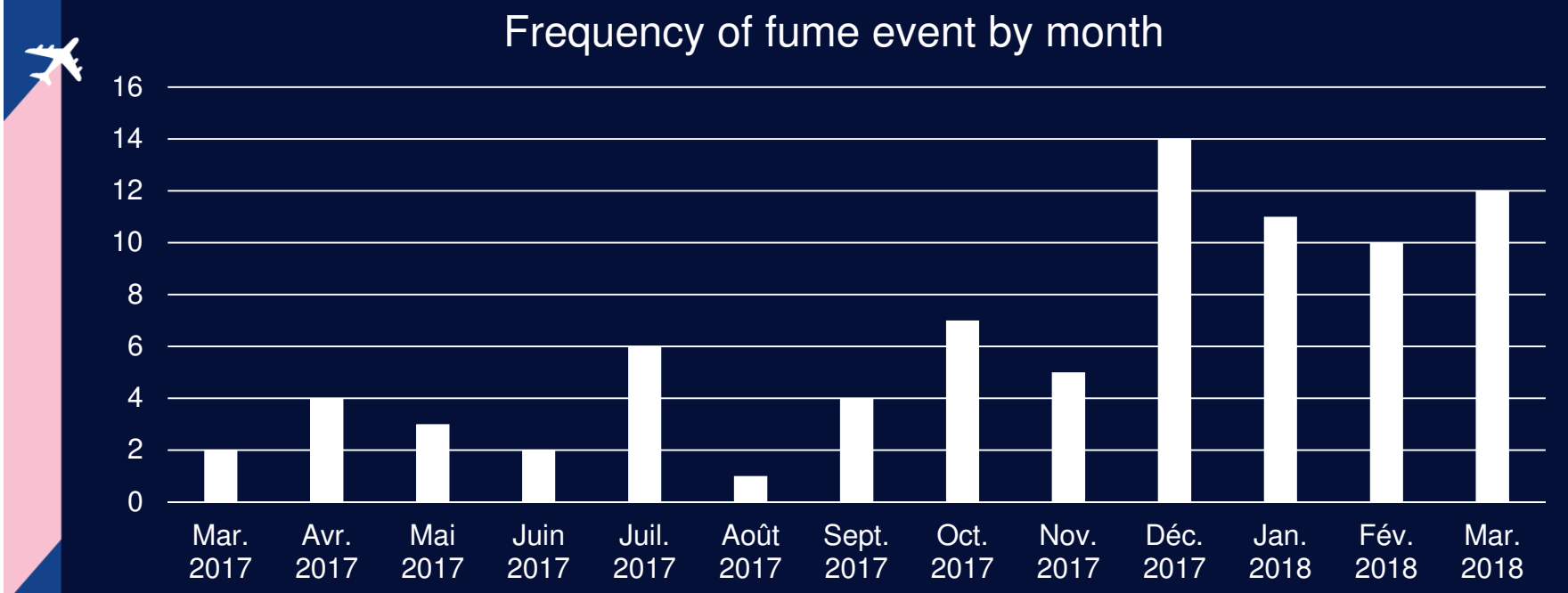
More fume events in winter



AIRFRANCE

The smells of a fume events

Category	Verbatim	Frequency (%)
Acrid odor	« acrid », « irritant », « bakelite […] acrid », « acrid and irritant smell of oil an dirty socks»	15/81 **(18,5)**
Dirty socks	« wet socks», « oil, wet socks», «wet mop and alcohol together»	22/81 **(27,2)**
Burning smell	« burned carton », « burnt (bakelite odor) », « burned plastic », « burned socks »	19/81 **(23,5)**
Electric	« electric », « electrically burned », « burned electrical circuit »	9/81 **(11,1)**
Solvent	« like ether», « chemical product », « motor oil », « like anti-icing fluid »	16/81 **(19,8)**
Plastic	« burnt (bakelite odor) », « burned plastic », « burned rubber or burnt lime »	9/81 **(11,1)**
Other	« could be ozon or sulphur», « manure »	6/81 **(2,5)**

What was the technical origin ?

Category	Suspected 22/81 (27,2%)	Quite certain 13/81 (16,1%)	Proved 11/81 (13,6%)	Unknown 35/81 (43,2%)
Circuit APU	De-icing residues near APU, motor oil	APU, APU bleed	De-icing residues near APU, motor oil	
Circuit PACK	packs	packs		
Air Con	Recent turbine cleaning	Recent cleaning		
Short-circuit	boilers	breakers in crew rest	FAC 2, recirculating fans, toilets lights	
De-icing fluid	Anti-icing	De-icing	Liquid residues near APU inlet	
Insecticide	insecticide			
Misc. trouble	Air con	Recirculating fans	fan	
Hold	Pharmaceutical products in hold	Non identified liquid		
Oven			Carton box in the oven	
Passenger luggage			Crushed iPad, electrnic cigarette device	

Main symptoms

Symptoms	n/N	%	Rank in the list of answers chosen: Median	Rank in the list of answers chosen: IQR
None	185/357	**51.80**		
ENT irritation	121/357	**33.90**	1	1-1
Headaches	77/357	**21.60**	1	1-2
Dyspnea	58/357	**16.30**	2	2-3
Fatigue	24/357	**6.70**	3	2-5
Nausea/Vomiting	18/357	**5.00**	1	1-2
Weakness	11/357	**3.10**	1	1-2
Lightheadedness	4/357	**1.10**		
Mental slowness	4/357	**1.10**		
Thoracic pain*	2/357	**0.60**		
Sweating	1/357	**0.30**		
Anxiety*	1/357	**0.30**		
Insomnia*	1/357	**0.30**		

* Answer not proposed in the initial questionnaire

Medical Advice

Medical Facility Visited	All Crew		Crew with at least one symptom	
	n/N	%	n/N	%
None	306/357	*85,7*	126/172	*73,3*
General Practitionner	7/357	*2,0*	7/172	*4,1*
Hospital	3/357	*0,8*	2/172	*1,2*
Airport Medical Service	24/357	*6,7*	21/172	*12,2*
AF Occupational Health	17/357	*4,8*	4/172	*2,3*
Other	2/357	*0,6*	2/172	*1,2*

Sum of frequencies > 100 % because one crew could select several answers

What does predict seeking medical advice :
multilevel logistic regression analysis

	Model 1			Model 2		
Function	**OR**	**P**	**CI 95%**	**OR**	**p**	**CI 95%**
Cabin Crew	**ref.**	**ref.**	**ref.**			
Pilot	0,7	0,60	0,2 ; 2,9			
Mental Slowness	1,2	0,99	0,0 ; 8,28E+10			
Nausea/Vomiting	10,6	0,07	0,9 ; 130,3			
Headache	4,4	**0,05**	1,0 ; 18,9	**5,9**	**< 0,01**	**1,6 – 22,9**
ENT Irritation	5,9	**0,01**	1,5 ; 23,6	**8,0**	**< 0,01**	**2,1 – 30,0**
Dyspnea	3,2	0,10	0,8 ; 12,6			
Odor type “acrid”	2,2	0,55	0,2 ; 31,5			
At least one crew disembark	38,9	**0,02**	1,7 ; 880,1	**60,3**	**< 0,01**	**3,1 – 1188**
Donning O2 mask	49,9	**0,01**	2,5 ; 972,6	**30,0**	**< 0,01**	**2,5 – 361,4**
Mayday emitted	1,4	0,83	0,1 ; 34,5			
Diverting flight	0,2	0,46	0,0 ; 0,0			

Model 1 included all the significant variables in a bivariate analysis

Model 2 included only the significant variables in model 1

In summary, in our study

❑ Symptoms during and after fume events are

- ➢ Very diverse
- ➢ Mainly mild and functionnal
- ➢ Not systematically present

❑ Fume events

- ➢ Are rare
- ➢ Have not a single origin
- ➢ Can cause serious threats to aviation safety (emergency diverting with oxygen mask…)
- ➢ Do not show evidence for sustainable health consequences

❑ Scientific gaps are still challenging

- ➢ What are the actuel chemicals present in cabin air during a fume event
- ➢ We are still waiting for a routine evidence-based laboratory test confirming health effect

A last question about exposure to fume events

Should the medical world be reassuring (and not medicalize excessively), or at the contrary be on the precautionary side (and support the low dose poisoning theories) ?

ICAM 2020

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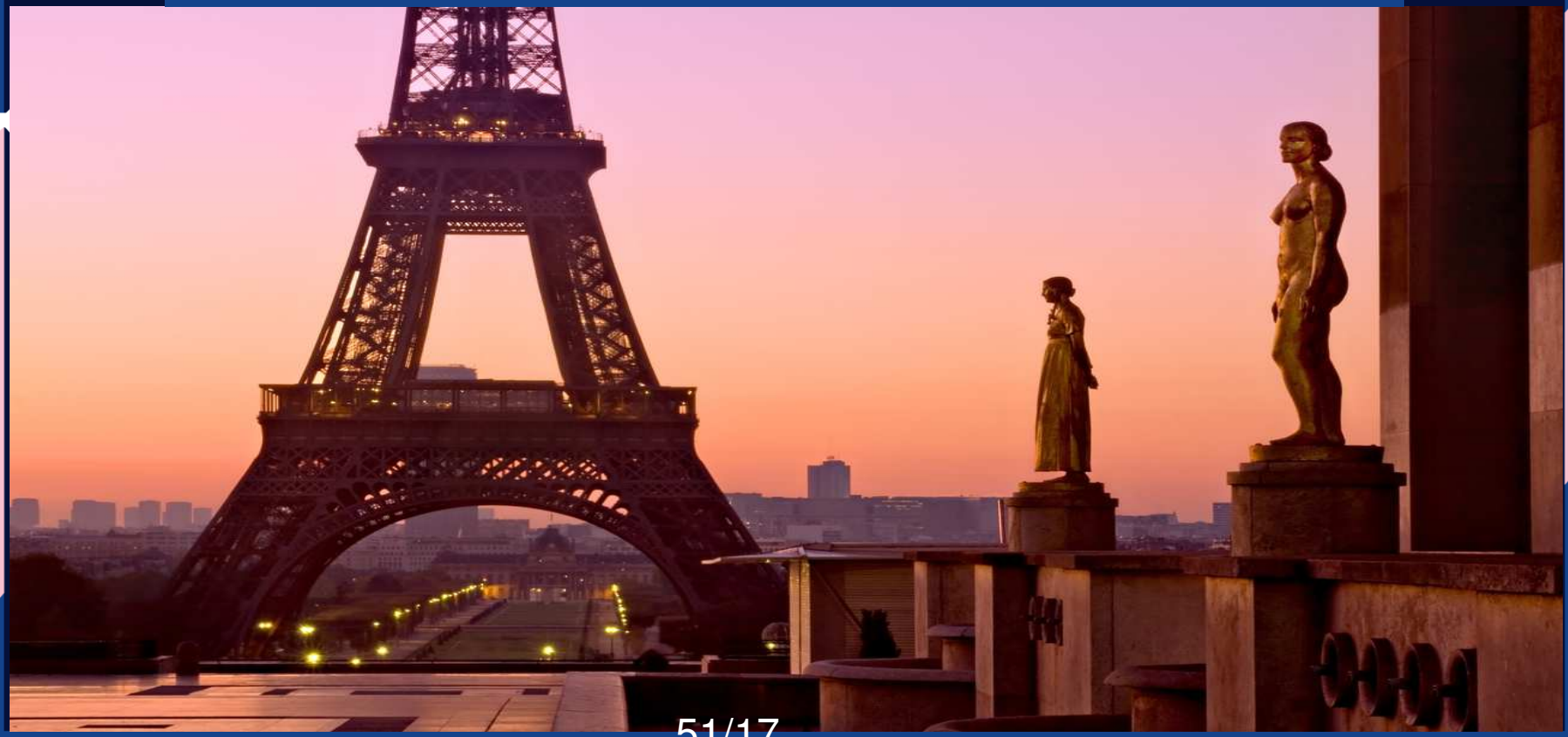
CENTRE DES CONGRÈS DE LA VILLETTE – **PARIS**, FRANCE

EXTENDING THE LIMITS OF GLOBAL AEROSPACE MEDICINE

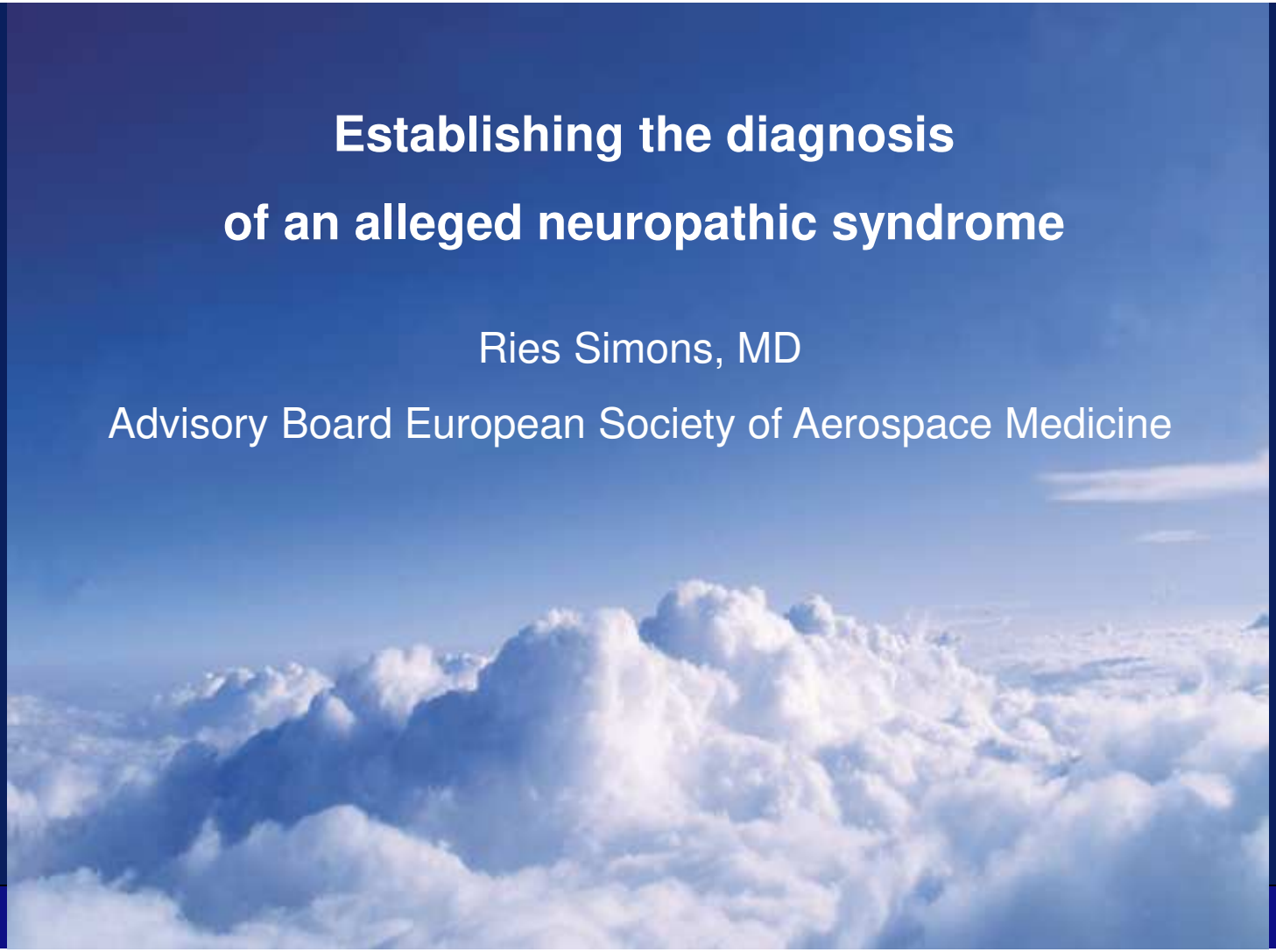
Merci !



Establishing the diagnosis of an alleged neuropathic syndrome

Ries Simons, MD

Advisory Board European Society of Aerospace Medicine



Disclosure Information

Ries Simons, M.D.

I have no financial relationships to disclose.

European Society of Aerospace Medicine

ESAM

PAN-EUROPEAN INDEPENDENT FORUM

We work together across Europe to promote the health,
performance, and safety of people who fly
through the use of evidence, science, and consensus.

Non-profit umbrella organization
for European Aerospace Medical organizations

Symptoms associated with exposure to CAC

Respiratory	Neurological	Systemic	Psychiatric	Dermal
Cough	Headache	Nausea, vomiting	Anxiety	Rash
Shortness of breath	Dizziness	Fatigue	Sleep disturbance	
Chest tightness	Lightheadedness	Muscle weakness	Depression	
Wheezing	Memory impairment	Palpitations	PTSD	
Eye, nose or throat irritation	Concentration difficulty	Diarrhea		
	Visual changes			
	Tremor			
	Gait problems			
	Paraesthesias			
	Balance problems			
	Slowed mental processing			
	Difficulty multi-tasking			

Possible Chemicals of Interest

Jet Engine Oil

- ✓ Tricresyl Phosphate (TCP)
- ✓ Triorthocresyl Phosphate (TOCP)
- ✓ Other TCP Isomers
- ✓ Pyrolyzed Oil

Organophosphate Induced Delayed Neuropathy (OPIDN)

Ataxia, Distal numbness, Muscle weakness and atrophy, Paresthesia, Flaccid paralysis, Gait abnormalities, Sensory deficits

Possible Chemicals of Interest

Hydraulic Fluid

- ✓ Tributyl phosphate (TBP)
- ✓ Dibutyl phenyl phosphate (DBPP)
- ✓ Butyl diphenyl phosphate (BDPP)
- ✓ Other lower % weight ingredients

Skin, eyes, nose, throat, lung problems
headache, drowsiness, tremors,
convulsions (coma at very high dose)

Based on the study on toxic effects of the oils after pyrolysis it can be concluded that data indicate that neuroactive pyrolysis products are present.

EASA.2014.C15: products detected sporadically in small amounts in almost every aircraft type including the non-bleed air operated B787.

PRESENCE ≠ TOXICITY

DOSE-RESPONSE RELATIONSHIP

Apart from Fume Events, toxicological assessments in aircraft showed similar airborne contaminations as observed in indoor environments like offices, schools, or dwellings

- TCPs / ToCP: very low Hazard Quotients in Worst Case scenarios.
- It appears unlikely that the health effects are due to exposure to ToCP.

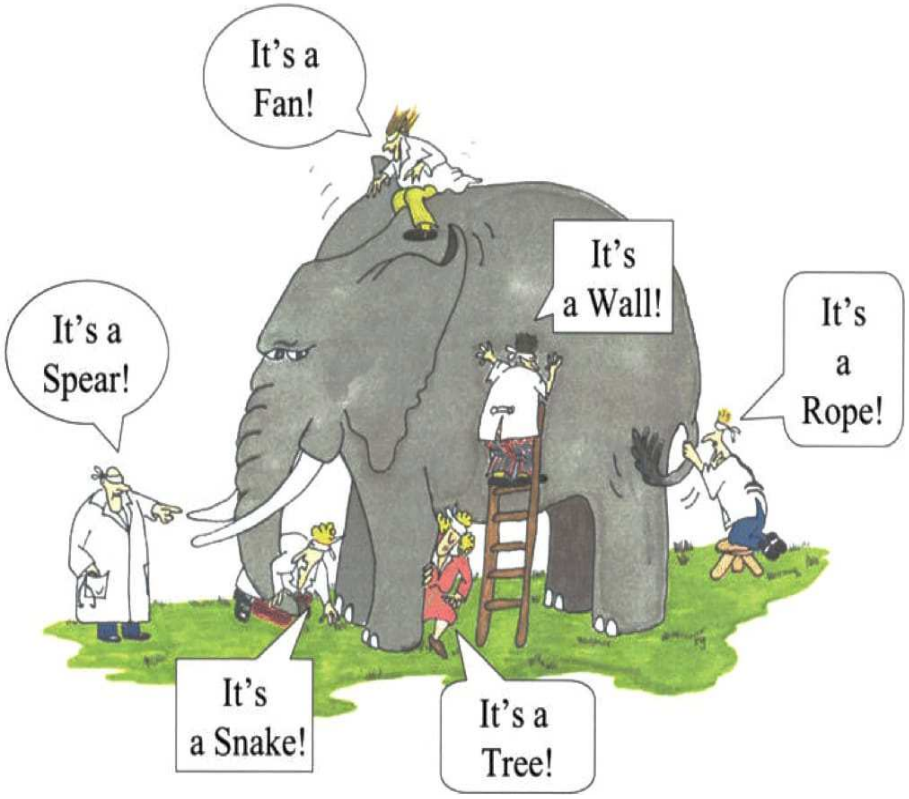
A 2019-literature search has not given us new insights into the cabin air quality issue

We should not ignore that there are crew members with
(severe) unexplained health problems
and cognitive impairment

Assess other occupational (combinations of) exposures?

- carbon-monoxide
- hypoxia
- ozone
- insecticides
- de-icing fluids
- exhaust fumes from ground service vehicles/other aircraft
- impaired sleep
- circadian disruptions
- long work hours, and irregular work-rest cycles

Differences in study objectives or interpretation of results may hinder the solution of the main problem



Chronic or Delayed Symptoms associated CAC

The symptoms are diverse and not in themselves characteristic and, therefore, not indicative of a specific form of chemical toxicity.

Can we establish a Syndrome in this case?

Syndrome : Greek = “running together”

a group of signs and symptoms that occur together and characterize a particular abnormality or condition

A broad range of symptoms related with different organ systems has been found among flight crew, but these have not been systematically studied:

Up to now a medically defined syndrome cannot be established

Lessons from the past may provide opportunities for the future

Chronic solvent-induced encephalopathy: European consensus of neuropsychological characteristics, assessment, and guidelines for diagnostics☆

Evelien van Valen [a,*], Christoph van Thriel [b], Ritva Akila [c], Linda Nordling Nilson [d], Rita Bast-Pettersen [e], Markku Sainio [c], Frank van Dijk [f], Gert van der Laan [a], Maarten Verberk [f], Ellie Wekking [a,g]

[NeuroToxicology (2012) 33:710-726]

Chronic Solvent-induced Encephalopathy

So-called ‘painters disease’ was considered as ‘pseudoneurotoxic disease’ by some scientists and doctors

Painters employer’s organizations denied the existence of the disease in public debate and strongly opposed the implementation of any preventive measures

Hallmark of CSE is cognitive dysfunction whose characterization requires neuropsychological assessment. It is a cornerstone in the differential diagnostic procedure for CSE with nonspecific symptoms resembling clinical features of many non-occupational conditions

Finnish neuropsychologist Helena Hänninen defined the psychological performance profile in occupational intoxications. Since then a multidisciplinary approach was used involving occupational physicians, neuropsychologists, and occupational hygienists

Since 1990, CSE has been recognized as an occupational disease in the EU list of occupational diseases, with a supporting document as a guide for diagnosis

The medical way forward

To determine if an illness or syndrome is work-related, a six-steps procedure is recommended:

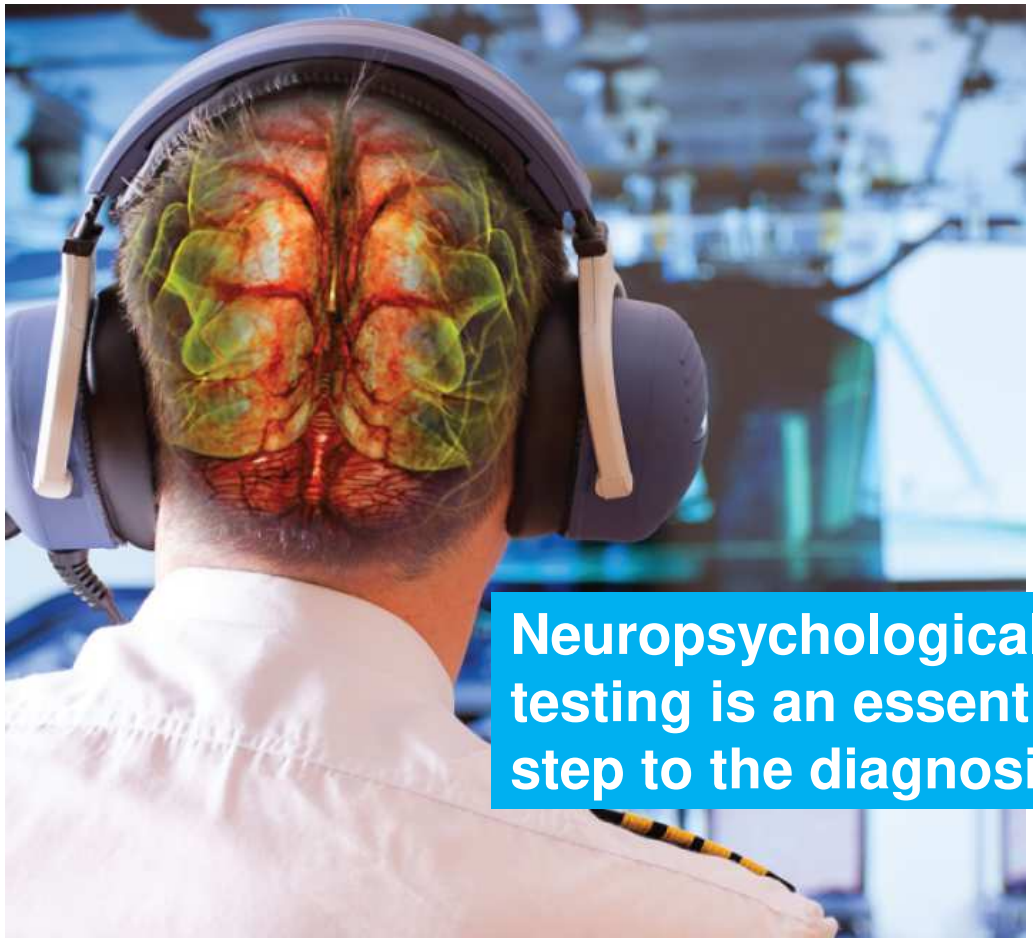
Step 1. **Establishing the diagnosis**

The alleged Aerotoxic Syndrome includes many different symptoms, such as reduced attention and concentration as well as memory impairment and general malaise. Until now, there is no definitive scientific proof for the existence of the syndrome.

