Aircraft Air Supply Contamination and Measurement Studies

Susan Michaelis PhD, MSc, ATPL University of Stirling/Michaelis Aviation Consulting BHR 25th Conference on Fluid Sealing Manchester 4-5 March, 2020





Who am I?

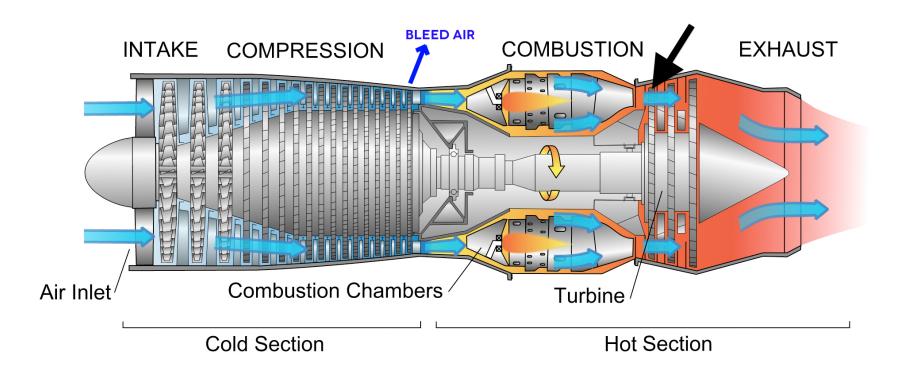




U UNIVERSITY of STIRLING



Jet engine and 'Bleed Air'







History

How far back does this issue go?

2000? 1970?





Synthetic engine oil Specifications

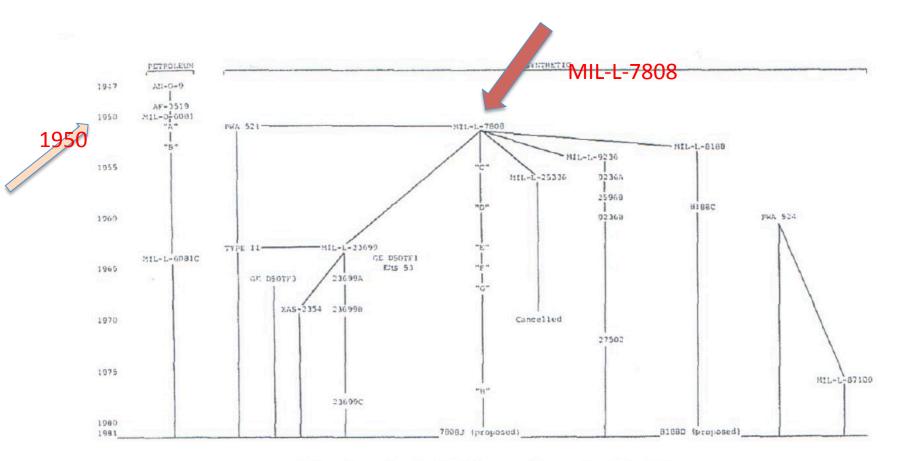


Fig. 2a - U. S. Military and commercial gas turbine engine lubricant specifications



Knipple, R, Thich, J- The history of aviation turbine lubricants, SAE 810851







1952/53 – J57 Engine



B-52 and the F-100 – Bleed Air

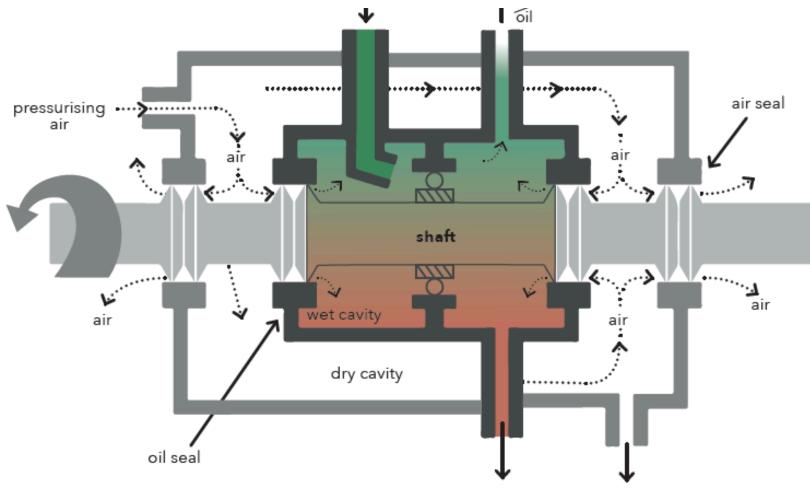


The J57 (JT3) Engine was the first Pratt & Whitney-designed turbojet.

Early use of MIL-L-7808 Synthetic oil Type I or 3 centistoke jet oils



Engine oil Bearing Chamber







How oil leaks within an engine





Mainz (German Television): Polluted Cabin Air. SWR, 2020-01-28 https://www.youtube.com/watch?v=jHGu83gC6V4&feature=youtu.be



Fume Event 1





Mainz (German Television): Polluted Cabin Air. SWR, 2020-01-28 https://www.youtube.com/watch?v=jHGu83gC6V4&feature=youtu.be



Oil drips & drips.....