A standardized Medical Protocol should be used to establish the diagnosis

Medical Research Protocol to assess medical symptoms caused by neurotoxic exposure

1. Intake by clinical occupational physician
2. Neuropsychological assessment according to standard protocol looking at attention, concentration, memory, information processing speed and planning.
3. Explorative neurological screening
4. Exposure estimation by occupational hygienist
5. Explorative blood sampling into hematological, liver- and renal function, vitamins (B1 and B12), and CYP450 genotyping tests (when indicated)



Neuropsychological testing is an essential step to the diagnosis

Neuropsychological assessment (NPA)

Examines the cognitive consequences of brain damage, brain disease, and mental illness.

Covers a wide range of cognitive domains: enabling a differential diagnosis

Generally accepted diagnostic value in patients with symptoms or suspected history

Analysis of the human sensitivity variability factor

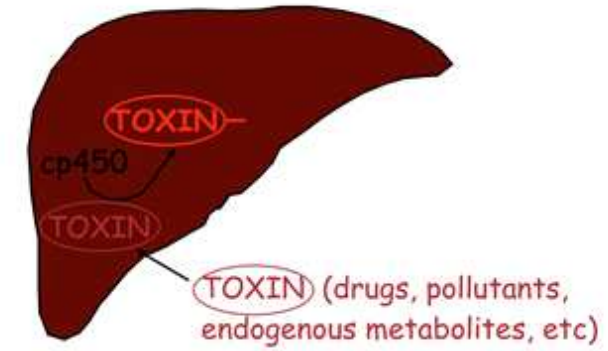
- Possible influence of stress and/or coping strategies that may intensify or trigger health complaints.

- Possible role of genetic differences in metabolism and detoxification between humans.

Differences in sensitivity between humans for the health effects of certain compounds can be expected for those compounds that rely on cytochrome P450 enzymes for their metabolism.

Individual differences via CYP450 enzymes

- Poor metabolizers
- Intermediate metabolizers
- Normal metabolizers
- Ultrarapid metabolizers



Cytochrome P450 2C19, 3A4, 2D6 and 1A2 one or more of these enzymes will likely play a role of importance in the metabolism of organophosphorous pesticides

Individual differences via CYP450 enzymes

Also, a 40-fold difference in paraoxonase1(PON1)-gene activity was found in humans.

As a result of inter-individual differences in P450 and PON1 enzyme activities a 4000-fold difference can be expected between individuals expressing a very low and very high sensitivity

CYP450 genotyping tests could be done to compare symptom-positive and symptom-negative individuals

Step 2. Is there a relationship between occupational exposures and the occurrence of symptoms associated with the defined Syndrome?

e.g. exposure to fume events, TCPs/ToCP, CO, etc.

Step 3. What is the actual exposure to the suspected causal agent/condition

Step 4. What is the influence of confounding factors?

e.g. increased individual sensitivity?

Step 5. Conclusion about the relationship between exposure and symptoms

During this step the diagnostic process of the preceding steps is evaluated to see whether it is possible to draw a conclusion about the probability of causal relationship.

It is important that the medical assessment according to protocol has been carried out.

Step 6. What can be done to prevent the occupational disease?

During this step preventive measures are defined, carried out and implemented when applicable.

Essential:

A multidisciplinary approach involving occupational physicians, neuropsychologists, and occupational hygienists

Recommendation

International Group of occupational physicians, neuropsychologists, and occupational hygienists to develop and implement a standardized protocol to evaluate all affected aviation personnel.

Members of the group should preferably be working in recognized national/academic occupational health institutes

European Society of Aerospace Medicine

ESAM

LEIBNIZ RESEARCH CENTRE
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AND HUMAN FACTORS

ODOR-RELATED HEALTH EFFECTS AND NEUROTOXIC RISK ASSESSMENT

Christoph van Thriel, IfADo
Stefan Kleinbeck, IfADo

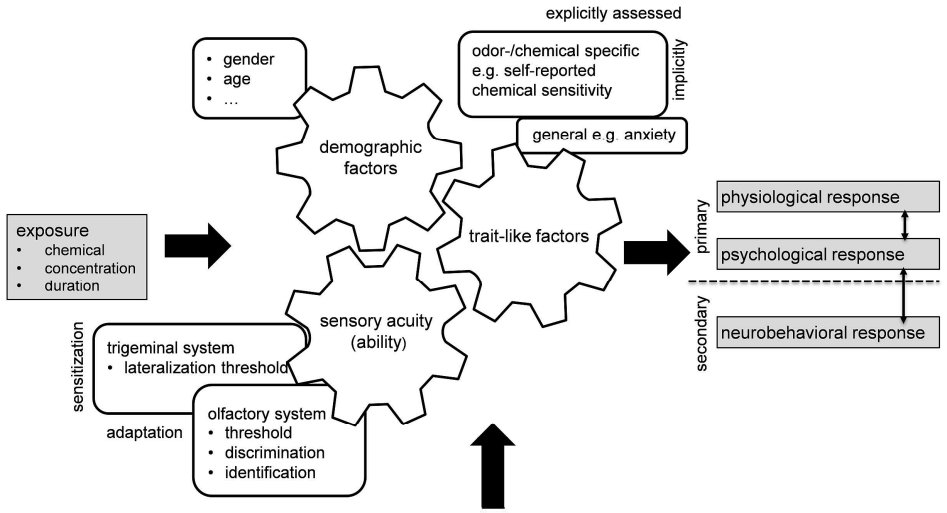
30.01.2020

Ardeystrasse 67, 44139 Dortmund, Germany

Odor-related health effects

- the olfactory system is the most sensitive pathway to inform the organism about indoor air pollutants
- especially in low concentrations
- the perception of odors are per se not adverse
- odor-related symptoms are usually caused be the induction of
  - annoyance, anger, disgust, anxiety
  - unspecific symptoms, e.g. headaches, nausea

Odor-related health effects



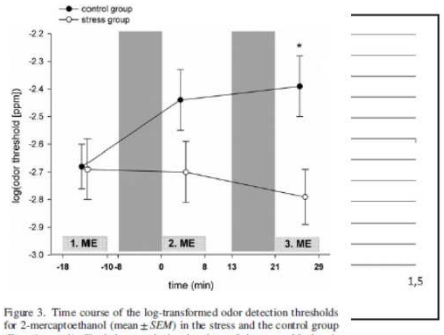


Figure 3. Time course of the log-transformed odor detection thresholds for 2-mercaptoethanol (mean ± *SEM*) in the stress and the control group (Experiment 1). Shaded areas depict the time of the stress blocks. 1. ME = first threshold measurement for 2-mercaptoethanol; 2. ME = second threshold measurement for 2-mercaptoethanol; 3. ME = third threshold measurement for 2-mercaptoethanol. *$p \leq 0.05$ Bonferroni-adjusted *post hoc* test.

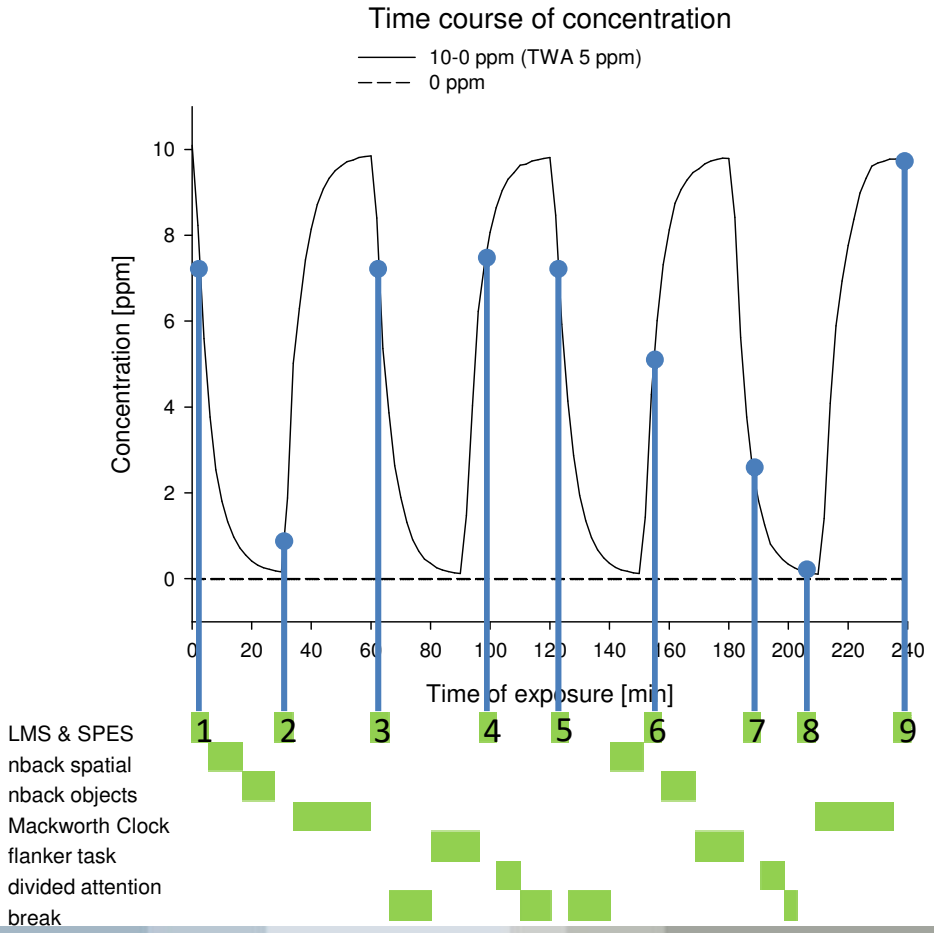
Figure 2. Relatio … and the respective UPSIT score … control session), the higher was the cortisol level i… 10).

Odor-related health effects

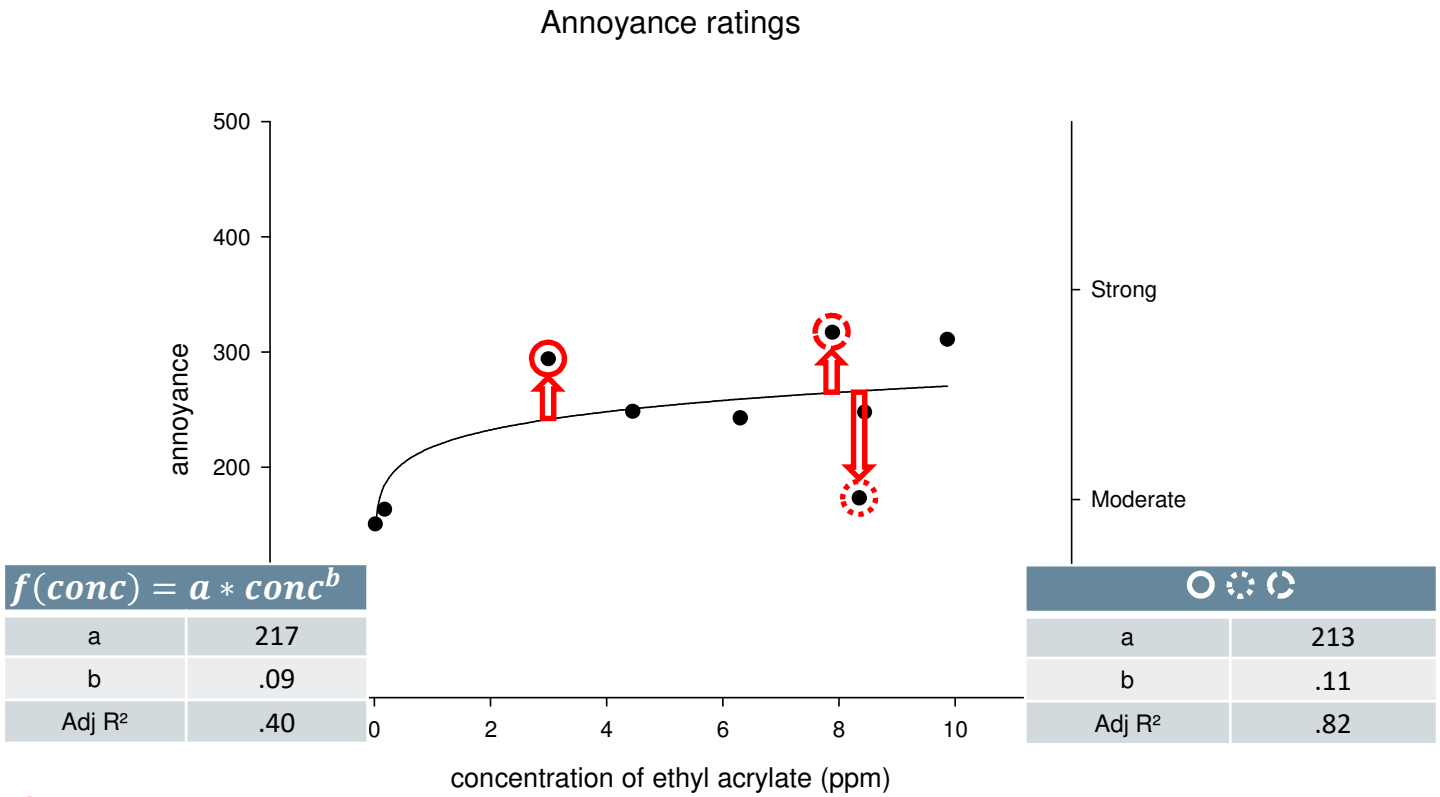
- Innate odor aversions, e.g. involuntary visceral responses
- Odor-related exacerbations of underlying conditions
- Odor-related aversive conditioning
- Odor-related, stress-induced illness
- ….

Shusterman (1992)

Concentration and context



Modulation of annoyance by ethyl acrylate



$f(conc) = a * conc^b$	
a	217
b	.09
Adj R^2	.40

○ ◌ ◌	
a	213
b	.11
Adj R^2	.82

Preceded by: spatial n-back
- visually and cognitively demanding

Preceded by: entering exposure
- First contact to ethyl acrylate / day

During break
- Relaxing

Discussion

- Subjects were able to discriminate different concentrations of ethyl acrylate
- Systematic outliers
  - Lower during break: relaxing situation
  - Higher when entering the lab
    - Not adapted to ethyl acrylate
  - Higher after spatial n-back task
    - Highly demanding task
- various ***situational factors*** and individual stress levels might modulate perceptions of odors that would be lower in other contexts

Neurotoxic risk assessment

- Neurotoxicity can affect the central and/or the peripheral nervous system
- cell-based assays are available to estimate the risk of a compound or mixture to cause neurotoxicity
- new mechanisms can be discovered
- facilitating more precise testing in humans
- extrapolation to human exposure scenarios is sometime possible

OXFORD SOT | Society of Toxicology
www.toxsci.oxfordjournals.org

TOXICOLOGICAL SCIENCES, 142(1), 2014, 274–284

doi: 10.1093/toxsci/kfu174
Advance Access Publication Date: September 8, 2014

Impairment of Glutamate Signaling in Mouse Central Nervous System Neurons *In Vitro* by Tri-Ortho-Cresyl Phosphate at Noncytotoxic Concentrations

Vanessa Hausherr*,[1], Christoph van Thriel*, Anne Krug†, Marcel Leist†, and Nicole Schöbel*,‡

*IfADo - Leibniz Research Center for Working Environment and Human Factors, 44139 Dortmund, Germany, †Doerenkamp-Zbinden Chair for in vitro toxicology and biomedicine, University of Konstanz, 78462 Konstanz, Germany and ‡Department of Animal Physiology, Ruhr-University Bochum, 44801 Bochum, Germany

NeuroToxicology 59 (2017) 210–221

Contents lists available at ScienceDirect

NeuroToxicology

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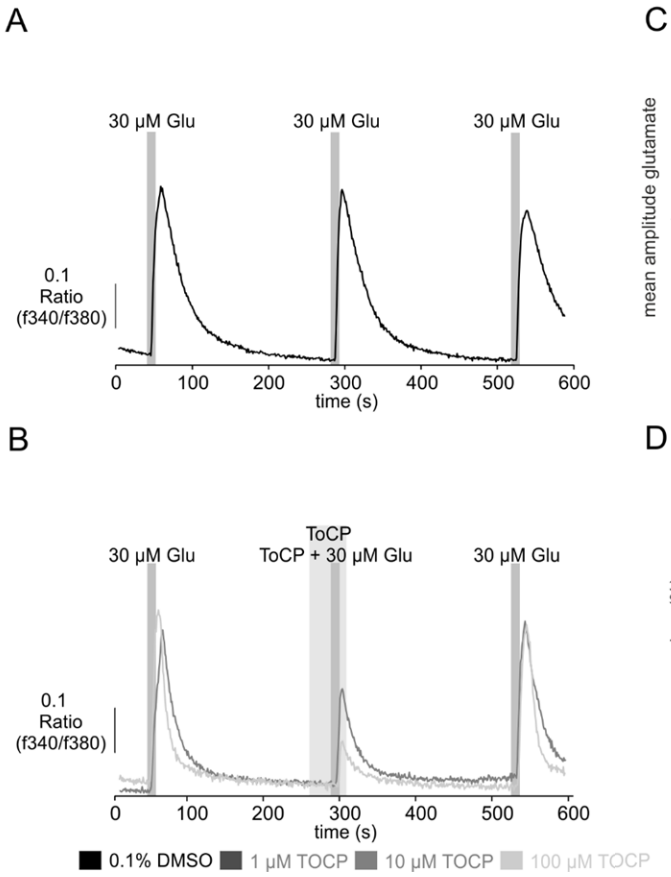
Full length article

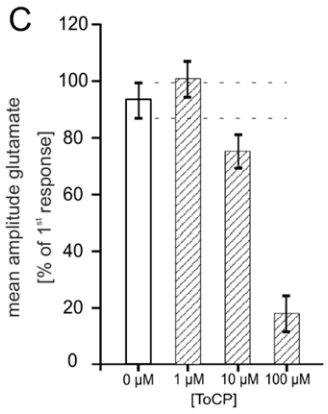
Assessment of neurotoxic effects of tri-cresyl phosphates (TCPs) and cresyl saligenin phosphate (CBDP) using a combination of in vitro techniques

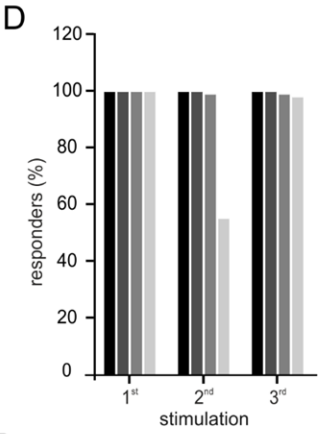
Vanessa Hausherr[a], Nicole Schöbel[b], Julia Liebing[a], Christoph van Thriel[a,*]

[a] IfADo—Leibniz Research Center for Working Environment and Human Factors, 44139 Dortmund, Germany
[b] Ruhr-University Bochum, Department of Animal Physiology, 44801 Bochum, Germany

ToCP







- dose-dependent block of glutamate receptors
- 24h incubations to lower ToCP concentration also affected glutamate signaling
- functional perturbations were observed at concentrations …
- **90-times lower** that cytotoxicity
- **10-times lower** that “neurite”-toxicity

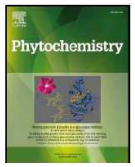
unknown toxicity to the PNS

- compounds extracted from a plant that causes neurotoxicity in horses were tested

Contents lists available at ScienceDirect

Phytochemistry

journal homepage: www.elsevier.com/locate/phytochem



Lignans and sesquiterpene lactones from *Hypochaeris radicata* subsp. *neapolitana* (Asteraceae, Cichorieae)

Oleksandr Shulha[a], Serhat Sezai Çiçek[a], Helle Wangensteen[b], Janina Kroes[c], Malte Mäder[d], Ulrich Girreser[d], Jandirk Sendker[e], Karin Jöhrer[f], Richard Greil[f,g], Wolfgang Schühly[h], Alfonso Mangoni[i], Laura Grauso[j], Christoph van Thriel[c], Christian Zidorn[a,*]

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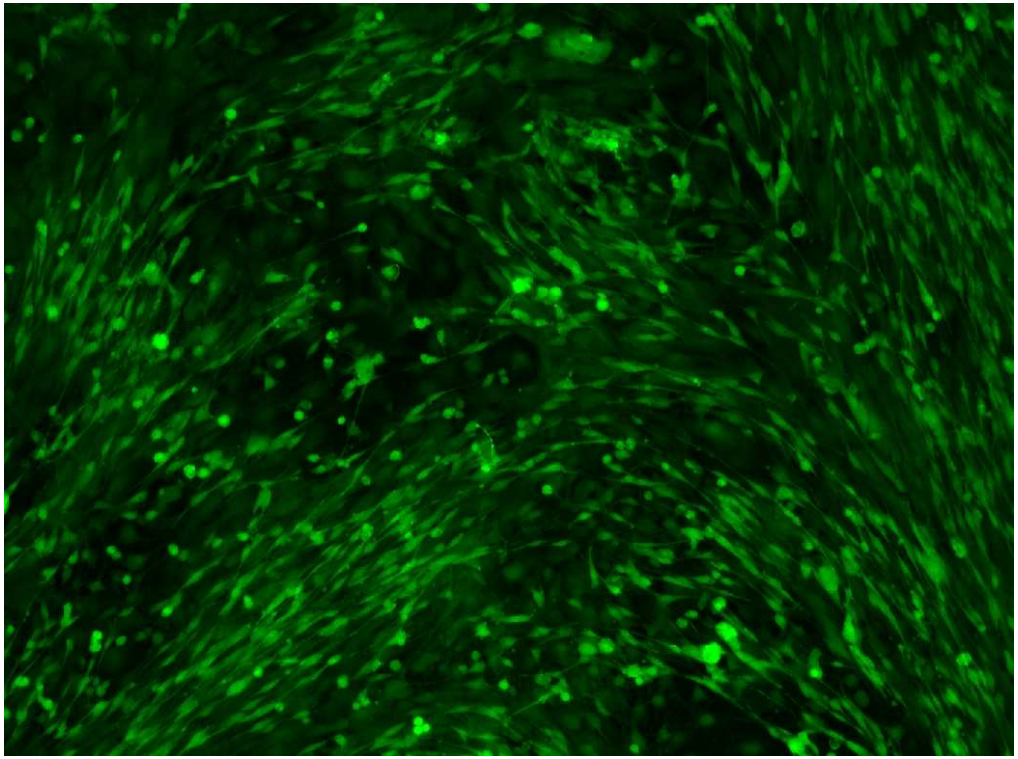
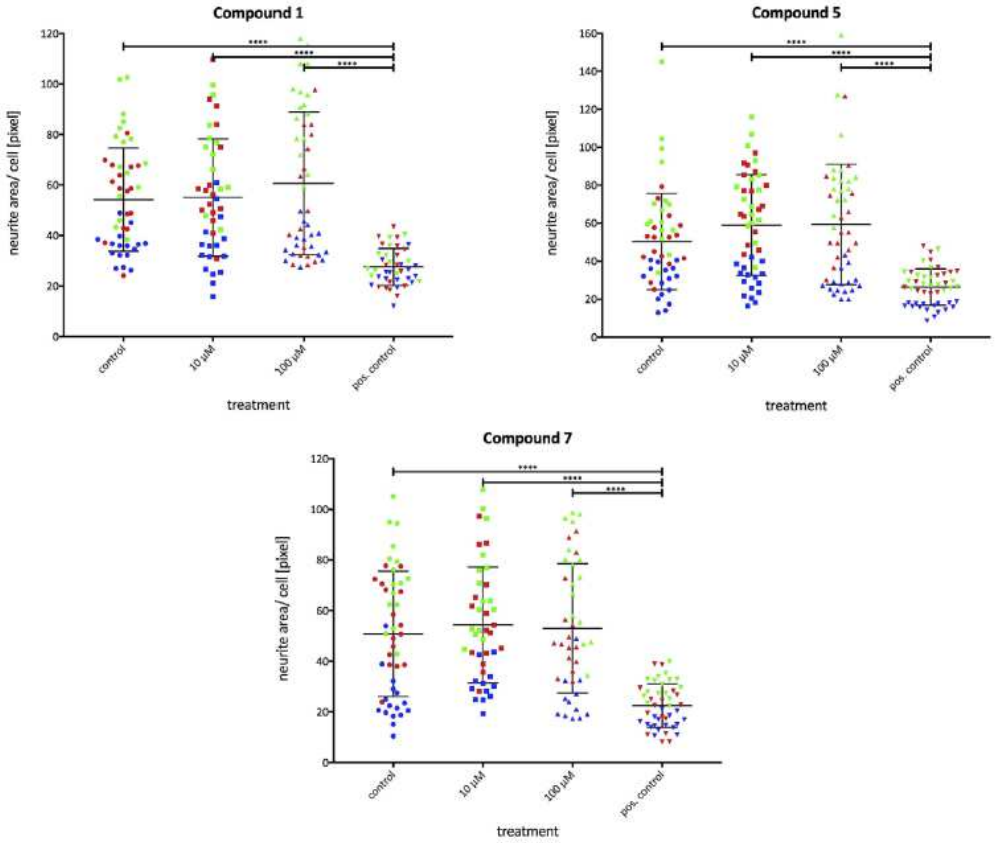
[j] *Dipartimento di Agraria, Università di Napoli Federico II, Via Università 100, 80055, Portici (NA), Italy*

Cell cultures from the dorsal root ganglion



no effects could be found …



Relevance for cabin air quality research

- relevant or newly discovered cabin air contaminates, or their mixtures can be tested for unknown neurotoxicity
- CNS and PNS effects can be analyzed
- very sensitive endpoint, such as the activation of receptors can be investigated
  - TRP channels in the PNS
  - AMPA, NMDA, GABA receptors in the CNS
- can be combined with behavioral tests in humans

DLR cabin air quality research – biodiagnostic, microbiological and ventilation approaches

PD Dr. Christine E. Hellweg[1], Prof. Dr. Christa Baumstark[1], Prof. Ralf Möller[1,2], Dr. rer. nat. Daniel Schmeling[3]

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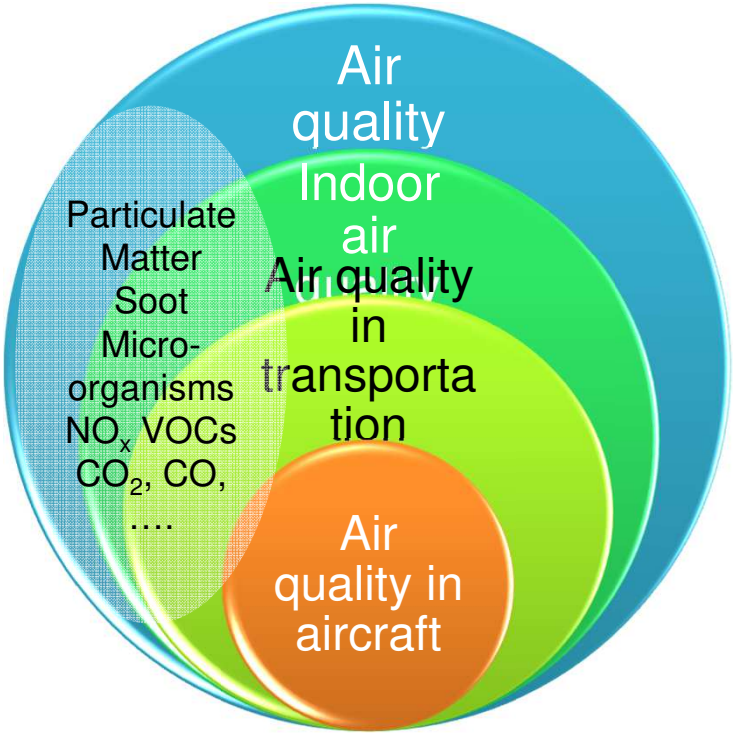
Cabin air quality - Part of a bigger problem



Epidemiology
- Short-term exposure
- Long-term exposure
- Different endpoints (e.g. hospitalizations)

Toxicology
- Short-term exposure
- Long-term exposure
- In vitro & animal experiments

Measurement & modeling of exposure
- Measurement flight
- Ground simulation
- Biomarkers

Cabin air quality – Some open questions

Exposure	Hazard	Risk
Cabin air composition during normal operations well described	Dry air, ozone – e.g. desiccation of skin & eyes	E.g. skin irritation, dermatitis, dry eyes & Nose
Cabin air composition during *Fume & Smell Event* unclear	Air pollutants – health hazard	FSE symptom complex (acute/chronic) from case studies
Concentration of toxic agents	Toxic agents could theoretically reach the cockpit or cabin	Do chronic or late effects due to long lasting cabin air exposure exist?
Formation of contaminations	Toxicity of complex contaminant mixtures under air travel conditions	Can chronic or late effects be assigned to FSE(s) Exposure?
Spreading/distribution of contaminations	**Bioassays**	
Role of microbial processes	Individual sensitivity to air pollutants	
Biomarker of Exposure	**Evaluation of genetic studies**	**Epidemiological study aircrew**
	Human exposure study	

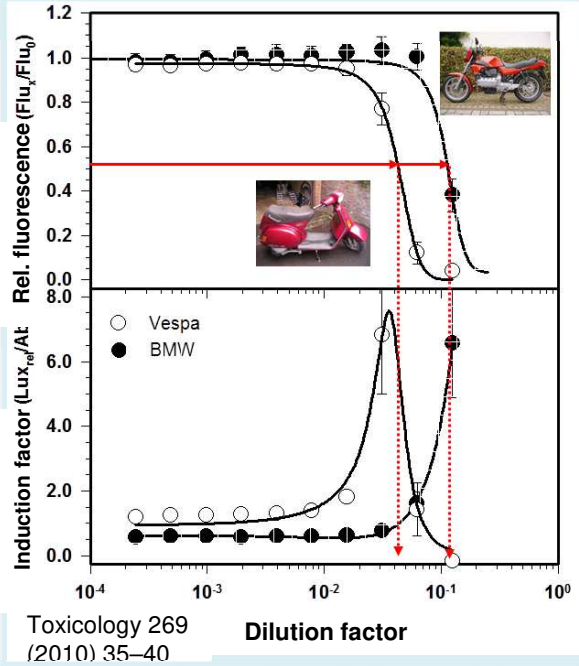
Biodiagnostic approaches – Use of bioassays

⇒ screening the toxicity of complex contaminant mixtures

Salmonella typhimurium

Cytotoxicity

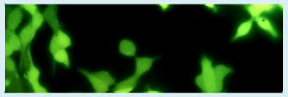
Genotoxicity



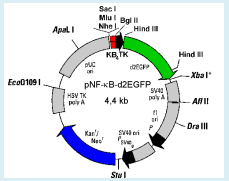
Toxicology 269 (2010) 35–40

SWITCH (Salmonella Weighting of Induced Toxicity (genotoxicity) and Cytotoxicity for human Health)

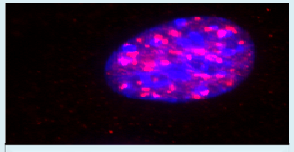
Human cells



Cell death & growth



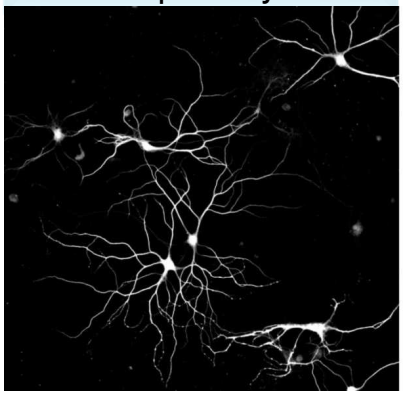
Inflammatory effects



DNA damage induction

Neurotoxicity

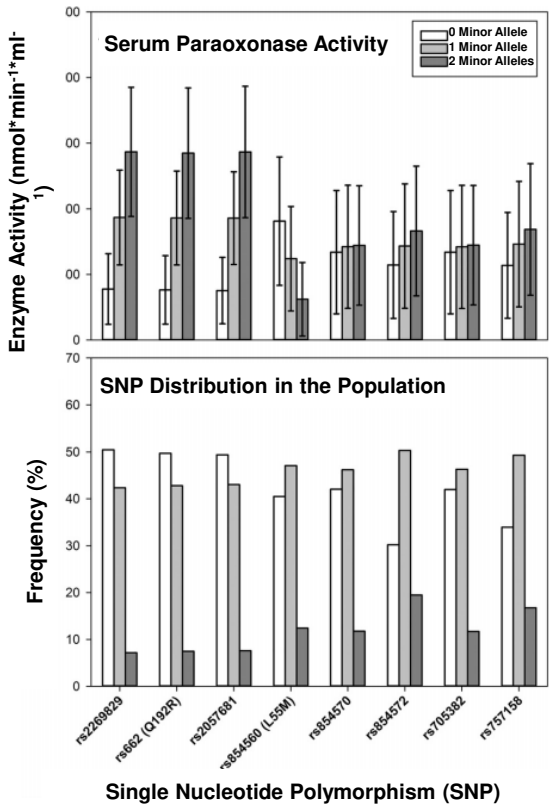
Mouse primary cells



O_2 concentration ⇓: hypoxia bench

Individual sensitivity – Evaluation of genetic studies

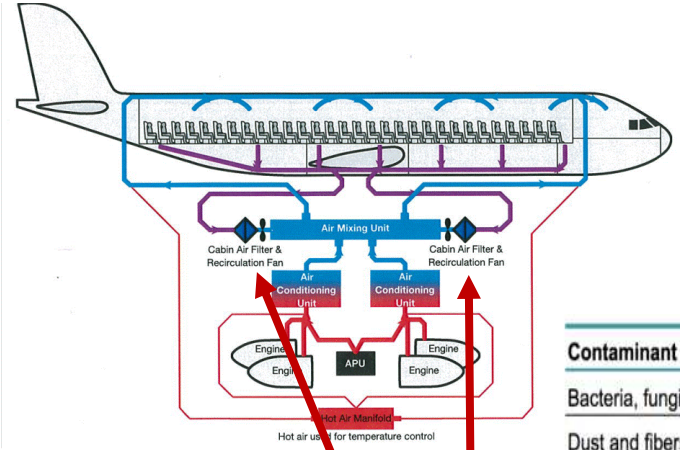
Gene Abbreviation	Gene Name
PON1/2	Paraoxonase 1/2
P450	Cytochrome P450 isozymes
BChE	Plasma butyrylcholinesterase
AChE	Acetylcholinesterase (EC 3.1.1.7)
NTE	Neuropathy target esterase
CES1	Carboxyl-esterase 1 (Gene ID: 1066)
APH	Acylpeptide hydrolase
SOD2	Manganese superoxide dismutase
GSTM1, GSTT1	Glutathione S-transferases
GCLM	Glutamate-cysteine ligase regulatory subunit
…	…



W. Rosenberger, S. Schuchardt, C. Baumstark-Khan, A. Hahn (2018) **VIII – 7.3 Innenraumluftqualität in Verkehrsflugzeugen.** Wichmann · Fromme – Handbuch Umweltmedizin 62. Erg. Lfg. 12/18

Toxification / detoxification / poor metabolizers …

Role of microbes and microbial processes



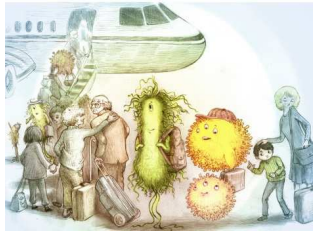
Breathing air: partly recirculated air
The supply is bled from the compressor sections of the engines and mixed with fresh air (“bleed air”)

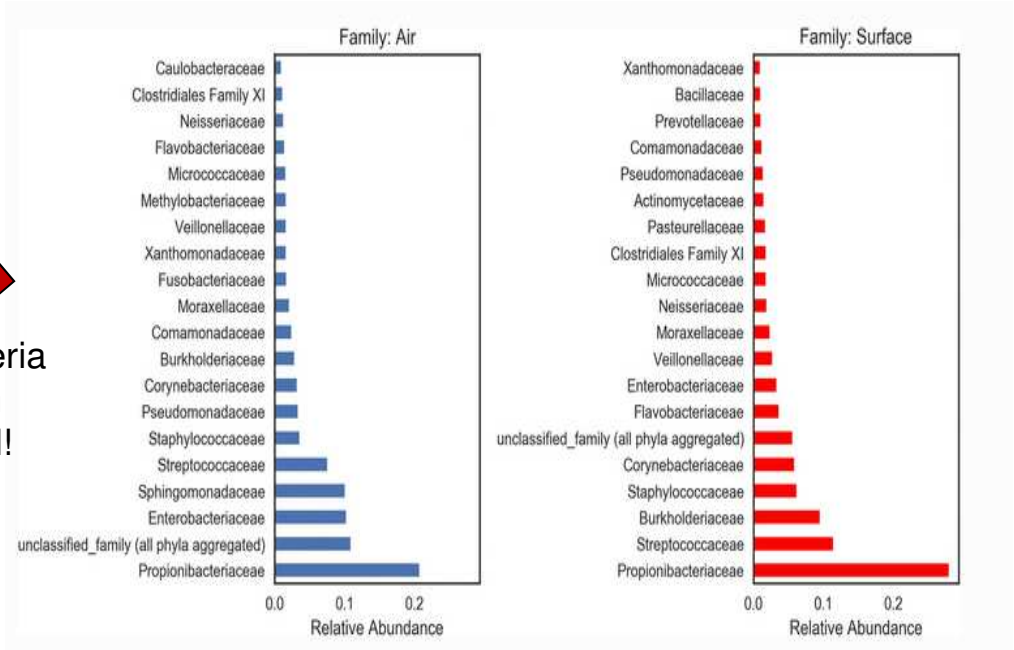
Contaminant	Solution
Bacteria, fungi and viruses	True HEPA filters with microbial efficiency of >99.999%
Dust and fibers	HEPA filters with efficiency of 99.97% DOP (or 99.99%NaCl) for submicron particles
Odors, VOCs and sVOCs	Adsorbent filters
Ozone	Catalytic Converters and Adsorbent filters

hospital-grade **HEPA filters**

Bacterial composition in airplanes

Most bacteria are human associated!



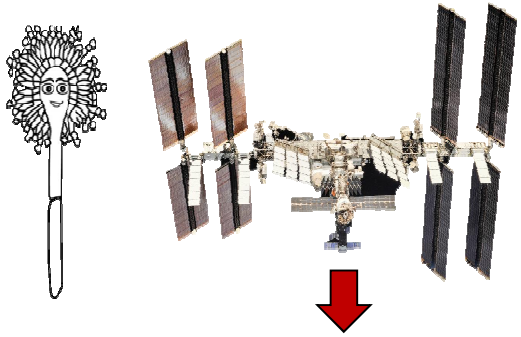


Most prevalent families in air (left) and touch surface samples (right) by relative abundance (proportion of families)

Weiss, H., Hertzberg, V.S., Dupont, C. *et al.* The Airplane Cabin Microbiome. *Microb Ecol* **77,** 87–95 (2019)

not necessarily pathogens but many have the potential to cause infections in immunocompromised people

Bacteria and fungi in airplanes?



Aspergillus ssp. were isolated from HEPA filters from ISS

- opportunistic fungal pathogen
- biodegrade materials, food, organic tissue
- produce “bad” smell due to secondary metabolites/Volatile organic compounds (VOCs)

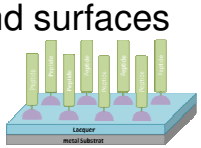
Research at DLR Institute of Aerospace Medicine

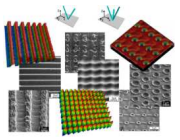
Characterization of the airplane microbiome

- Microbial sampling
- Long-term monitoring of airplane cabin air

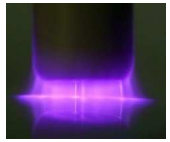
Countermeasures

- Antimicrobial insulation materials and surfaces





- Plasma sterilization, blue LED light, etc.

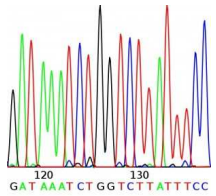


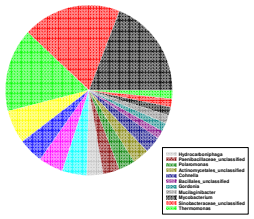
Microbial monitoring: Sampling microbial contamination (swabs & wipes)



Cultivation-based detection methods


PCR or Sequencing of microbial DNA





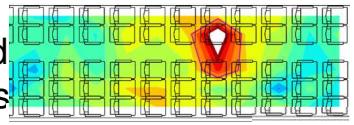
Microbial monitoring:
Sampling microbial contamination (air sampling)

Aircraft Cabin Ventilation

Institute of Aerodynamics and Flow Technology

German Aerospace Center (DLR)
Dr. Daniel Schmeling
daniel.schmeling@dlr.de
+49 (0)551 7092381

- Experimental and Numerical
  - Flow and temperature field
  - Local age of air (tracer gas)
  - Ventilation efficiency
  - Thermal comfort
  - Subject Tests (with ME-PSY)
- Flight Tests in A320 ATRA
- Ground-based research aircraft Do728
- Dual-aisle cabin mock-up with temperature-controlled fuselage



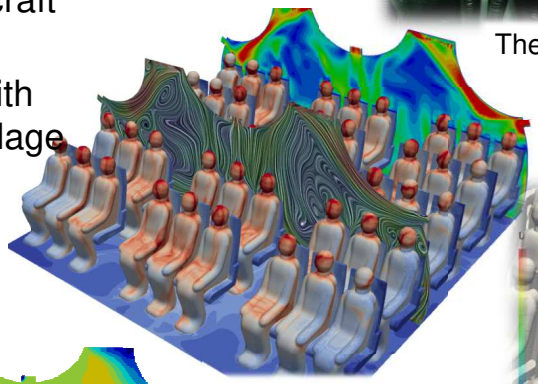
Propagation of scalar quantities

Do728

Thermal manikins

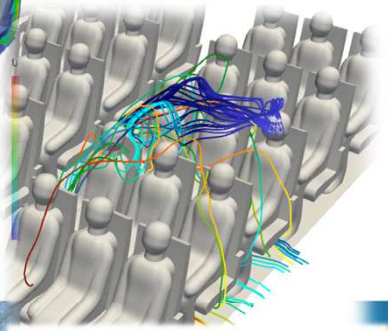
CO_2 exhalation

Long-range mock-up



Temperature and velocity fields

Age of air



Spreading of contaminants

Summary: DLR cabin air quality research – biodiagnostic, microbiological and ventilation approaches

Role of microbial processes	Toxicity of complex contaminant mixtures	Spreading/distribution of contaminations
Microbial monitoring	**Bioassays**	**Numerical and experimental techniques Aircraft Cabin Ventilation**
Countermeasures (antimicrobial surfaces, plasma sterilization)	Individual sensitivity to air pollutants	
	Evaluation of genetic studies	

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Susan Michaelis, PhD, MSc, ATPL*

Cabin Air Quality Research Proposals

Workshop on future Cabin Air Quality Research
30-31 January, 2020
EASA
Cologne

*Occupational and Environmental Health Research Group, Centre for public Health and Population Health Research

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- Is more research required in-order to take risk mitigating action now?

No

- Future research must be independent of risk mitigation actions undertaken now
- Future research will simply enhance our understanding ,but is not necessary to determine whether risk reduction actions are required now.

Any further research must ask the right questions

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Michaelis et al. (2017)

Public Health Panorama 2017 (3) 198-211 (WHO)

World Health Organization REGIONAL OFFICE FOR Europe

- 2 studies
  - Study A- BAe 146 pilots
  - Study B – 15 specific incidents

- Clear pattern of acute and chronic effects to neurotoxic & wide range of thermally degraded substances
- Extensive medical findings and diagnosis
- Identifying new occupational disorder
- Medical protocol required

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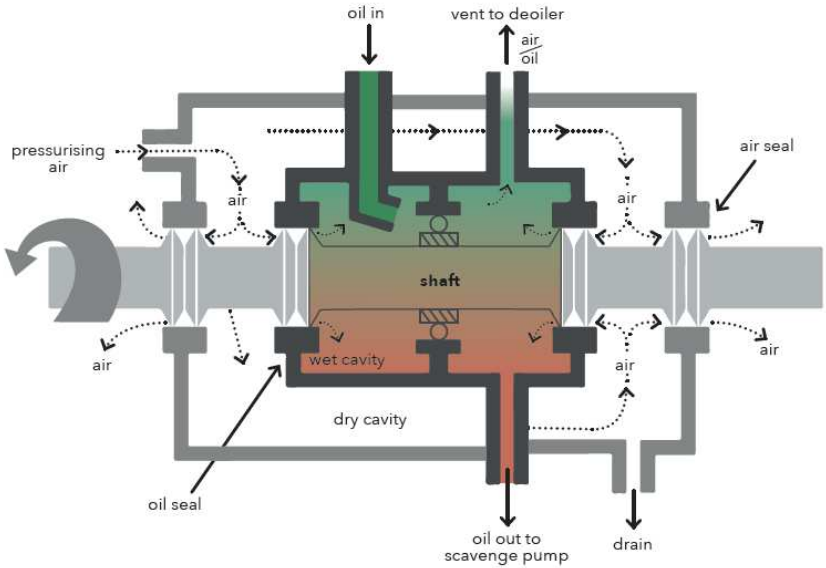
Oil system



- Permissible (normal) consumption of oil (loss) via - deoiler/vent/seals,leakage.
- Low level leakage in normal ops (Michaelis, 2016, 2018) – confirmed by many.

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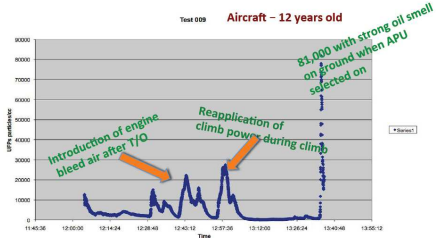
Research studies to enhance understanding 1/3

- Very low level chronic exposure to Triaryl phosphates (TAP) e.g. Tricresyl phosphate (TCP)– Alvin Terry (University of Augusta) – extensive publications (dozens of animal human epidemiology, cell cultures studies/papers. See Terry, 2012 & Naughton,2018)
  - Animal studies, Non cholinesterase mechanisms(axonal transport, cognitive function, molecular mechanisms)

- Chronic inhalation exposure to low levels of pyrolysed / hydrolysed engine oils

- UFP measurements study during engine APU power changes and bleed air configuration changes + characterize UFP surfaces.



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Research studies to enhance understanding 2/3

- Prospective epidemiological study of aircrew exposed to suspected bleed air supply fume events utilising established medical protocol*
- Establishment of of European wide medical network to deal with aircrew/passengers after fume events: using established medical protocol*
- TAP biomarker study- University of Washington (Furlong lab)
  - Definitive biomarker blood test for TCPs (Durad 125 / Syn-O-Ad 8484) used in aviation oils
  - Inhibition of various enzymes (AcHE, BChE, CES, APH)

- Investigating health and exposure circumstances of persons after aircraft fume events : a narrative review with medical protocol - International Fume Events Task Force with working groups from the DiMoPEx COST-Action and Collegium Ramazzini. (due April 2020)

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Research studies to enhance understanding 3/3

Other

- TAP gene expression study - University of Washington
- Epidemiological study of retired pilots / crew – Parkinson's, Dementia
- Epidemiological study of aircrew after fume events - Glial Autoantibody study – Duke University – Injury to the brain

References:

- Naughton et al. (2018) Neurotoxicity in acute and repeated organophosphate exposure https://doi.org/10.1016/j.tox.2018.08.011
- Terry Jr, A.V., et al. (2012) Functional consequences of repeated organophosphate exposure: potential non-cholinergic mechanisms. Pharmacol. Ther. 134, 355–365 DOI: 10.1016/j.pharmthera.2012.03.001
- Michaelis et al.(2017) Aerotoxic Syndrome: A new occupational disease? Public Health Panorama 2017 (3) 198-211 http://www.euro.who.int/en/publications/public-health-panorama/journal-issues/volume-3,-issue-2,-june-2017
- Michaelis, S. (2016) MSc Thesis. Implementation Of The Requirements For The Provision Of Clean Air In Crew And Passenger Compartments Using The Aircraft Bleed Air System. Cranfield University, Cranfield - https://www.susanmichaelis.com/about
- Michaelis, S. (2018) Aircraft Clean Air Requirements Using Bleed Air Systems. Engineering, 10, 142-172. https://doi.org/10.4236/eng.2018.104011

Contact: susan@susanmichaelis.com

Session #3

→ **Sampling & Measurement of Cabin Air Quality, Bio-monitoring**

→ Presentations: NLR, BG Verkehr, VITO

Dedicated to innovation in aerospace

Cabin Air Quality Research Workshop, 30-31 January 2020, EASA, Köln

Time-resolved cabin air quality measurement

Presenter: Johan Kos (NLR)

Prepared with: Ricardo Reis (Embraer), Theo van Veen, Henk Jentink, Wim Lammen (NLR)

Dedicated to innovation in aerospace

Overview

1. Introduction to NLR
2. Time-resolved cabin air quality measurement: the challenge and proposal
3. Cabin air quality in Future Sky Safety project
4. Concluding remarks

Introduction to NLR

- Royal Netherlands Aerospace Centre is global player with Dutch roots dedicated to innovation in aerospace
  - 650 employees / various research facilities

- Time-resolved air quality measurement is part of NLR's portfolio for environmental measurements, in particular air quality measurements inside and outside aircraft
  - Supported by in-flight testing expertise (including aircraft), modelling expertise, big data analysis capabilities

- Used to work in European collaboration and with various stakeholders (industry, defence, government/public)

Overview

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Over-arching questions

- How are the oil, fluids, and pyrolyzed products distributed from the engines, into the Environment Control System (ECS), and throughout the cabin environment?
- How does the frequency of these events vary with the type of engine or bleed-air system?
- What is the toxicity of the constituents and pyrolyzed products of the materials?
- What is their relationship to reported health effects?

EASA published studies (2), EASA FACTS project, CEN TC 436 committee & SAE committee, REACH regulation and new materials

Background: cabin air quality measurements during flight

- Reports included measurements of air quality during flights involving non-routine events: mainly missing
  - notable exception (Rosenberger, 2018)
- Low frequency of fume events (0.02-0.05% of flights, (Shehadi et al., 2016))

W. Rosenberger, Effect of charcoal equipped HEPA filters on cabin air quality in aircraft. A case study including smell event related in-flight measurements, Building and Environment, Vol. 143, pp. 358-365, 2018
M. Shehadi, B. Jones and M. Hosni, "Characterization of the frequency and nature of bleed air contamination events in commercial aircraft," Indoor Air, vol. 26, pp. 478-488, 2016

In-flight measurement methods: common

- Common methodology: (discrete) sampling and off-line analysis.

- Sampling time issue for events of low frequency and short duration:
  - Samples with short sampling times:

  Disadvantage: insufficient coverage of the many flights needed.
  - Samples with long sampling times:

  Disadvantage: averaging makes events invisible.

In-flight measurement methods: proposed

- Proposal for contamination events of low frequency and short duration:
  - Real-time measurement
  - Analysis: combined on-line and off-line, combine with other relevant (flight) data
  - Benefit: increase understanding of occurrence of possible cabin air pollutants (variation of concentrations in time)
  - Studied in EU Future Sky Safety project

Overview

1. Introduction to NLR
2. Time-resolved cabin air quality measurement: the challenge
3. Cabin air quality in Future Sky Safety project
4. Concluding remarks

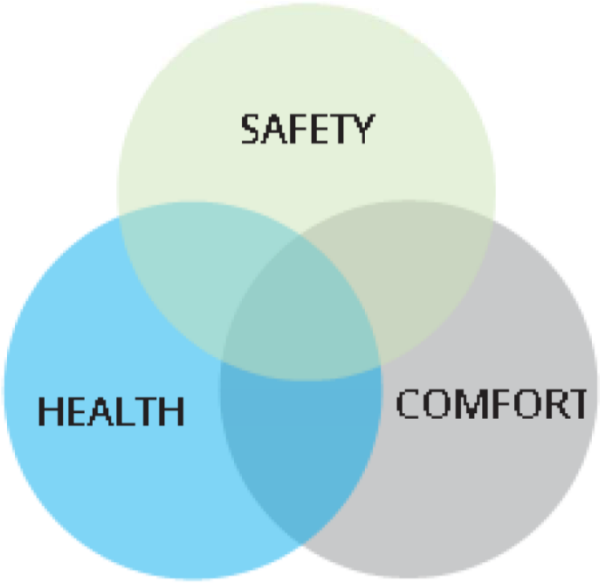
Future Sky Safety (FSS) project context

- EU H2020
- 33 European parties
  - Research establishments
  - Academia
  - Industry (aircraft man. / airlines / authorities / ATM providers …)
- Lead: NLR

European Plan for Aviation Safety Main Pillars

- Cabin Air Quality team

Cabin air quality



FSS working definition:

Cabin air quality

is the holistic
(physical, chemical, biological, radiological)
characteristics of cabin air

Aircraft architectures context

- Air traffic growth expected to keep on doubling each 15 years
- Global Warming
- Increased air quality awareness
- Democratization of monitoring and reporting (see for example https://waqi.info)
- Cost

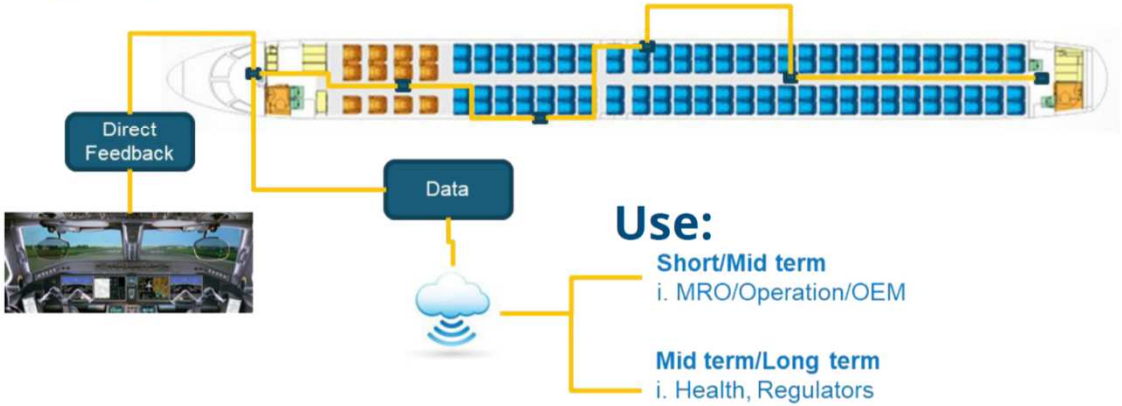
Monitoring technologies for air quality

- Sensors:
  - Recent developments:
    - Miniaturisation and digitisation (big data)
    - COTS sensors
    - Sensor networks and e-noses
  - Suitability for cabin environment (cost, weight, fit-for-purpose)
- Human-based assessment
  - Standardised, available (Guidelines on Education, Training and Reporting Practices related to Fume Events, ICAO Circular 344-AN/202, 2015)
  - Humans are prone to subjectivity, consistency, and reliability issues

IFCAS: Industrial cabin air quality Framework based on Continuous Air quality Sensing

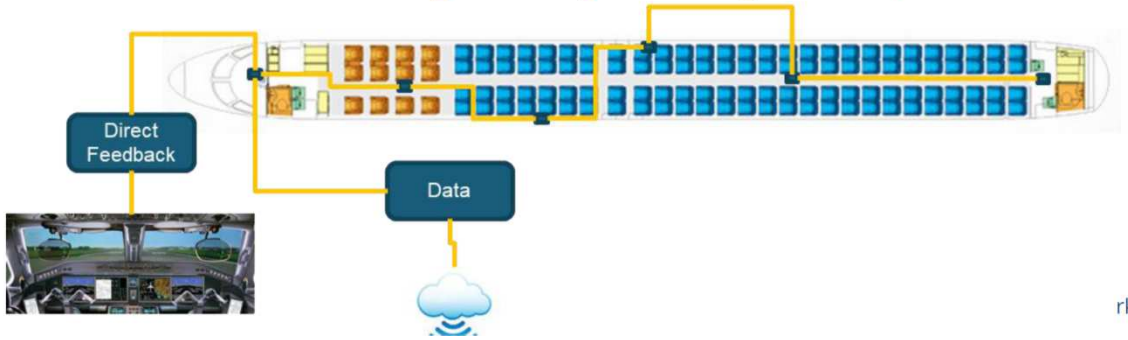
Requirements:

- Interface with (future/legacy) aircraft
- Interfaces for sensors and operation
- Low weight, power, cost, and reliable

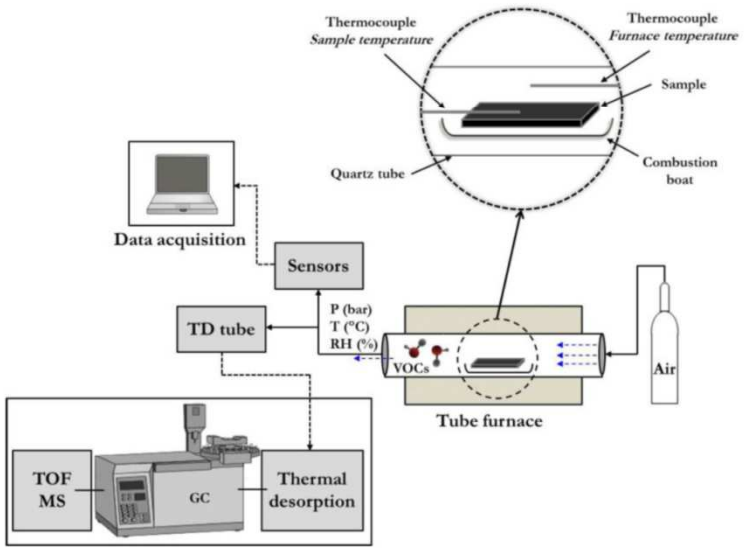


IFCAS key enablers and challenges

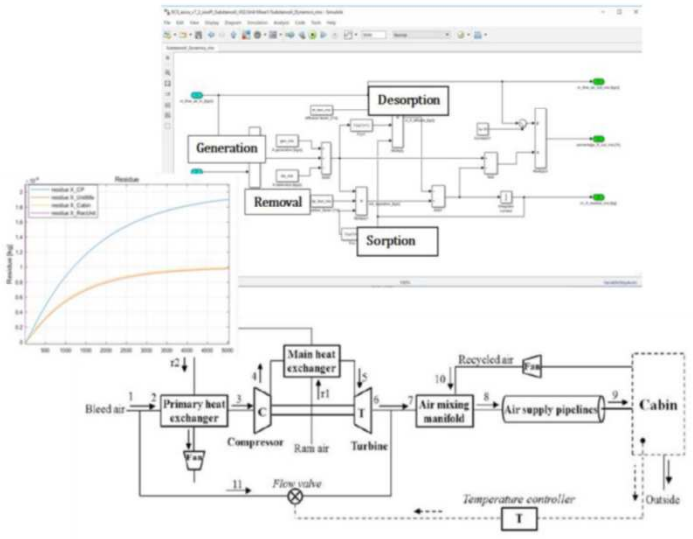
- Technical requirements and specifications for aircraft air quality monitoring
- Availability of fit-for-purpose low cost sensors
- Deployment challenges in cabin environment: sensor placement and operation, power needs, data collection and retrieval, standardisation
- Business cases: usage of data, within and beyond use of cabin environmental data for operations and maintenance (cf., big data initiatives in Future Sky Safety and by EASA)



IFCAS key enablers and challenges: studies in FSS



Experimental methodology and facility development for COTS-based gas sensing (Cranfield University)



Modelling developments at NLR

ECS schematic from H. Yin et al., "Modeling dynamic responses of aircraft environmental control systems by coupling with cabin thermal environment simulations," Build. Simul., vol. 9, no. 4, pp. 459–468, 2016

Overview

1. Introduction to NLR
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3. Cabin air quality in Future Sky Safety project
4. Concluding remarks

Concluding remarks: summary

- Cabin Air Quality research for contamination events of low frequency and short duration: proposal:
  - Real-time measurement
  - Analysis: combined on-line and off-line, combine with other relevant (flight) data
  - Benefit: increase understanding of occurrence of possible cabin air pollutants (variation of concentrations in time)
- In a wider perspective, Future Sky Safety proposes IFCAS framework for Continuous Air Quality Sensing,

CAQ research and development recommendation from FSS

- Business case development (PHM/CBM, safety events warning, ….)
- Low-cost CAQ sensors development, including electronic nose concepts
- COTS sensor and new material validation for cabin environment
- Multi-fidelity CAQ modelling to enable improved cabin designs, validated by IFCAS data
- Exploit IFCAS for improving understanding of passenger comfort and crew performance
- IFCAS as CAQ surveillance facility for monitoring non-routine CAQ events and their contamination signatures
- International cooperation for synergic results
- CAQ observatory (configurations/governance)

Acknowledgement & further reading

- The Future Sky Safety Programme has received funding from the European Horizon's 2020 research and innovation programme under grant agreement No 640597.

- www.futuresky-safety.eu, Deliverable D7.14 (Final report), Cabin Air Quality White paper (to be published)

IPA
Institut für Prävention und Arbeitsmedizin
der Deutschen Gesetzlichen Unfallversicherung
Institut der Ruhr-Universität Bochum

BG Verkehr
Verkehrswirtschaft
Post-Logistik
Telekommunikation

Biological Monitoring in Air Crews after Fume and/or Smell Events

Organophosphates, VOC and AChE activity

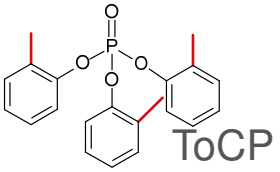
Aircraft Cabin Air Quality Research –
EASA workshop on future research
30. – 31. January 2020 - Cologne, Germany

Dr. rer. nat. Tobias Weiss
Head of Human Biomonitoring

RUHR UNIVERSITÄT BOCHUM
RUB

FUSE I: Biomonitoring after fume events

(Schindler et al. 2013, Weiss et al. 2015)



OP flame retardants:

- Di-n-butylphosphate
- Di-(2-chloro-iso-propyl)-phosphate
- Di-(2-chloroethyl)phosphate
- Diphenylphosphate

- 332 Flight attendants and pilots from 51 flights (< 12 h after event)
- HBM of organophosphorous (OP) flame retardants and TCPs in urine

- Metabolites of OP slightly elevated in comparison to controls
- No metabolites of ToCP or Di-oTCP isomers (LOD < 0.5 µg/L urine)
- Metabolites of m-, p-TCP or mixed (m,p) TCP in one air crew sample above LOD but below LOQ
- $LOD_{ToCP} \approx 8 \times TLV \times 8h$; $LOD_{TmCP;\ TpCP} \approx 20 \times TLV \times 8h$

FUSE II: Reason for the study

Heutelbeck, Budnik and Baur; Oral presentation at Ramazzini Days 2016

11 Flight attendants with blood sampling < 24h after event
- HBM for **VOC** and **AChE** activity (blood)
- 10 - 125 µg/L blood n-hexane, declining to < 40 µg/L (10/11)
- 12 control persons: n-hexane < 10 µg/L

"The clinical finding are plausible in the context of the toxicological potential of **VOC**s which may **affect** the **peripheral and/or central nervous system** and the **respiratory tract**."

„The measured **AChE** activities indicate a subordinate contribution of **organophosphates** […] to the observed symptoms"

FUSE II: Recruiting

375 Flight attendants and pilots after self reported „Fume and/or Smell-Event“
(completed in 12/2019)

- Sampling of blood and urine within 5 hours after landing (possible at 12 German airports)
- Standardised sampling box incl. prescribed disinfectant
- Immediate transfer of blood and urine into gas-tight tubes
- Transport to laboratory over-night
- 3 Short questionaires (technical/medical)

100 Persons from the general German population
(expected to be completed in 02/2020)

- No flight within 4 weeks before sampling

100 Flight attendants before taking up professional activity
(expected to be completed in 03/2020)

FUSE II: Study parameters

- VOC: - i-hexane, 2-propanol, acetone, 2-butanone, **n-hexane**, n-heptane, **toluene**, n-octane, n-decane, 2-heptanone, 2,5-hexandione (metabolite of n-hexane) und o-cresol **in blood**

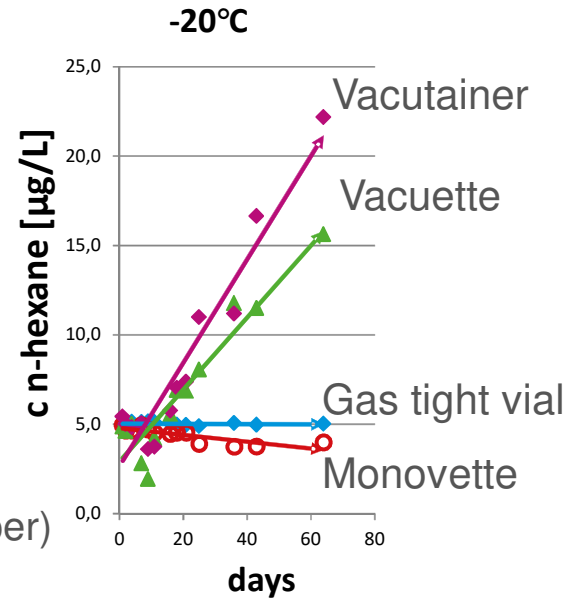
  - 2,5-hexandione (metabolite of n-hexane), o-cresol and acetone **in urine**

- OP: - 9 isomers of tricresylphosphate (TCP), tri-(2-chloroethyl)phosphate (TCEP), tri-(2-chloroisopropyl)phosphate (TCPP), tributylphosphate (TBP) and triphenylphosphate (TPP) **in urine**

- AChE: - Inhibition of acetylcholinesterase **in blood**
  (2 samples: 1. within 4 hours after event, 2. about 6 weeks later)

FUSE II: Evaluation of pre-analytical procedure

- Risk of sample contamination with VOC
  - Desinfection of the skin before blood sampling
  - Materials for blood sampling
- Stability of samples



- Only Octenisept ® did not contain target analytes
- Sampling material was free of target analytes
- Vacutainer® and Vacuettes® are contaminated with n-hexane (stopper)
- Monovettes are not gas-tight, losses of analytes even at -20 °C
- Gas-tight headspace vials did not show losses of analytes at any tested temperature

FUSE I & II: Summary and Outlook

FUSE I (N = 323 self reported cases)
Slightly elevated blood concentrations of OP flame retardants

TCP: No metabolites of ToCP (< 1/8 TLV over 8hrs) and Dio-CP; meta- and para-TCP metabolites in one single sample

TCP and measured OP are unlikely to be the cause of reported symptoms

FUSE II (N = 375 self reported cases)

Analysis of VOC needs a stringent protocol to avoid sample contamination and underestimation

Recruiting of control persons will be completed in 03/2020

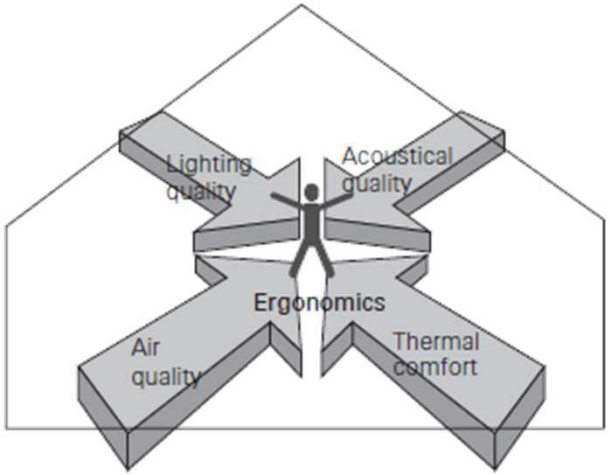
Statistical analysis of VOC, OP and AChE until mid-2020

HUMAN BIOMONITORING & EXPOSURES

SIMILARITIES WITH OTHER INDOOR ENVIRONMENTS

VITO, Health Unit
Marianne Stranger, Gudrun Koppen

23/04/2020

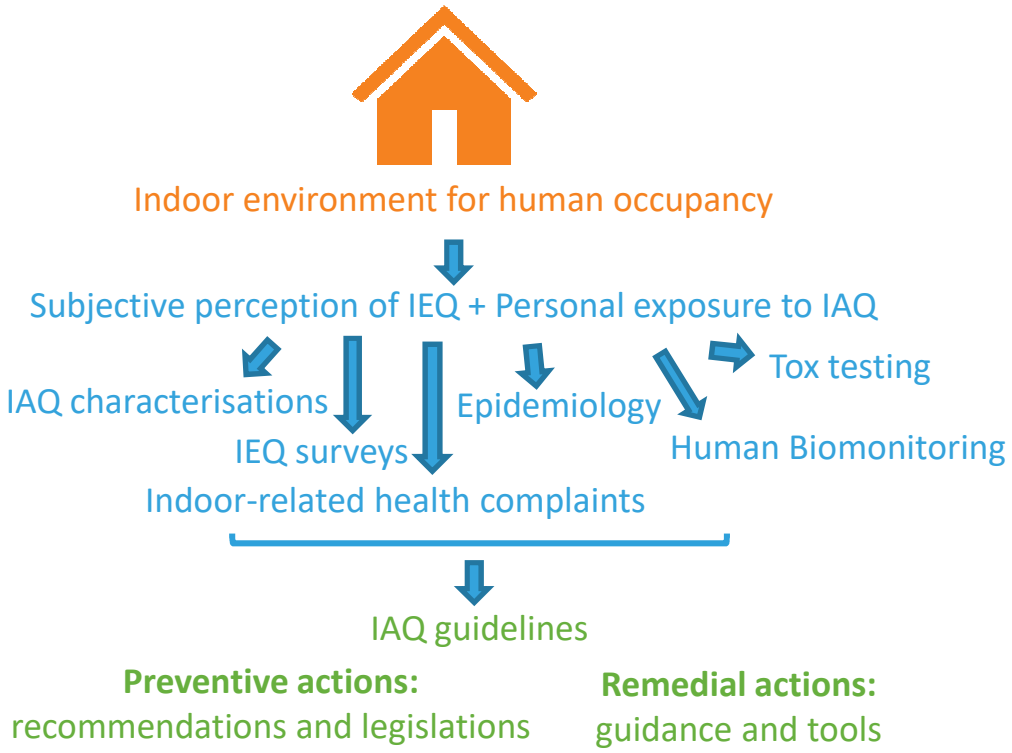


Source: Bluyssen

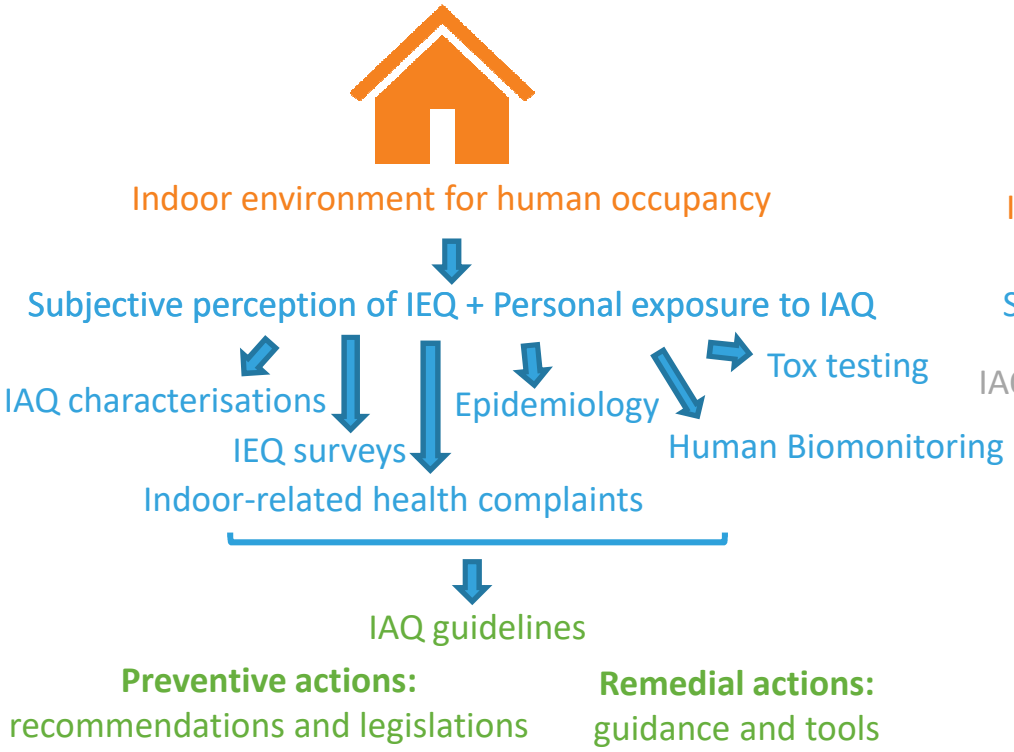
Figure 3.1 *Basic environmental factors in an indoor space*

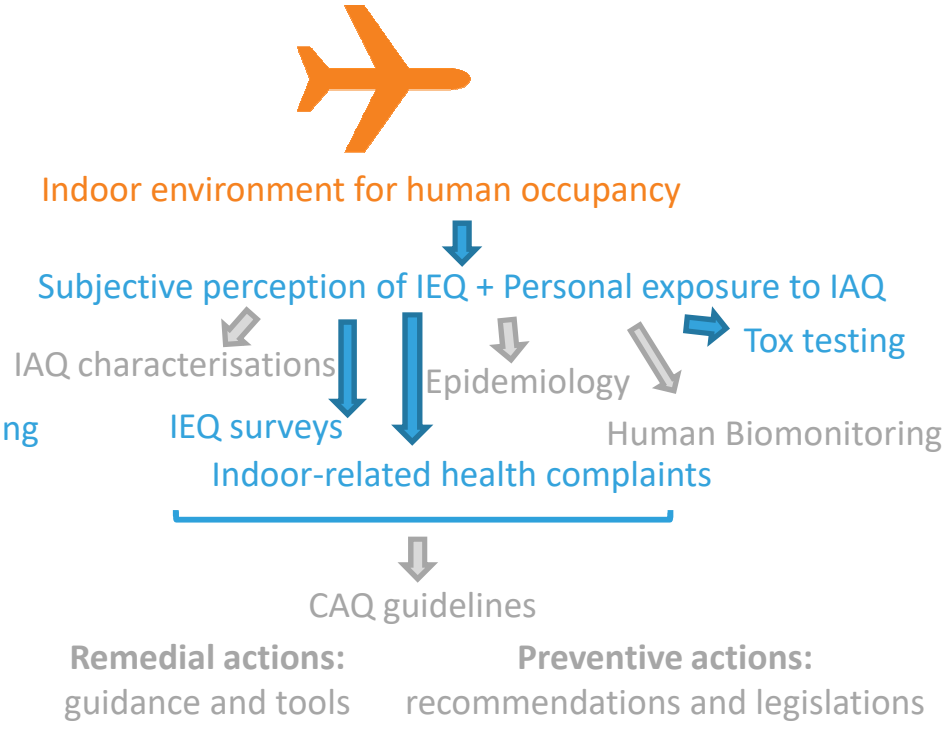
Bluyssen P. The Indoor Environment Handbook - 2009

THE STATE OF THE ART OF IAQ IN THE BUILT ENVIRONMENT



WHAT ABOUT CAQ?





FUTURE HUMAN BIOMONITORING & CAQ MONITORING: METHODOLOGICAL NEEDS

Recruitment strategy

Large scale, systematic routine occupational follow-up in workers, systematic follow-up of incidents (post-factum)

Human biomarkers

- **Exposure**: urinary or breath suspected profiling on fume-related compounds -> possibly on-the-body sensors for specific fume-related 'indicator compounds'
- **Effect:** Neurotoxicity testing (NES testing), indoor-related health complaints questionnaires (eye irritation, attention deficit, noise, odor), on-the-body sensors for stress assessment

Routine and dedicated CAQ monitoring methods, for follow-up and screening

- **Indicator compounds**, identified by means of chemical screening of CAQ, optimize/develop (new) methods
- **Miniature-type sensor box** for continuous assessment of 'indicator' compounds as proxy for fume events. New sensors needed? Enhanced sensor array? Performance in aircraft? Calibrations and validations needed
- **E-nose sensors** (patterns)
- **Gas generation system** for complex gas mixtures in order to test, calibrate & validate; at (simulated) realistic cabin environment conditions

FUTURE HUMAN BIOMONITORING & CAQ MONITORING: DATA ASSESSMENT NEEDS

Four essential aspects:

- **Compilation of existing data:** collaboration with aircraft industry to explore confidential data of (health)complaints, oils, de-icing fluids, incidents - respecting confidentiality -> what brings linking private data?
- **Routine control assessments:** broadening routine medical examination of flight crew (attention tests, combustion urine profiles), routine analysis of CAQ in 'complaint-free' flights
- **Instantaneous assessments when suspected CAQ event:** in case of event e.g. immediate data collections using 'HBM kit', instantaneous characterization of CAQ (particle collections, analytical characterization of chemical profiles)
- **Post CAQ event follow-up:** more frequent follow-up of flight personnel that reported CAQ event

Main advantages of this approach:

- Identification/quantification of dissimilarities between routine situation and suspected CAQ event
- Occupational health follow-up increases confidence and avoids the development of psychosomatic complaints
- Allows the identification of mitigation strategies (oil types, flight characteristics, other…)

HUMAN BIOMONITORING AND INDOOR AIR QUALITY IN FLANDERS: SOME EXAMPLES OF VITO PROJECTS

Flemish

Clean Air Low Energy

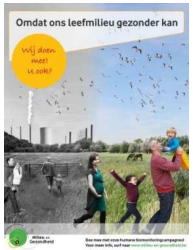
indoor box

FLEHS I
2002-2006

FLEHS II
2007-2011

RENOVAIR

Elgas



FLEHS III
2012-2015

FLEHS IV
2016-2020

Bouw Gezond

my healthy home

biba
binnenlucht
in basisscholen

European

DEMOCOPHES
Demonstration of a study to coordinate and perform human biomonitoring on a European scale

2010- 2012

sinphonie

Officair

ET'Air

HBM4EU

science and policy for a healthy future

2017- 2021

EPHECT

INFLAME

Federal

DO IT houtbouw

HEMCPD

2004- 2007
2008- 2012
2013- 2016

World Health Organization

Local

3XG
GEZONDHEID GEMEENTEN GEBOORTEN

2011-
(2029)

EA²
Enhancing Air Quality in Qatari Indoor Environments

Session #4

→ **Fume Event Reporting & Investigation**

→ Presentations: EASA, BEA, GCAQE, KLM

EASA
European Union Aviation Safety Agency

Reported events involving cabin air contamination and investigations performed

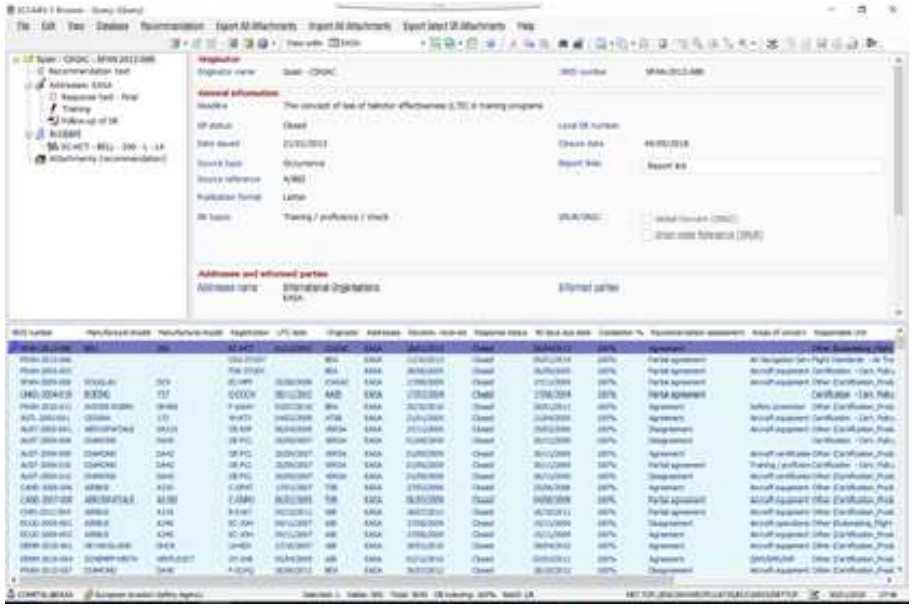
Alessandro Cometa
Senior Safety Investigation Officer

Your safety is our mission.

An Agency of the European Union

Standard search for Cabin Air Quality data

- Queries on ECR, IORS, Accident Incident DBs
  - They are all based on ECCAIRS system, ADREP Taxonomy
  - Usually the search is based on the “Occurrence Category” field



Occurrence Category

Smell of smoke?

- F-NI: Fire/Smoke (non-impact)

  - *Includes fire due to a combustive explosion from an accidental ignition source.*
  - *Includes fire and smoke from system/component failures/malfunctions in the cockpit, passenger cabin, or cargo area.*
  - *Non-combustive explosions such as tire burst and pressure bulkhead failures are coded under System/Component Failure - Non-Powerplant (SCF-NP).*
  - *Fire/Smoke resulting from an accident impact is coded under Fire/Smoke (post-impact) (F-POST).*

Occurrence Category

Incapacitation?

- MED: Medical

  • *Includes:*

  - Crewmembers unable to perform duties due to illness.

  - Medical emergencies due to illness involving any person on board an aircraft, including passengers and crew.

  Does NOT include:

  - Injuries sustained during flight operations as per Turbulence etc

Occurrence Category and Narrative

- **“F-NI” includes real/visible Smoke related events?**
- **Is a Cabin Air Quality event classified as F-NI or MED?**

A way to search for a Cabin Air Quality related event is to look into the Narrative field.

Search into the Narrative

Selected parameters

- **CAT (FW) ops**
- **2018-2019 timeframe**

- **Words in the Narrative field:**
  - Odour
  - Headache
  - Dizzy
  - Incapacitation
  - Cognitive
  - Nausea

Search into the Narrative

After reviewing the outcome of the query, only 10 events could be linked to a Cabin Air Quality event:

- 6 related to “odour”
- 2 related to “headache”
- 1 related to “cognitive”
- 1 related to “nausea”

Only in two cases there was a Annex 13 investigation

Annex 13 investigation

- **A330, Jul 2018, rated as Serious Incident:**

The crew smelled a strong odour in the cockpit and were partially impaired in their performance. The flight diverted and landed safely.

Annex 13 investigation

- **B767, Jan 2018, rated as Serious Incident:**

Flight attendants experiencing nausea and dizziness, unable to perform duties

Roughly an hour after departure the entire cabin crew and shortly thereafter a number of passengers indicated that they were feeling unwell. After the aircraft landed back and had come to a standstill, the cabin crew was examined by the airport medical service and ambulance staff.

No records of injuries.

Other events

- **A319, 2019:**

Event details: During approach at Toulouse Airport (TLS), a strong odour of "smelly feet" was noted in the flight deck. Within a couple of minutes, the copilot began to feel physiological effects: light headedness, headache and difficulty in performing duties. Hence, the co-pilot donned oxygen mask. QRH actions were performed by the pilot and the flight continued to a normal landing.

Other events

- **A320, 2019:**

Event details: During climb flight attendants noticed a strange odour in the cabin, similar to menthol or disinfection fluids, for some brief moments, the smell dissipated again. Later into the flight a female passenger fainted and became unconscious for a brief period of time.

Troubleshooting reveals oil leak from the oil transfer tube seal. The oil transfer tube seal was replaced without resolving the issue.

Conclusions

- **Annex 13 investigations and other events**
  - Small number of events available
  - Few details available, need to wait for a Final Report
  - No records of injuries
  - In some cases the cause was identified as a system failure (APU, Engines, Electrical equipment)

EASA
European Union Aviation Safety Agency

Thank you

easa.europa.eu/connect

Your safety is our mission.

An Agency of the European Union

BEA

Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile

www.bea.aero

Partial Incapacitation Case

Didier DELAITRE
BEA Medical Advisor

Summary of the event

- On November 17th 2017, after take-off from Geneva, the flight crew of a Vueling A320 experienced symptoms leading to incapacitation (nausea, headhache, dizziness).

- They diverted to Marseilles in Emergency where they landed safely. They were taken to hospital. They left the hospital a few hours later. They kept strong symptoms during a few days.

History of the flight (1/3)
(from CVR+ crew interviews)

- Crew scheduled to perform the following rotation: BCN – GVA – BCN – IBZ – BCN, starting their flight duty period at 0525 UTC. First leg BCN-GVA was uneventful. No discrepancy regarding the technical performance of the aircraft.
- Turnaround time at GVA : 36 minutes
- At 0805 UTC, taxied behind a Cessna Citation and held position for 2-3 minutes behind it before line-up, with a safe distance approximately twice the length of the A320. At this point, the crew started to smell a mix of burned jet fuel and chemicals
- The odour increased in intensity and turned to be very disturbing (throat irritation)
- Crew ventilated the cockpit by opening the air gaspers
- Cessna lined up and the odour disappeared.

History of the flight (2/3)

- Passing 9000 feet, the captain started to feel dizzy and slow in his performance.
- First officer called the chief purser asking him to look after them.
- Chief purser mentionned that the cabin + passengers were OK.
- Soon after the F/O started to feel dizzy too + vertigo, nausea and light-headedness as well as a sudden extreme urge to urinate.
- Captain ordered to quickly don the oxygen masks. F/O had to leave urgently the flightdeck to go to the lavatory. Came back one minute later.
- When coming back in the cockpit, the captain was declaring PAN PAN due to pilot incapacitation and was requesting diversion to Marseilles.

History of the flight (3/3)

- F/O felt a little bit better with the oxygen, no improvement for the captain.
- Captain decided to give controls to the F/O.
- F/O requested the best straight in approach of all available, whereas the captain instructed the Chief Purser to be prepared to set 10.000ft on the FCU ALT window in case the crew would pass out.
- Radar vectored by the ATC for straight-in approach on RWY 13 instead of RWY 31 which was in use.
- Landing was uneventful. Crew taken to hospital by the emergency services. Released 3 hours later.
- Both crew members continued to have moments of dizziness + headaches + vertigo during the weekend and the beginning of the week.

BEA actions (1/2)

- BEA was immediately notified by the ATC. Full investigation was decided.
- The hospital was contacted. The crew had already left. Blood analysis performed only for carbon monoxyde research. « Negative » results. Blood samples not kept.
- FDR and CVR were preserved and conveyed to the BEA
- The cockpit and cabin filters + tray tables + sunvisors were preserved for further analysis.
- ATC radio and radar recordings requested
- Plane was maintained at Marseilles for troubleshooting.

Aircraft inspections

- Aircraft maintained at Marseilles for Troubleshooting
  - TSM TASK 05-50-00-810-831-A - Identification the source of the smell
  - TSM TASK 05-50-00-810-831-A - Identification of the Cause of Cabin Odors or Smoke
  - AMM Task 05-50-00-810-831-A related to APU.
  - Engine run as per workpackage.

Nothing abnormal was found . Aircraft released and flew back to its base, Barcelona. Flight was uneventful.

- On November 22nd , the aircraft entered a “20-months check” in the maintenance installations in Iberia . Aircraft thoroughly checked to try to locate the origin of the smell. Nothing abnormal was found.

Since then, the aircraft has been flying without any pilot report on smells/odours.

Cockpit parts analysis

- Cockpit and cabin filters, tray tables and sunvisors were taken to a laboratory contracted by the BEA. These parts can keep the memory of some toxic agents present in the air.
- Objective was to search for TOCP, organophosphate present in engine oil additive
- TOCP is known for triggering the aerotoxic effect such as the one experienced by the Vueling crew.
- Results were negative.

Cessna Citation

- The Cessna Citation was identified as operating for Netjets in Portugal.
- Netjets carried out the inspections requested by the BEA.
- The aircraft was last in maintenance from the 16th of August until the 29th of September for a Major Inspection which consisted of 4A/4C + Right Engine change.
- On the day of the incident, the aircraft was not operating with any engine-related ‘special conditions’ (not under MEL , no aircraft technical pending items).
- Engine oil was analysed. Results sent to the BEA. Oil characteristics in the standards.

BEA actions (2/2)

- Vueling crew interviews, **active support of the operator**
- Cessna Citation identified and operator + crew questionned
- Crew hair analysis, search for toxic agents, **active support of the operator**

Hair analysis

- Hair samples were taken on the cockpit and cabin crew (total of 7)
  - ✓ The hair can keep a very good memory of toxic agents inhaled by an individual. This operation has to be done roughly a month after the intoxication. This was done on 22nd december 2017.
- A leading expert in toxicology was appointed adviser to the BEA for the analysis of the results.
- Results were « negative » : pollution-comparable rate of TCP, TOCP, TPPA

Preliminary results

Challenges for SIAs

- Need for a quick reaction and intervention (preservation of CVR, checks on the plane, contacts with the hospital)
- Have a clear view on what aircraft parts to preserve.
- Know about laboratories/medical experts capable of chemical analysis on aircraft parts (plastic parts, filters) and hair samples.
- Collect knowledge on the aerotoxic syndrome and its possible origins.

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pour la sécurité de l'aviation civile

www.bea.aero

BEA

A step further?

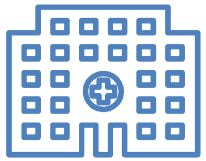
Time & Response To Incapacitation I

- In-Flight :

  F/crew, C/crew, emergency kits on board, medical teleassistance

- At the Airport :

  First aid, emergency medical services



- At the Hospital :

  Emergency units, hospital care services

- Afterwords

  Family doctor, etc.

Response To Incapacitation

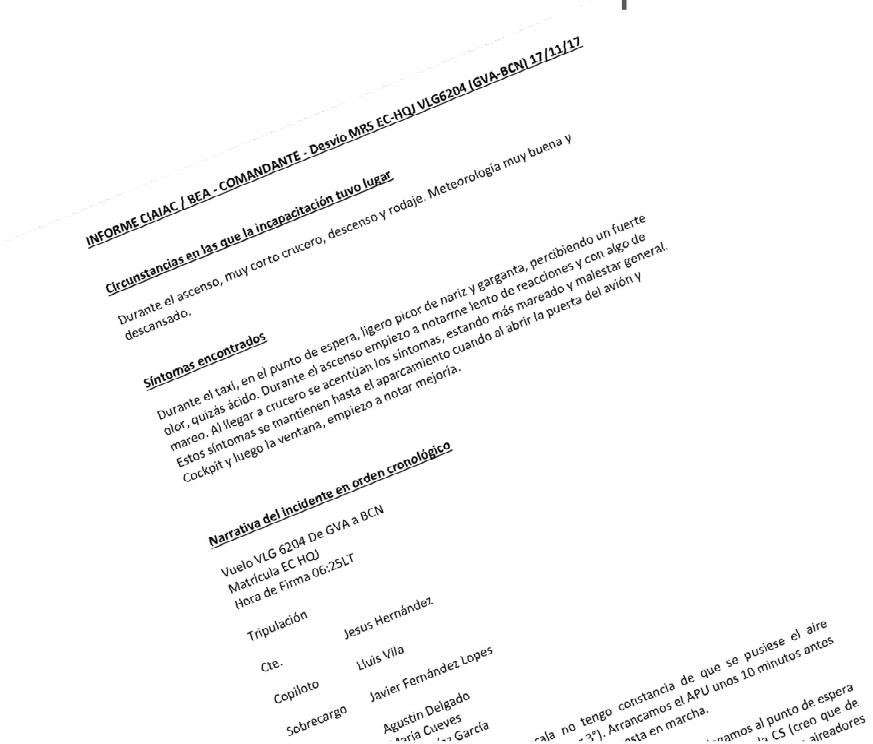
- Care :
  - Pre-identified dangers
  - Emergency units : protocols
  - Clinical examination, medical biology* (vs occupational/industrial, environmental)
- Investigation :
  - Second step
  - Race against the clock
  - All means in an ethical manner
- ... Operations : ?
  - .

Care & Response To Incapacitation II

- Orientation : medical questionnaire, non specific
- Examination :
  - Clinical (symptom oriented), non specific
  - Biological : medical approach
- Fire/Fumes : Carbon monoxide, cyanids
- Treatment :
  - Results of biological examinations : CO/CN negative
  - Clinical evolution : no health-threatening

Forensic Approach

- Orientation : medical questionnaire, **narrative (CPT, F/O)**



INFORME CIAIAC / BEA - COMANDANTE - Desvío MRS EC-HQJ VLG6204 LGVA-BCN) 17/11/17

Circunstancias en las que la incapacitación tuvo lugar

Durante el ascenso, muy corto crucero, descenso y rodaje. Meteorología muy buena y descansado.

Síntomas encontrados

Durante el taxi, en el punto de espera, ligero picor de nariz y garganta, percibiendo un fuerte olor, quizás ácido. Durante el ascenso empiezo a notarme lento de reacciones y con algo de mareo. Al llegar a crucero se acentúan los síntomas, estando más mareado y malestar general. Estos síntomas se mantienen hasta el aparcamiento cuando al abrir la puerta del avión y Cockpit y luego la ventana, empiezo a notar mejoría.

Narrativa del incidente en orden cronológico

Vuelo VLG 6204 De GVA a BCN
Matrícula EC HQJ
Hora de Firma 06:25LT

Tripulación

Cte. Jesus Hernández

Copiloto Lluis Vila

Sobrecargo Javier Fernández Lopes

Agustin Delgado

[illegible] García

[illegible] no tengo constancia de que se pusiese el aire [illegible]). Arrancamos el APU unos 10 minutos antes [illegible]sta en marcha.

[illegible]amos al punto de espera [illegible] CS (creo que de [illegible]alreadores

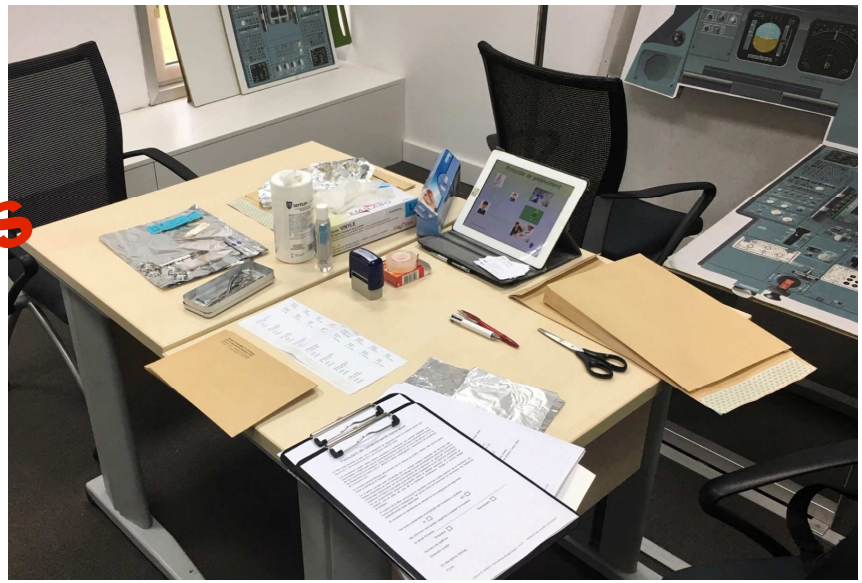
Forensic Approach

- Orientation : medical questionnaire, **narrative (CPT, F/O)**
- During symtoms/crisis, ASAP : sampling / cold storage, -80 °Celsius
  - Blood gas & saliva analysis (minute-hour)
  - First urination (hour-week)
  - Skin & mucous membranes

Forensic Approach

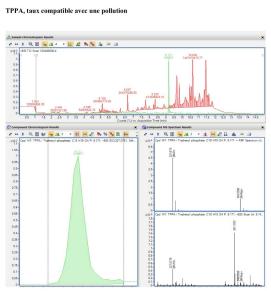
- Orientation : medical questionnaire, **narrative (CPT, F/O)**
- During symtoms/crisis, ASAP : sampling / cold storage, -80 °Celsius
  - Blood gas & saliva analysis (minute-hour)
  - First urination (hour-week)
  - Skin & mucous membranes
- **Hair analysis** (month)

What substances can you find?



Investigation: Forensic Approach

- Orientation : medical questionnaire, **narrative (CPT, F/O)**
- During symtoms/crisis, ASAP : sampling / cold storage, -80 °Celsius
  - Blood gas & saliva analysis (minute-hour)
  - First urination (hour-week)
  - Skin & mucous membranes
- **Hair analysis** (month), ambient air storage
- **Highly sensitive and precise non-targeted screenings**



UPLC – Q-TOF (full scan, exact mass, anteriority without stadard reference material, sample processing shortened, robustness improved)

Lessons Learned

- Data gathering
  - Care -> Treatment, non-exhaustive, (too late)
  - Investigation -> Report, safety recommendation, too late
  - Operator -> **KEY ROLE**: leading thread, since the beginning... and before !
- Need of specific tools
  - Open questionnaires, narratives, etc.
  - Sampling procedures
- Highly sensitive screening methods of the 2020'

Any questions?

GCAQE presentation for EASA workshop
30/31 January, 2020

Development of an Event Reporting System Global Cabin Air Reporting System (GCARS)

Captain Tristan Loraine
GCAQE Spokesperson

GCAQE
Global Cabin Air Quality Executive

EASA position 2015 and 2017

1. Contaminated air is not a flight safety issue – based on the number of pilot incapacitations and accidents.

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Global Cabin Air Quality Executive

EASA position 2015 and 2017

1. Contaminated air is not a flight safety issue – based on the number of pilot incapacitations and accidents.
2. Not enough reports.

GCAQE
Global Cabin Air Quality Executive

EASA position 2015 and 2017

1. Contaminated air is not a flight safety issue – based on the number of pilot incapacitations and accidents.
2. Not enough reports.
3. Air quality on an aircraft was better than in a home or office.

GCAQE
Global Cabin Air Quality Executive

EASA v GCAQE Chemical exposures

EASA

Chemicals measured below exposure standards

GCAQE

Heated engine oils have no published exposure standards.

It is the mixture that has the effect.
(SHK - Malmo event)

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Global Cabin Air Quality Executive

31 October 2005
British Government View

The Countess of Mar asked Her Majesty's Government: What exposure standards currently apply to any synergistic effects of simultaneous exposure to numerous chemicals which may be experienced by aircraft passengers and crew during a contaminated air event in a reduced pressure environment. [HL1761]

Lord Davies of Oldham: None.

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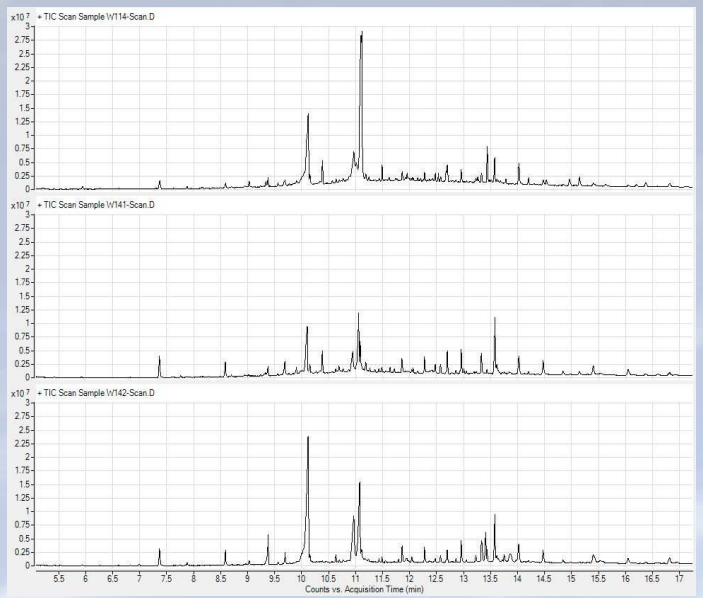
Global Cabin Air Quality Executive

Airbus A380 swab samples



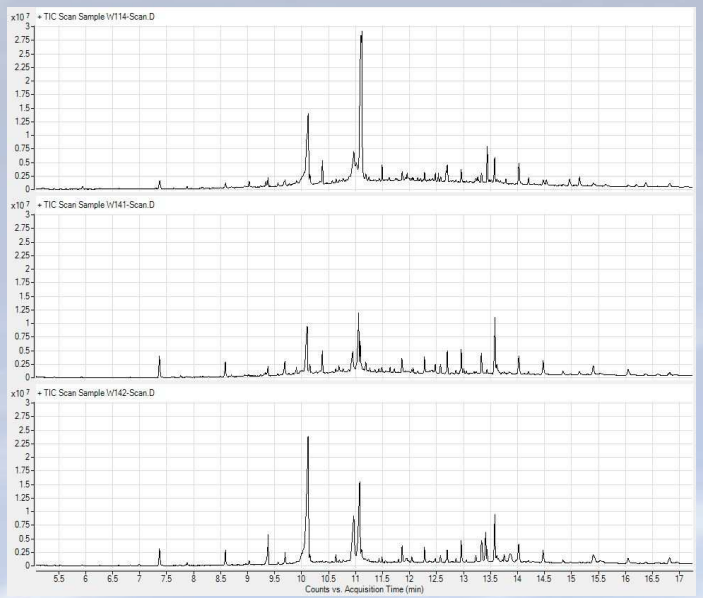
Positive for tricresyl phosphate and/or tributyl phosphate

GCAQE
Global Cabin Air Quality Executive

Airbus A380 swab samples

Regulator response

Plastic in seats, walls but NOT from oils or hydraulic fluids



Positive for tricresyl phosphate and/or tributyl phosphate

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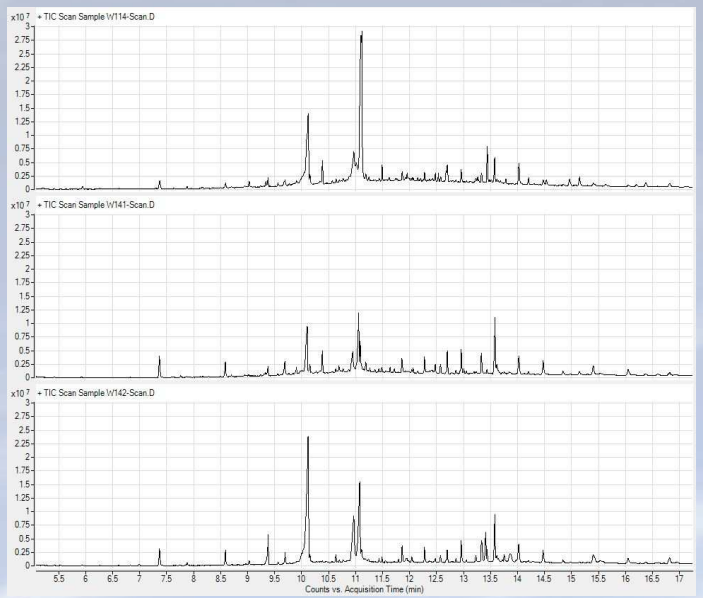
Airbus A380 swab samples



Regulator response

Plastic in seats, walls but NOT from oils or hydraulic fluids

Positive for tricresyl phosphate and/or tributyl phosphate

GCAQE
Global Cabin Air Quality Executive

CABIN AIR QUALITY TESTING

FILM 1

GCAQE
Global Cabin Air Quality Executive

ULTRA FINE PARTICLE (UFP)
Measurement Findings - 4 flights
Airbus 320/319

Levels increased with power changes / APU.
Elevated UFPs on all flights.
Levels lowest at steady state - cruise.
Dirty sock smell twice on 4 routine flights.

Levels on 4 routine flights 25 x higher than domestic kitchen

GCAQE
Global Cabin Air Quality Executive

UNDER REPORTING

Impairment absolutely occurring

GCAQE
Global Cabin Air Quality Executive

UNDER REPORTING

Impairment absolutely occurring

ISSN 1400-5719

Report RL 2001:41e

Incident onboard aircraft SE-DRE during flight between Stockholm and Malmö, M county, Sweden, on 12 November 1999

Case L-102/99

GCAQE
Global Cabin Air Quality Executive

UNDER REPORTING

Impairment absolutely occurring

ISSN 1400-5719

Report RL 2001:41e

Incident onboard aircraft SE-DRE during flight between Stockholm and Malmö, M county, Sweden, on 12 November 1999

Case L-102/99

– that an international database is established with factual information from flights where suspicion of polluted cabin air exists *(RL 2001:41e R3); and*

GCAQE
Global Cabin Air Quality Executive

GLOBAL CABIN AIR REPORTING SYSTEM

GCARS

FILM 2

GCAQE
Global Cabin Air Quality Executive

GCAQE
Asking and recommending…

- We believe there is enough data to mandate the introduction of cabin air quality sensors and bleed air filtration to enhance flight safety and protect crew and public health.

GCAQE
Global Cabin Air Quality Executive

GCAQE
Asking and recommending…

- We believe there is enough data to mandate the introduction of cabin air quality sensors and bleed air filtration to enhance flight safety and protect crew and public health.
- To work with the GCARS oversight team to use or integrate GCARS into existing reporting systems to enhance data collection and understanding of these events along with training and education.

GCAQE
Global Cabin Air Quality Executive

GCAQE
Asking and recommending…

- We believe there is enough data to mandate the introduction of cabin air quality sensors and bleed air filtration to enhance flight safety and protect crew and public health.
- To work with the GCARS oversight team to use or integrate GCARS into existing reporting systems to enhance data collection and understanding of these events along with training and education.
- Carry out an enhanced UFP research program based on our proof of concept work.

GCAQE
Global Cabin Air Quality Executive

Thank you

Captain Tristan Loraine
GCAQE Spokesperson

EASA; report & analyses of fume events KLM

Huub.Agterberg@KLM.com

January 2020

Content

1. Reports & registration
2. Investigation
3. Number of reports
4. Monitoring crew health
5. Awareness

Huub Agterberg
Occupational hygienist
KLM ISSO

1. Reports & registration

Goal:

- Report of all fume and smell events in the I-SMS.

Status:

- Q-pulse reports ASR/OSR. Possible by ipad/PC (mobile phone).
- Follow-up conform I-SMM (ERC, investigation)
- Data report to authority (IL&T via analyse bureau luchtvaart)

2. Investigation

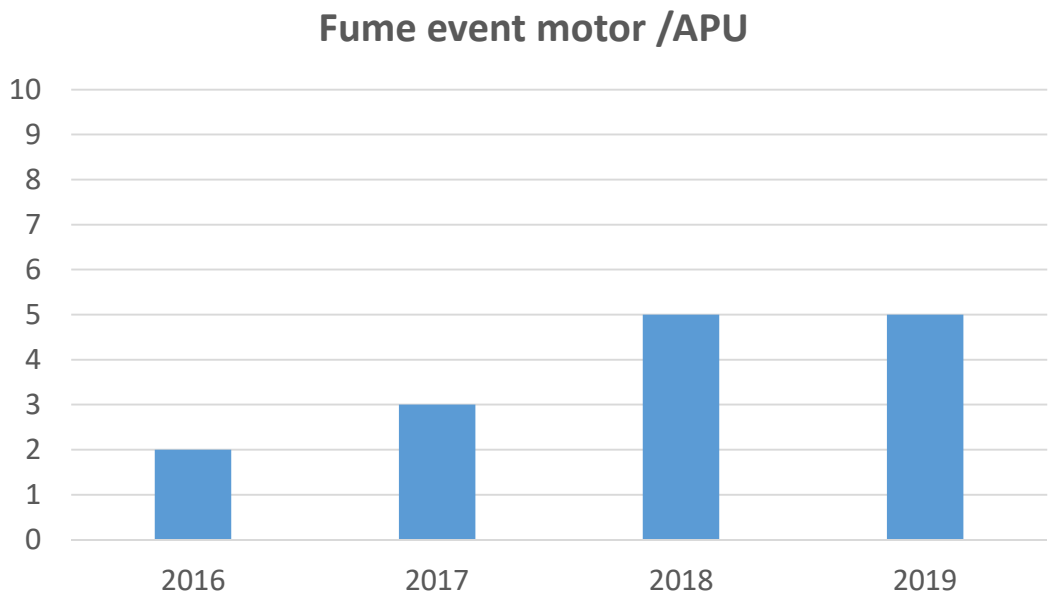
Goal:

- Investigation to address:
  - Cause of fume/smell event
  - Estimated exposure for crew/pax
  - Health effects crew/pax.

Status:

- Questionnaire for fume events available.
- Technical notification and investigation
- Monitoring of toxic gasses (not fully in place),
- Crew/pax are sent to medical services for investigation.

3. Reports in 2016-2019



Note: Most reported smell incident come from the galley.

4. Monitoring crew health

Goal:

- Surveillance of crew that experience physical complaints in relation tot cabin air

Status:

- Monitoring of short term health effect is in place. Crew and pax go to medical services to follow research protocol.
- Long term surveillance of health effect is difficult while no specific health effect has been set. General surveillance is performed by company doctor.

5. Awareness

Goal:

- Promote awareness by employees to make sure they report the technical fume/smell event and have their possible physical effects monitored.

Status:

- Promotion on reporting culture and investments on easy reporting
- Intranet (MyKLM) gives information on the subject.
- Subject is adressed in the national advisory committee with government, scientists, operators and employees.

Thank you

Session #5

- → **Risk Mitigation**
- → Presentations: ADSE, University of Brussels, Pall Aerospace, Honeywell

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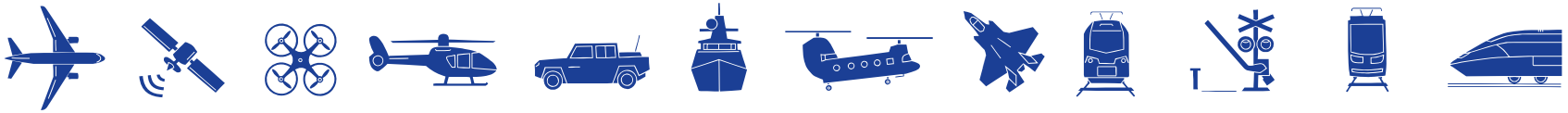
CONSULTING AND ENGINEERING

EASA Workshop on future Cabin Air Quality Research

ADSE input

30 & 31-01-2020

Ferdinand Spek & Ellen Norde



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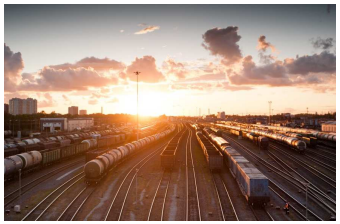
Issue 2017-03-10

Content

- Assignment of different research topics in context of mitigation strategy
- Need for engine (simulation) testing
- Need for enhanced flight testing

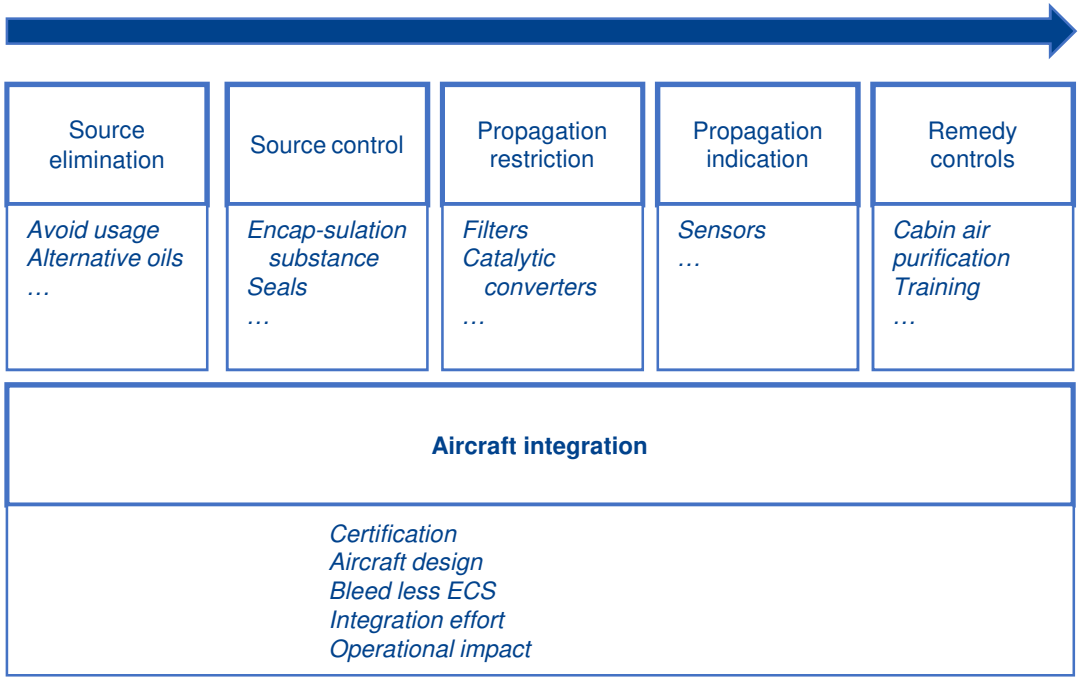


Mitigation strategy

- The use of any potential dangerous substance must be accompanied by a mitigation strategy
- This consists of several elements:
  - Source elimination
  - Source control
  - Propagation restriction
  - Propagation indication
  - Remedy controls

- In the context of cabin air quality onboard aircraft special consideration must be given to aircraft integration and operation aspects

Mitigation strategy



Mitigation strategy

- The mitigation strategy provides a way to assess potential research topics
  - Coverage of specific mitigation strategy elements in line with the total mitigation strategy
  - Context of aircraft integration

Engine (simulation) testing

- Oils have been tested at high temperature; AVOIL
  - No pressure, slowly rising temperature
- Oils have been tested when ingested in engine on a/c; VIPR
  - Complicated ground testing, limited range of engine settings

- These studies did not cover the actual path of oil through an engine under all operating conditions
  - Complex mix of near instantaneous compression and associated thermal process, combined with axial and radial flow components
  - Process can be simulated in suitable compressor, preferably axial flow

- We advise to properly test the process of contaminants entering an aircraft engine up to the bleed port
  - Either engine test at test stand or using separate compressor able to reach engine bleed air conditions

Enhanced flight testing

- Current flight testing has focussed on air quality within the cabin and cockpit
  - Contaminants can enter cabin air either from outside or from the process in the a/c (engine and ECS packs)
  - When measuring only inside the a/c the source cannot be determined
- For new flight testing it is advised to measure at all relevant positions:
  - Outside air
  - Supply air from ECS packs
  - Cabin/cockpit air
- In this way the source of a contaminant can be properly determined

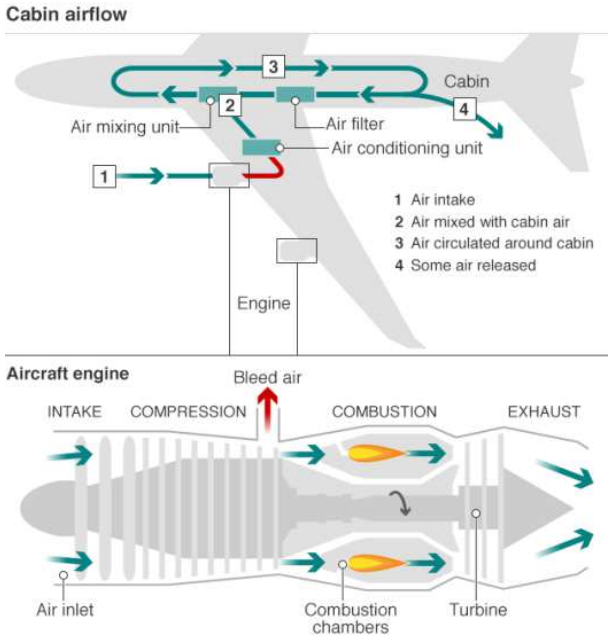
Engine and Flight testing

Flight testing:

- Sample locations 1, 2 and 3 simultaneously

Engine testing:

- Be sure to fully simulate path from air inlet to bleed air as taken by possible contaminant



Source: FlightGlobal, Pall, Airbus

Source: https://iitindoorair.wordpress.com/2016/10/11/introduction-to-aircrafts-indoor-air-quality/

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Enhanced aero-engine oil system components for an improved cabin air quality

M. Di Matteo, B. Outirba, O. Berten and P. Hendrick

Speaker: M. Di Matteo

Aircraft Cabin Air Quality Research
EASA workshop on future research
30-31 January 2020 - Cologne, Germany

ENGINE BREAKTHROUGH COMPONENTS AND SUBSYSTEMS

Outline

Introduction
ATM Lubrication Lab and test rigs
Methodology
Test results
Conclusions

Introduction

De-oiling = Separation system

Breather or De-Oiler

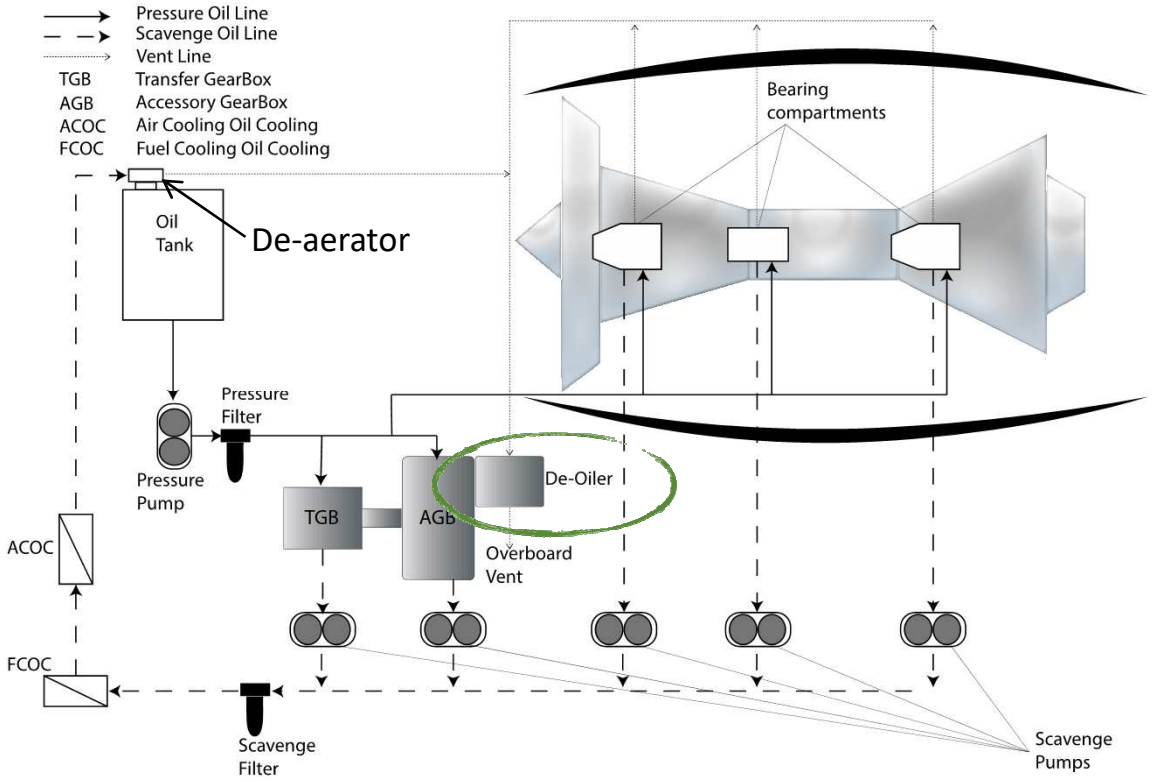
Centrifugal force to separate oil from air

- Allows air flows out through the vent but limited pressure losses
- Treating a two-phase air-oil mixture

The separated oil returns to the engine

The oil not separated contributes to the engine oil consumption

Increase efficiency of breather mandatory

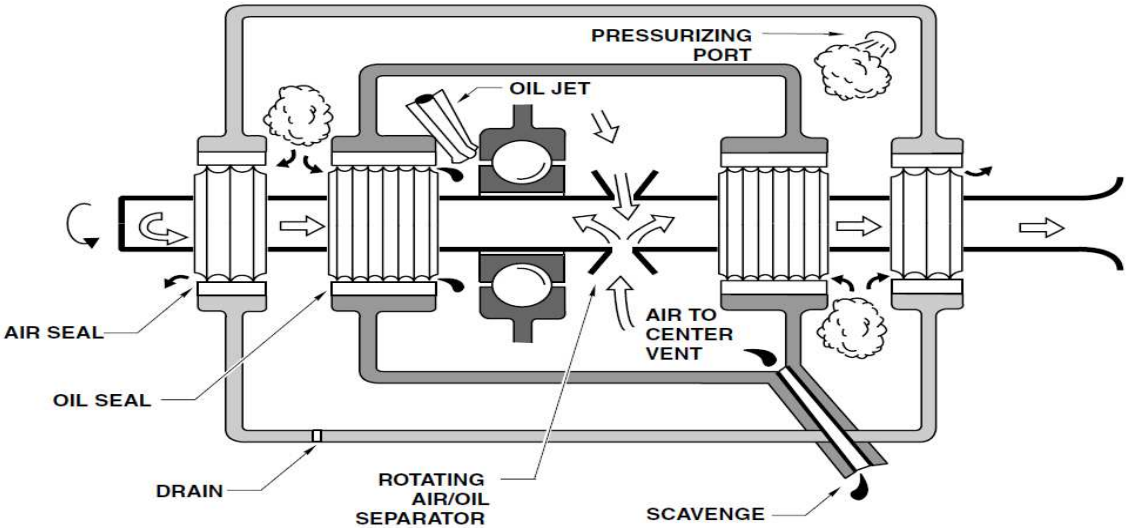


Introduction

Origin of the two-phase flow of oil and air

- Lubrication and cooling of bearings supporting the engine and of gear boxes (rotating up to 20 000 RPM)
- Oil is not allowed to flow freely in the engine

→ lubrication line in sumps sealed with compressed air to avoid oil leaks



Introduction

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Life > Health & Families > Features

Cabin fever: A bad case of Aerotoxic syndrome?

Campaigners claim toxic fumes inside aircraft pose serious health risks to passengers and crew. Now MPs are asking for a public inquiry. Should we be worried? Jimmy Lee Shreeve reports

TUESDAY 17 MARCH 2009

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Airline crew 'hit by oil fumes'

A captain was forced to bring down a plane carrying 75 passengers after "oily petrol" smells made him and his co-pilot feel sick, a report has found.

AERO/THERMO/MECHANICS

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ULB

E-BREAK

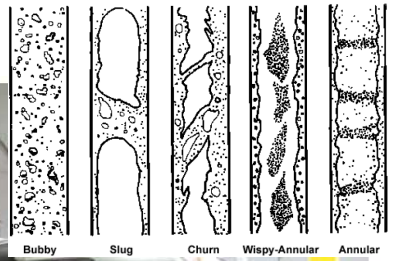
ENGINE BREAKTHROUGH COMPONENTS AND SUBSYSTEMS

ATM lub oil test rigs

Different test bench configurations, same principle:

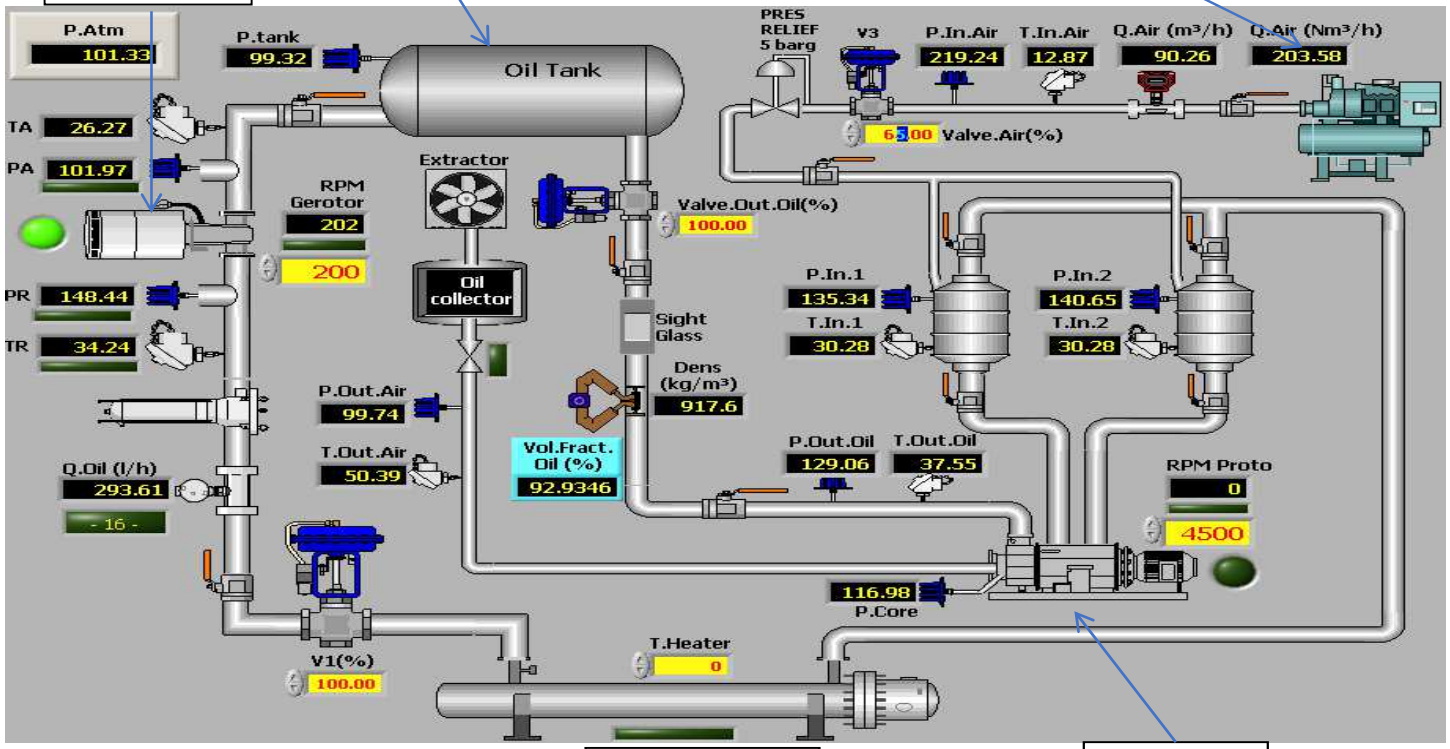
Oil tank and air compressor
Oil heater (engine ratings)
Vacuum pump (altitude effects)
Fully instrumented
Bearing chambers (air-oil mixtures)

T (˚C)	20 -205
Oil flow rate (l/h)	0 – 8/14.000
Air flow rate (Nl/min)	0 - 200
Rotational speed	0 – 16000 RPM



Test bench ATM 01

- Supply line
- Air Cooling Oil Cooling
- Cavitation problem



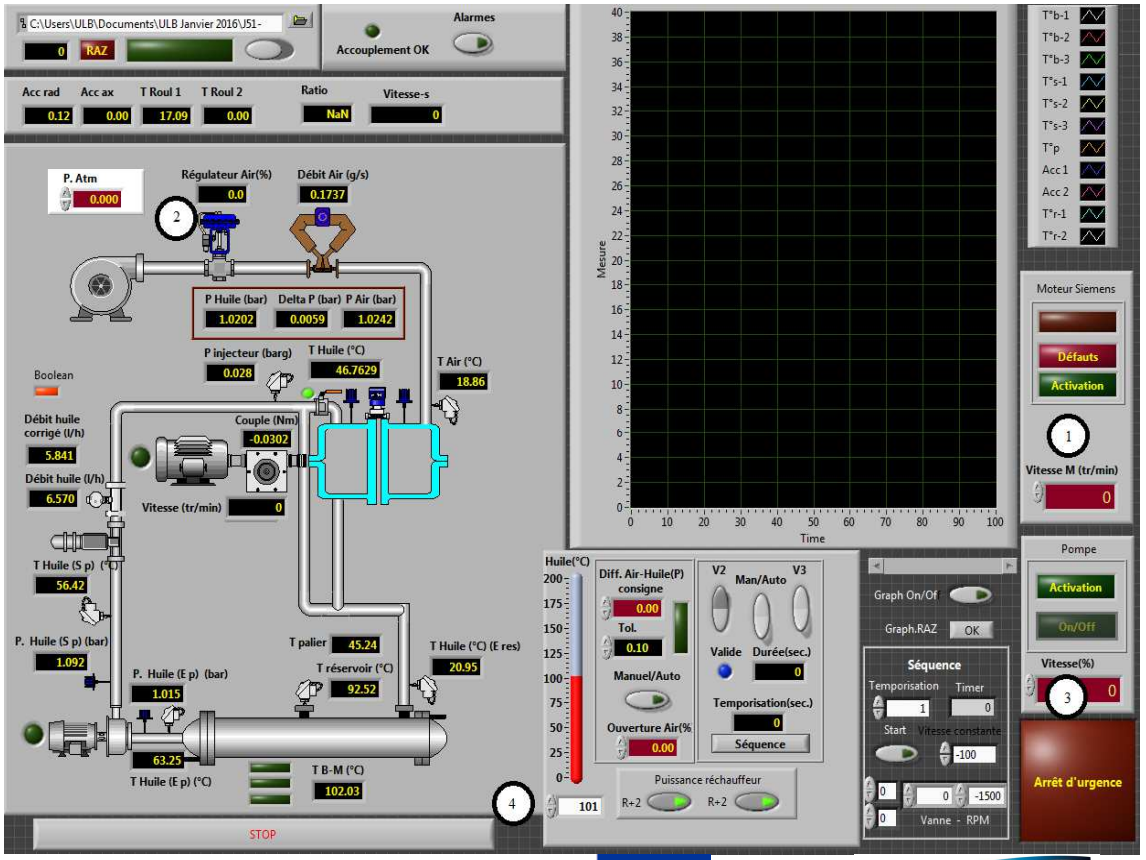
Test bench ATM 02/a

Modular and flexible test bench

- Torque
- Oil leaks
- Pressure losses

Focused on brush seals

ULB investigated the idea to replace labyrinth seals by brush seals (oil air) in bearing chambers



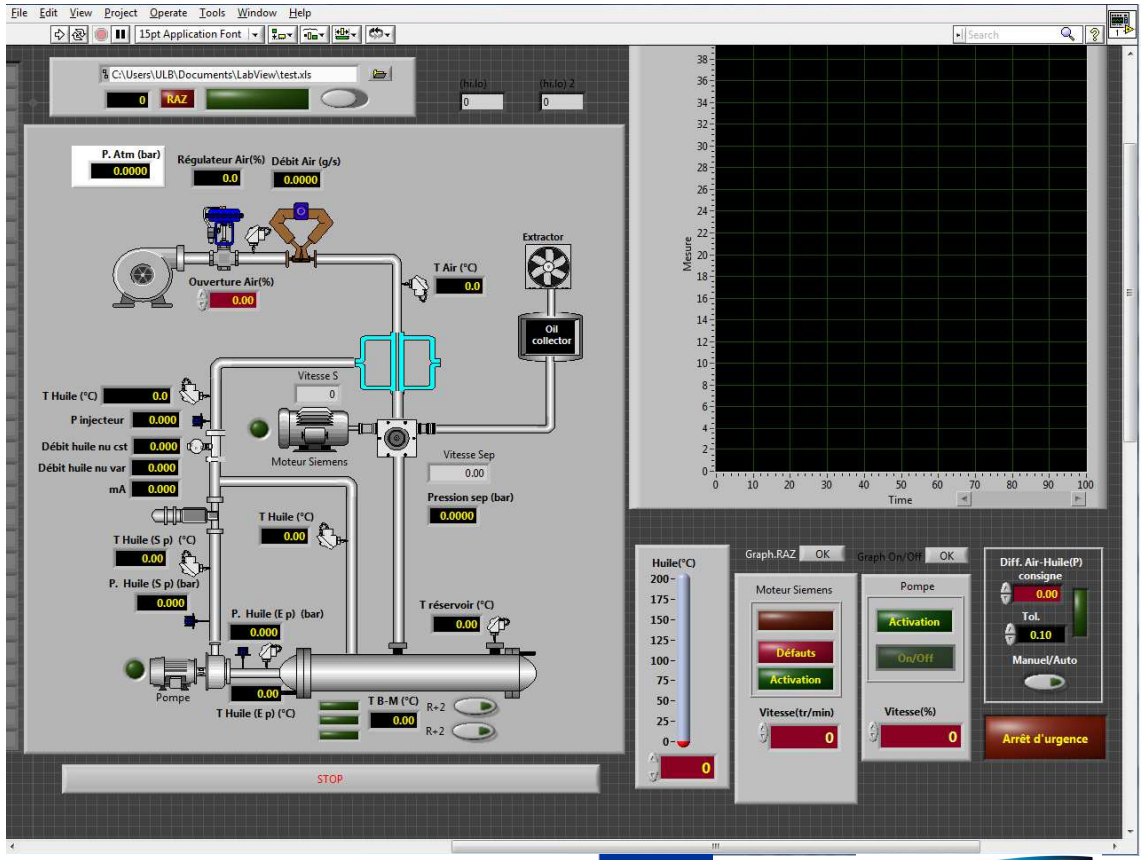
Test bench ATM 02/b

Modular and flexible test bench
- Inlet granulometry
- Oil consumption
- Pressure losses
- Outlet granulometry

Focused on air oil breather

ULB investigated experimentally new breather designs

Ideal to validate CFD models



Methodology

Particle grading:

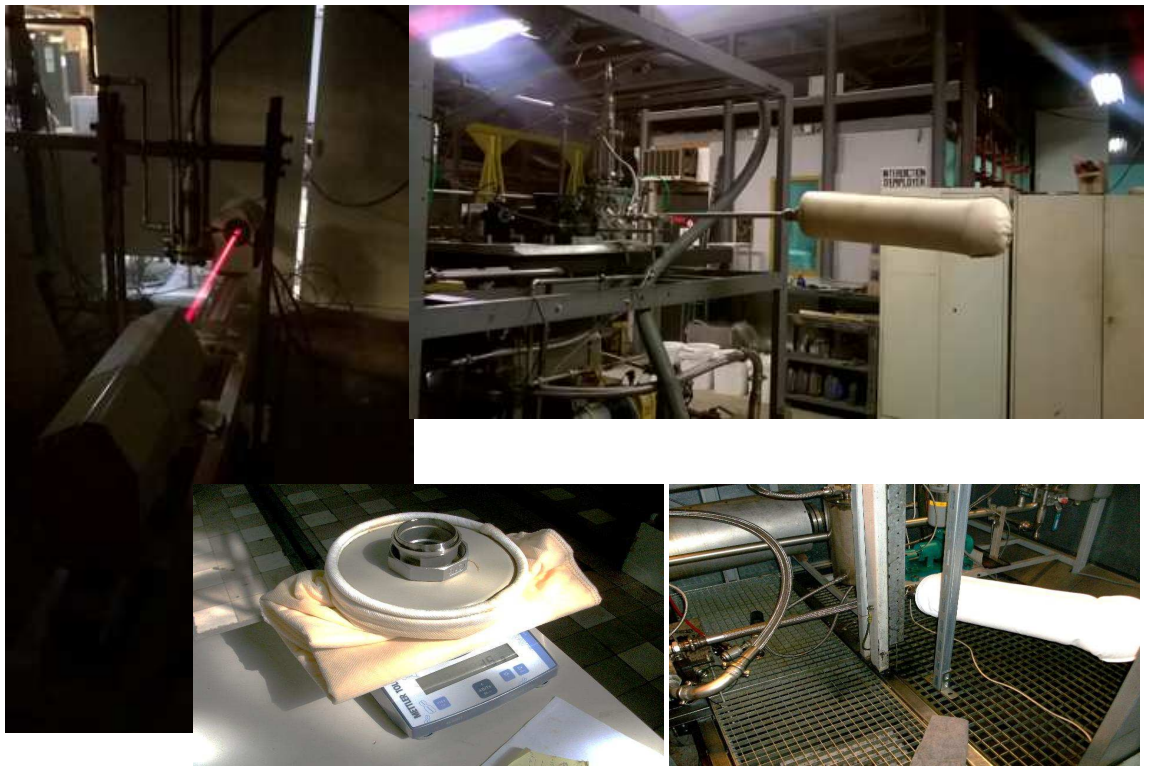
- Particle generation:
  - Impact injectors (BETE)
  - Air assisted injector (XAPR)
- Particle Measurement:
  - Laser Helos-Vario/KR

Oil consumption: Qualitative methodology

- Gravimetric analysis

Weighed Filter oil consumption measurements

$$Oil\ consumption = f(\frac{Oil\ mass\ collected}{Time})$$



Testing methodology

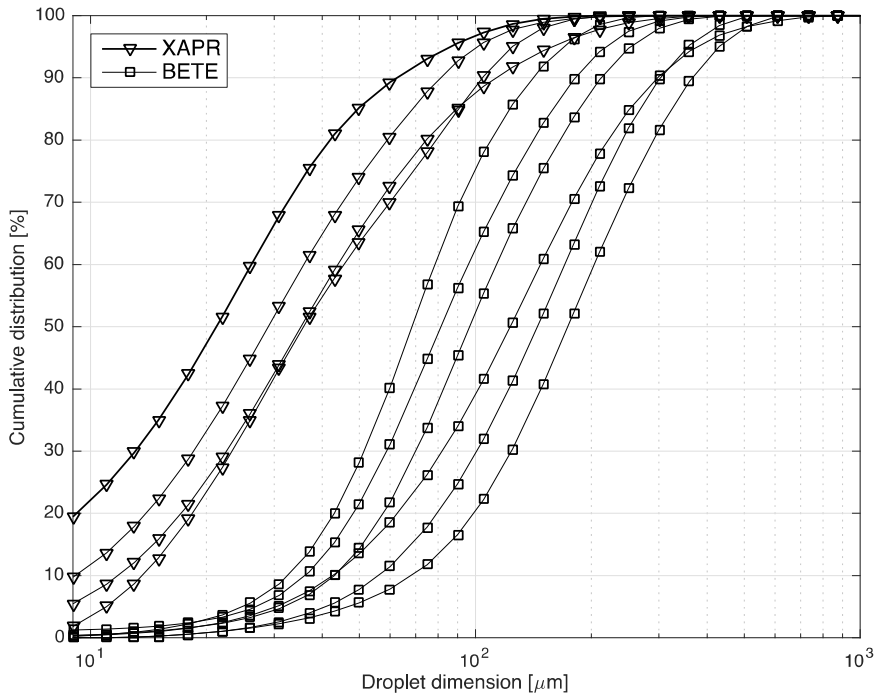
Performance analysis of different breather configurations

Performance criteria:

- Separation power
- Pressure losses

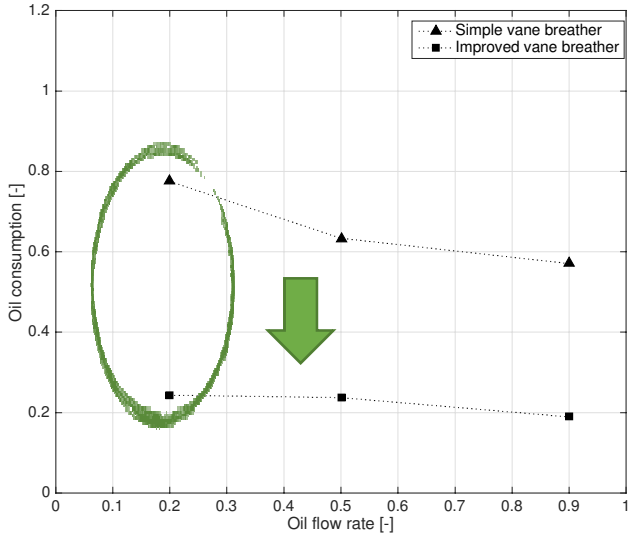
Impact on their performance of different parameters:

- Scavenge Air flow rate
- Oil flow rate
- Rotational speed
- Particle/droplet size



Results – Oil consumption

Lower air flow rate

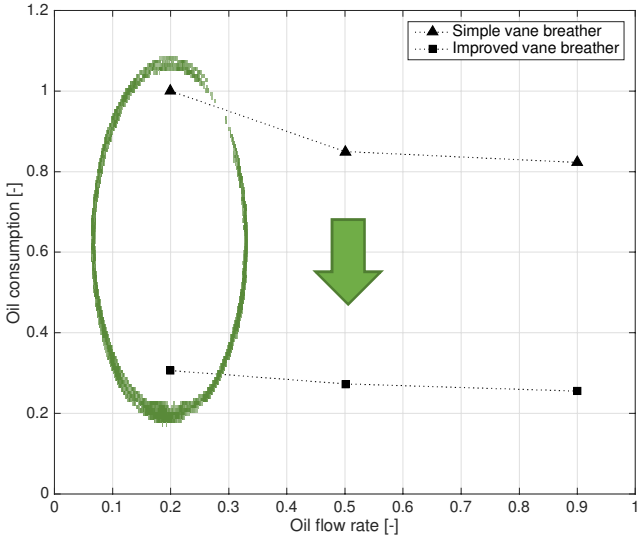


The improved vane shows a better separation efficiency

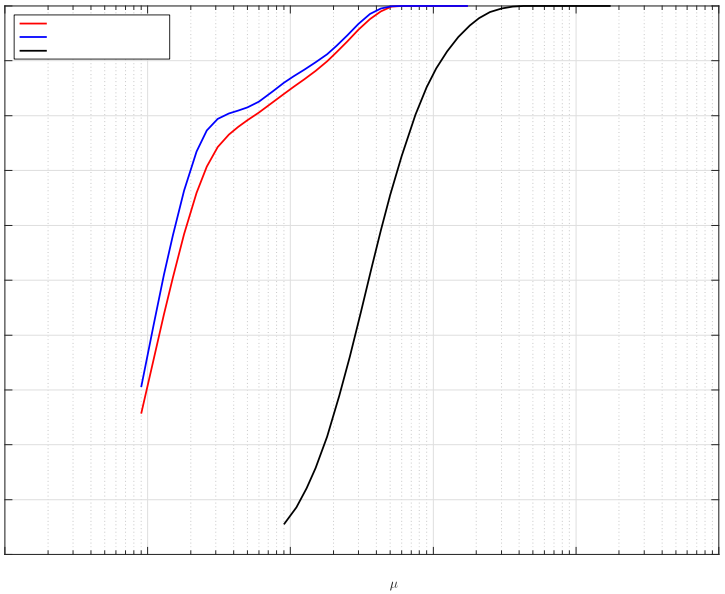
Lower oil flow rates lead to higher consumption due to the presence of smaller droplets.

Increase of air flow rate increases oil consumption

Higher air flow rate



Results – Oil consumption

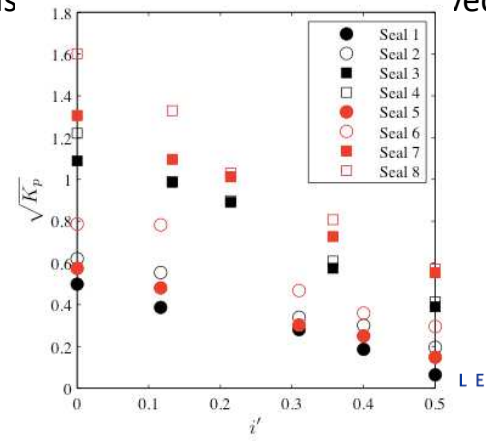


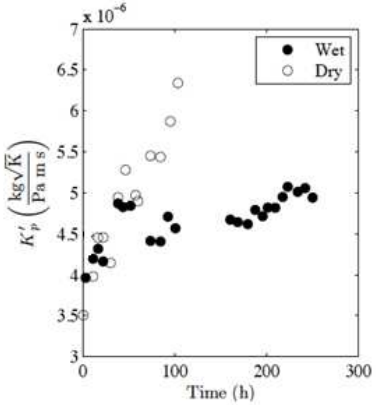
μ

Conclusions

Main achievements on brush seals

- Brush seal leakage performance and seal torque characterization in dry conditions and wet through 1-D empirical non-dimensional laws
- Demonstration of the suitability of carbon fibre brush seals to withstand bearing chambers working conditions
- Air consumption savings of up to 95% compared to labyrinth seals
- Negligible oil leakage after hundreds of hours of endurance testing
- Brush seal life reaches +/- 500 hours without oil, and 2000+ hours with oil
- Brush seal cas[illegible] ved very recently, therefore life expectancy is likely even higher.





Conclusions

Main achievements on breather performance study

- Separation efficiency and pressure losses of the different designs are affected by the working conditions
- Results show that oil consumption is mainly influenced by the droplet size: the smaller the droplets the higher the consumption. The droplets cut-off size changes in function of the geometry!
- Consumption is impacted as well by the rotational speed and air flow rate:

  The higher the rotational speed the lower the oil consumption.

  The higher the air flow rate the higher the oil consumption
- Pressure losses are impacted by the rotational speed and air flow rate, increasing rotational speed or air flow rate leads to higher pressure losses
- Tests results are coherent with the literature, thus, the test bench brings good behavior prediction on operational conditions

Cabin Air Quality Sensor

Aircraft Cabin Air Conference

January 2020

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*PURE*cabin Concept

CSI *– sensing and identifying the odor*

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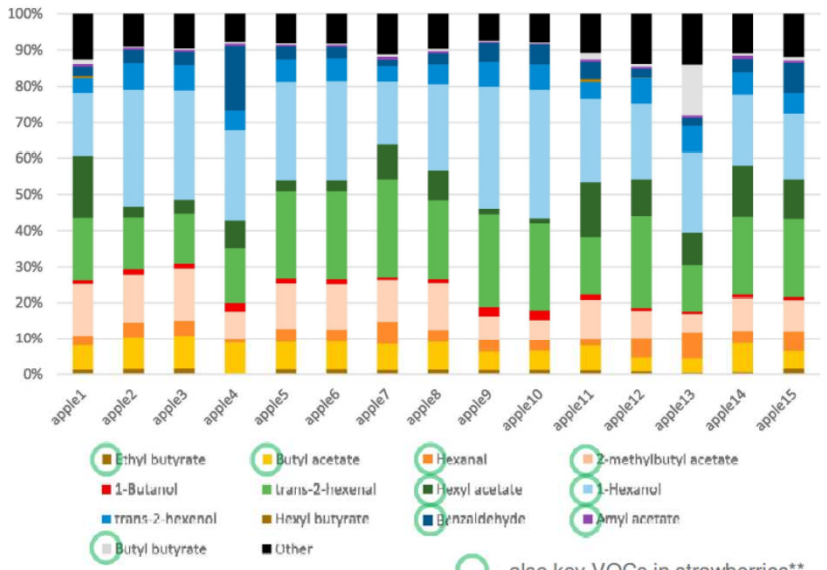
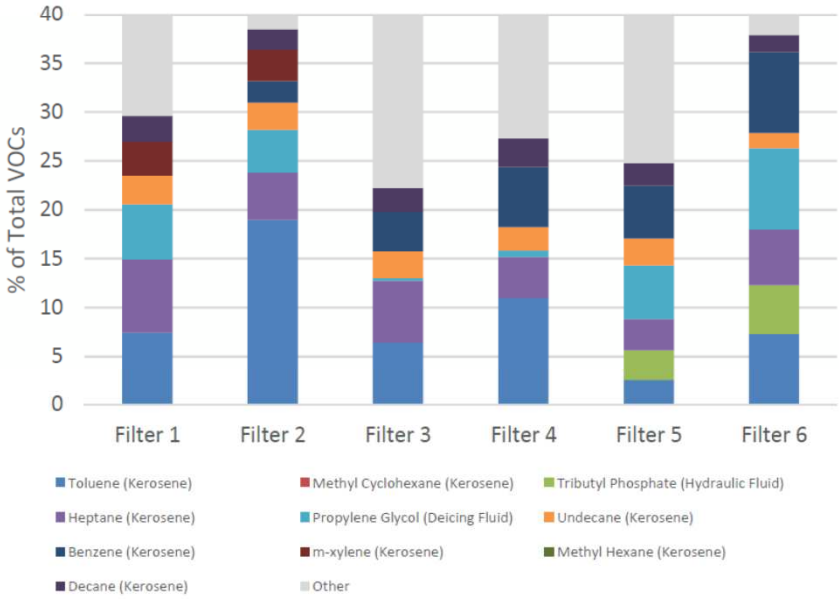
Identification: Smell vs. Marker Compounds

Odors are identified by concentration ratios

There are over 300 compounds in the smell of an apple…*



GCMS measured chemical concentrations desorbed from cockpit filter



*https://www.sciencedirect.com/science/article/pii/S030881461831923X#b0035; **https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3921181/

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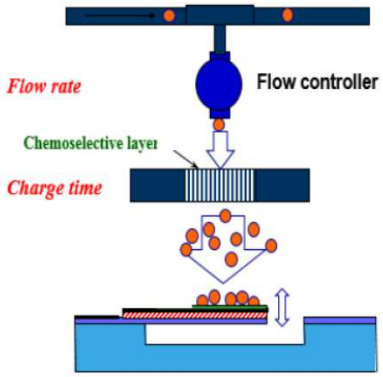
Technology



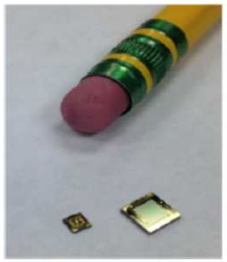
Signal magnitude is proportional to # molecules collected

Analyte in carrier gas

Preconcentrator collects analyte(s) of interest, and "flash desorbs" them when heated

Analyte is collected on resonator surface

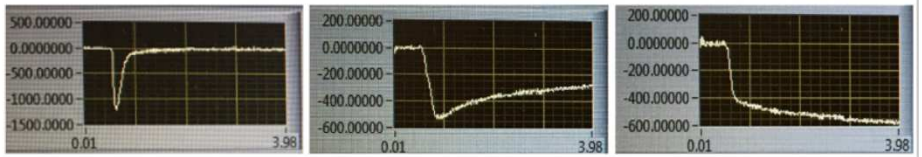
Concentration is determined from change in resonant frequency

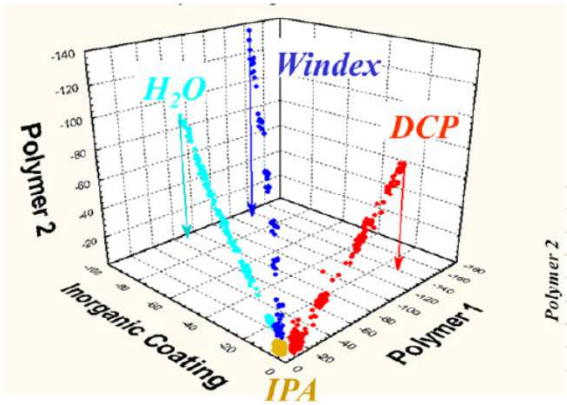


2.5 mg/m3
Deicing Fluid Type 1

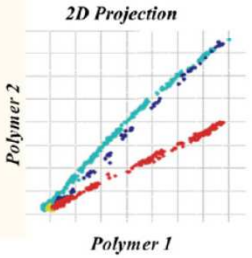
1.25 mg/m3
Mobil Jet Oil #2

7.5 mg/m3
Exxon Hijet





Maximum exposures:
DCP: 100 ppm
IPA 10% of saturation
Water: 60% RH
Windex: 50% Saturation



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Conditions and Qualities of Aircraft Fluid Contaminants

Quality	Mobil jet oil	Skydrol PE-5
flash point (°C)	270	160
fire point (°C)	285	177
autoignition temp (°C)	404	400

CONCENTRATIONS IN CABIN:

Total fluids
~1 to 10 mg/m^3

Markers
~ 1 to 50 µg/m^3

FORM IN CABIN AIR:

- → Mostly primary constituents (little is burned in bleed system)
- → Both aerosols and vapors due to low vapor pressures
- → Aerosols foul electronic noses and VOC sensors
- → Inlet filters (to protect against aerosols) generate residual false positive signals

Sensor must tolerate exposure to lube and hydraulic oils
→ fouling mitigation features required

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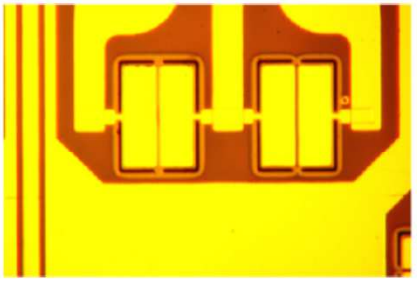
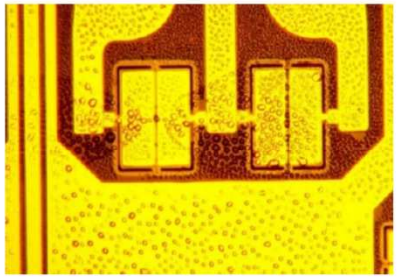
Managing the Environment: Trials Results

Oil Vapors & Ultrafine Particles (aerosols) can:

- Coat the surfaces of sensors
  - *Affect accuracy*
  - *Affect Life*
- 'Stick' to other surfaces
  - *Generate false positives*

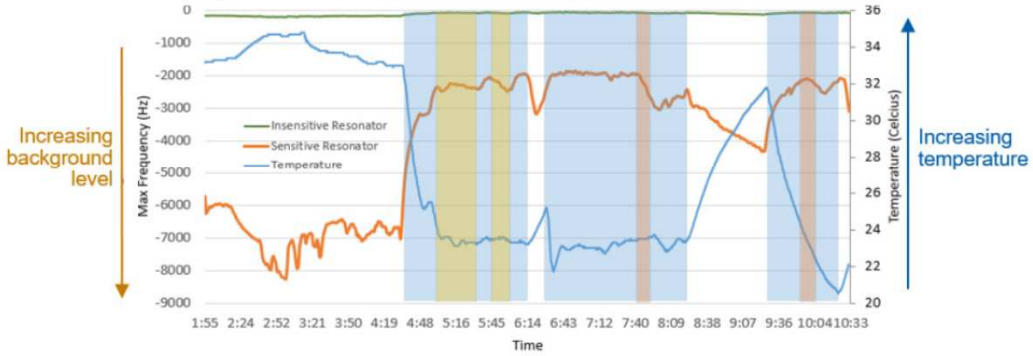




Aircraft background levels are variable and can generate false positives.

- *High background levels impacted by*
  - *Aircraft age*
  - *Temperature*
  - *ECS state*

Sampling from cabin: background level is strongly correlated with cabin temperature



White = APU off. Blue = APU on. Beige: simulated de-icing fluid contamination.
Pink #1: simulated new BP2389 contamination. Pink #2: simulated used BP2389 contamination.

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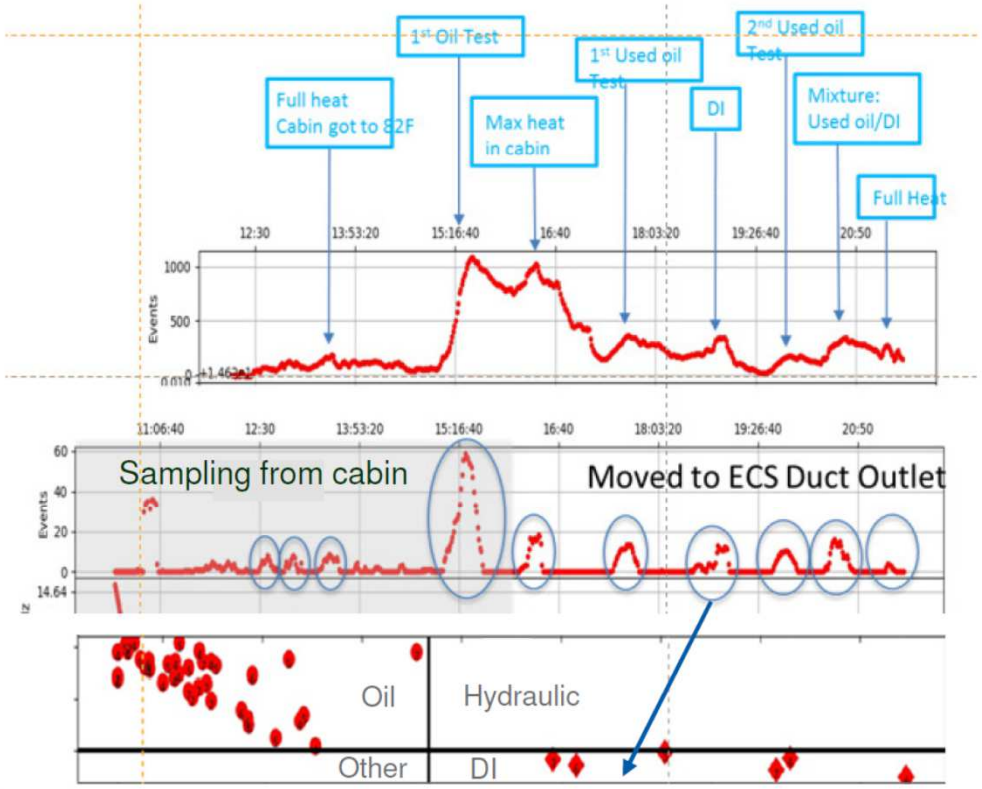
Sensor Design Validation Results



- Oil and de-icing fluid are injected into APU inlet and passed through the ECS
- Background levels are measured during the trial
- Event Detection Algorithm identifies increases in contaminant events
  - Performance improved when sampling from ECS duct
- Classification Matrix identifies the contaminant by fluid type
  - 100% Recognition Accuracy of injected challenges

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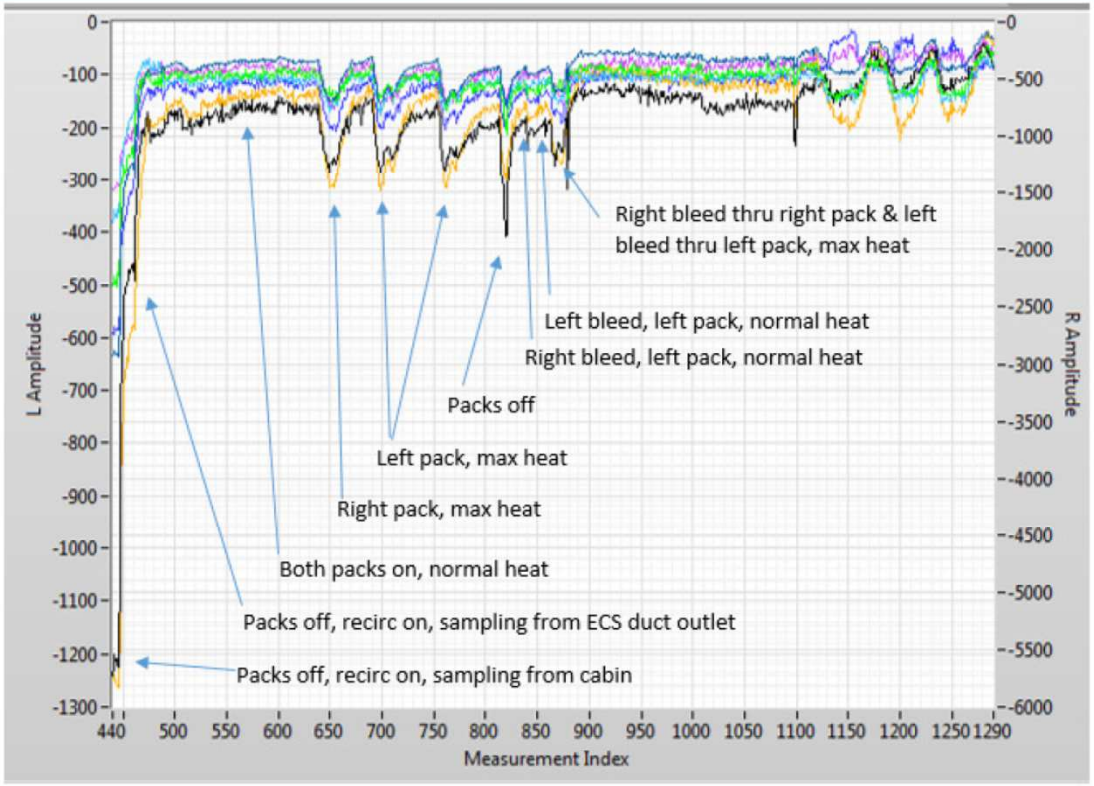
Aircraft Ground Bleed Air Test & Functional Flight Check

Increasing background level



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THANK YOU

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Filtration. Separation. Solution.SM

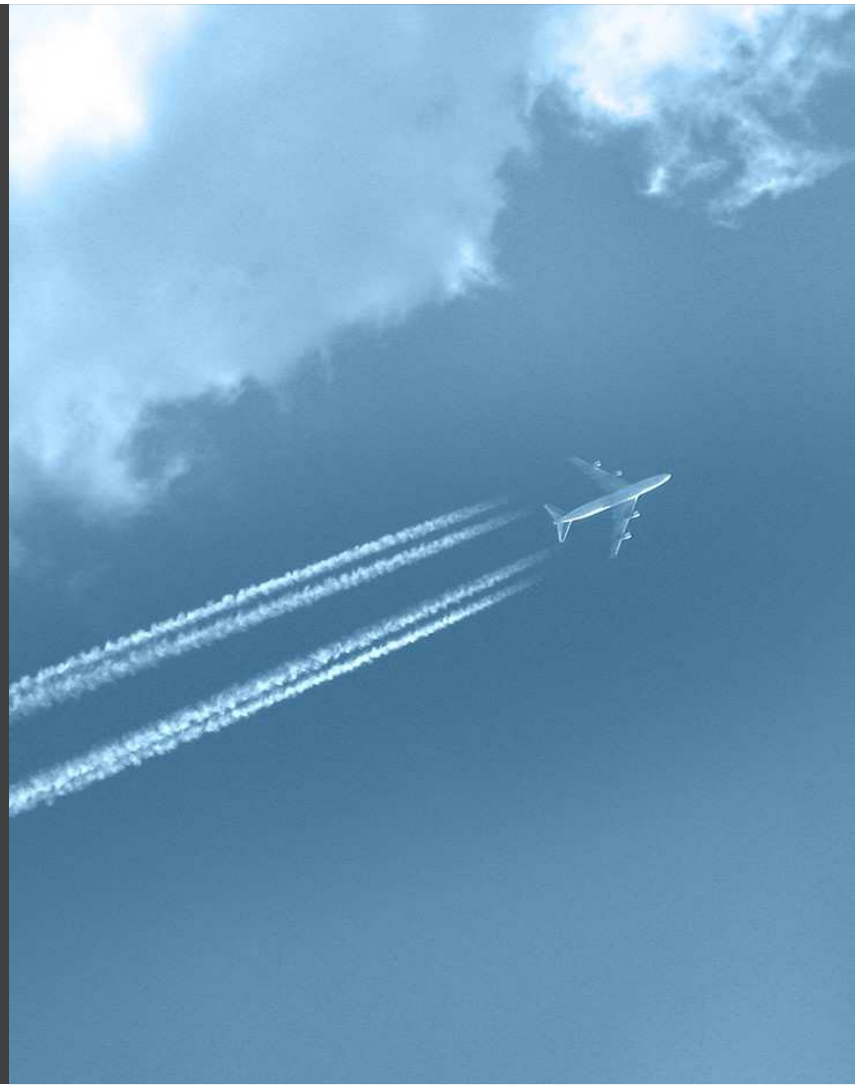
EASA WORKSHOP ON FUTURE CABIN AIR QUALITY RESEARCH

RISK MITIGATIONS

30TH - 31ST JANUARY 2020, COLOGNE

IAN KERR, RALF VON FRIELING

Honeywell



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Honeywell Connected Enterprise (HCE) was established in 2018 to accelerate software development and IIoT solutions. We focus on software development, from the gateway to end-user applications, bringing scale and capability across all of Honeywell. These new offerings are then commercialized through Honeywell's businesses.

Aligned to Key Global Macro Trends

HONEYWELL AEROSPACE

Business Portfolio:

- Electronic Solutions
- Engines and Power Systems
- Mechanical Systems and Components
- Connected Aerospace

Headquarters:

Phoenix, Arizona

$12.9B
2018 Sales

Technologies:

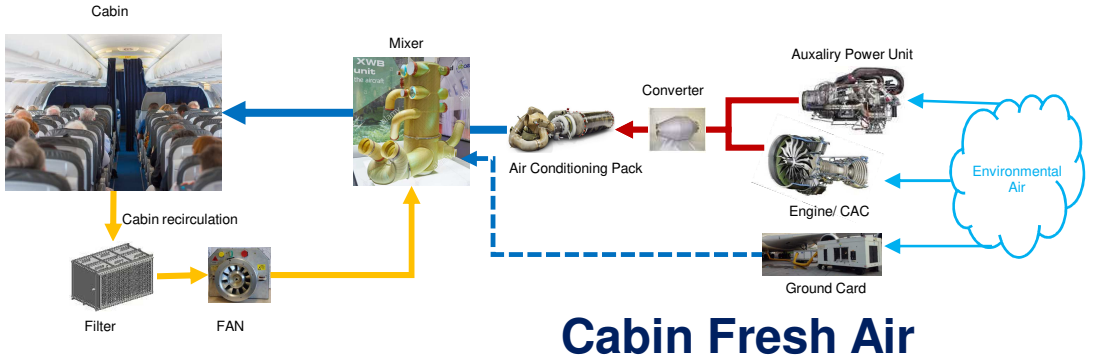
- **Air and Thermal Management**
- Connectivity Systems and Connected Aircraft Services
- Federal Solutions Management and Operation
- Hybrid Electric Systems
- Integrated Avionics Offerings and Flight Management Systems
- Manned/Unmanned and Satellite Applications/Space
- Mechanical Components
- Navigation, Safety, and Surveillance Solutions
- Propulsion and Power Systems
- Runway and Flight Safety Technology
- Wheels and Braking Systems

AIR QUALITY MANAGEMENT – TODAY

- **Cabin Fresh Air (bleed air)**
  - Potential contamination by environmental air pollution or in failure case by engine oil, hydraulic fluid or inporper de-icing procedure
  - Removal of contamination by converters

- **Cabin Recirculation Air**
  - Potential contamination by in-cabin operations, electronic failures, ...
  - Removal of contamination by particle/ gas filter

Cabin Recirculation Air



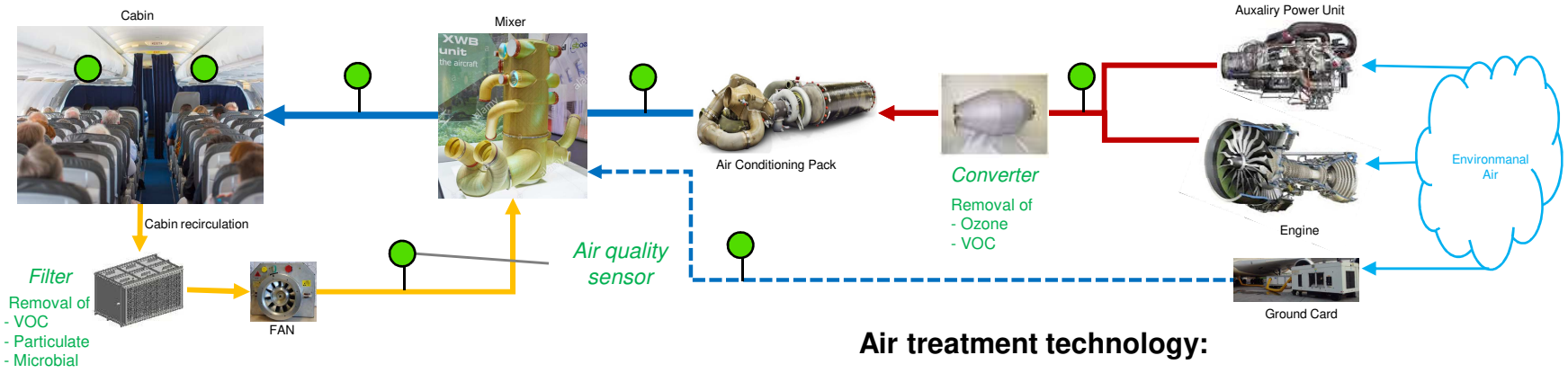
Cabin Fresh Air

Passive Air Contamination Treatment - No Monitoring

AIR QUALITY MANAGEMENT – GO FORWARD

Cabin Recirculation Air

Cabin Fresh Air



Introduction of Sensors to monitor Bleed and Cabin Air Quality:

- Detection of contamination events and source identification
- ➢ Continued monitoring of air quality and predective air management

Air treatment technology:

- Recirculation filter to remove dust, viruses and bacteria from cabin with capability to remove contaminants causing odor events
- Bleed air filtration by Combined Hydrocarbon and Ozone Converter (CHOC) to remove ozone and other airborne contaminants

Monitoring of Air Quality and Active Air Management

WHAT IS CLEAN AIR

Technologies to improve Air Quality are in place or under development and can be improved to meet expectations!

BUT - WHAT ARE THE EXPECATIONS? -

- **Air quality**
  - What is the dream clean air on aircraft for passenger, crew, airline, … and how clean is clean?
    - Like in the offices? At homes? In nature like on sea or in the forest? Or on ISS?
      - **Let's define it and "GO FOR IT"**

- **Technology**
  - Are the various contamination events sufficiently determined? Are there undefined events that needs to be mitigated?
    - Understanding of events and the potential impact on air quality is the prerequisite to develop or fine tune technologies to protect crew and passengers!
    - Mitigation of potential effects on air quality needs to start from the probable source of contamination, its avoidance, potential restrictions, detection and air treatment.

- **Requirements**
  - CEN TC436 is calling for bleed air sensors – but no baseline requirements are set - data not available for sensor developers
  - CEN TC436 is calling for supply air treatment – but no requirements are set – data not available for air treatment developers
  - Definition of prerequisites/ requirements to improve cabin ventilation certification prescribes fixed ventilation rates by Air Quality regulated ventilation
  - Database of airport environment data to plan precaution measure to prevent intake of contaminated air in polluted airports

DATA DRIVEN APPROACH REQUIRED TO GUIDE R&D/ FIELD SOLUTIONS

THANK YOU

Honeywell

EASA
European Union Aviation Safety Agency

End of “Future Cabin Air Research” Workshop Presentation Stream

Thank you

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