Fume Event 2 – London-Valencia



Sky News- 6/8/19 https://news.sky.com/video/smoke-filled-plane-makes-emergency-landing-in-valencia-11778282





The outcome





BBC: 17/10/19 https://www.bbc.co.uk/news/business-50074402? fbclid=IwAR1WU32pIqX_XGM2OFtrn_LPSR2LQU_knDrN9wYto-Tpc_1m5JXDJFTOMRY



What was the cause?

✤ "it appears at this stage that the incident was caused by a failure of an engine bearing".

Despite the engine being replaced, two more fume events have been recorded on the same aircraft in the last two months.

26/10/19: The Telegraph https://www.telegraph.co.uk/news/2019/10/26/british-airways-plane-filled-smoke-has-had-two-fume-incidents/



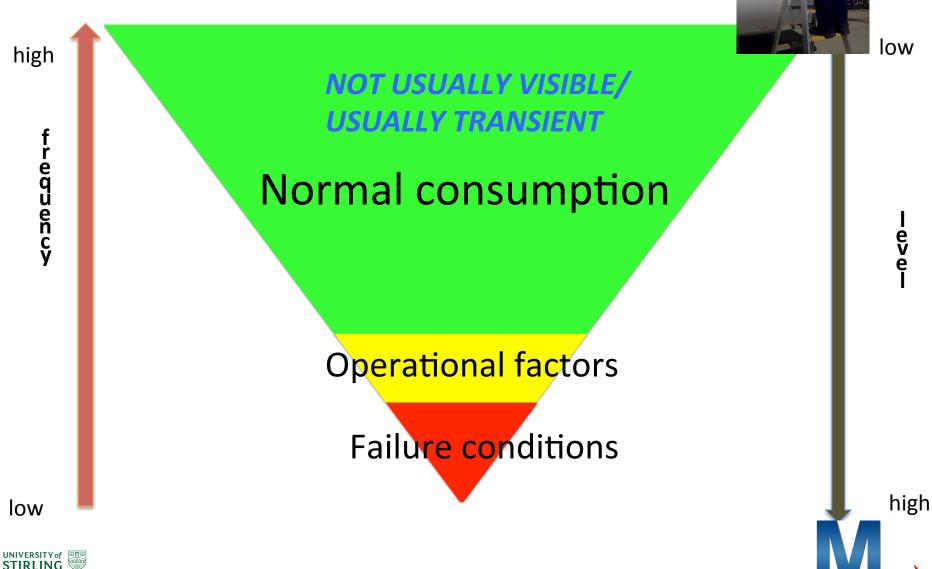
Why did the problem occur?

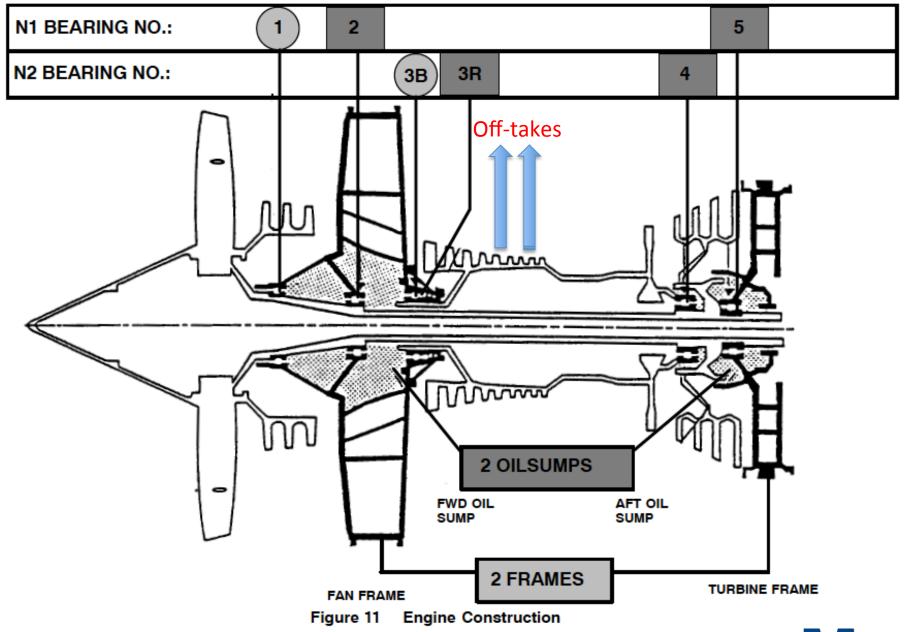
- More advanced engines (1950s) required synthetic engine oils
- Contamination coincided with synthetic oil use & use of bleed air
- Civilian aircraft did not use bleed air initially due to contamination concerns
- Bleed air then introduced on all aircraft except the new B787 Dreamliner
- Why bleed air?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





Oil consumption







Lufthansa (1999)https://www.metabunk.org/attachments/docslide-us_a-320-engine-pdf.16733



Normal oil consumption

Normal "permissible" oil consumption via:

- Breather/deoiler vent system
- past seals \rightarrow core airflow
- Oil leaks



Style of seal, balance ratio, Lubricating regime, operating conditions (speed, temp, pressures), component condition, wear life, distortion...

All dynamic seals are designed to leak





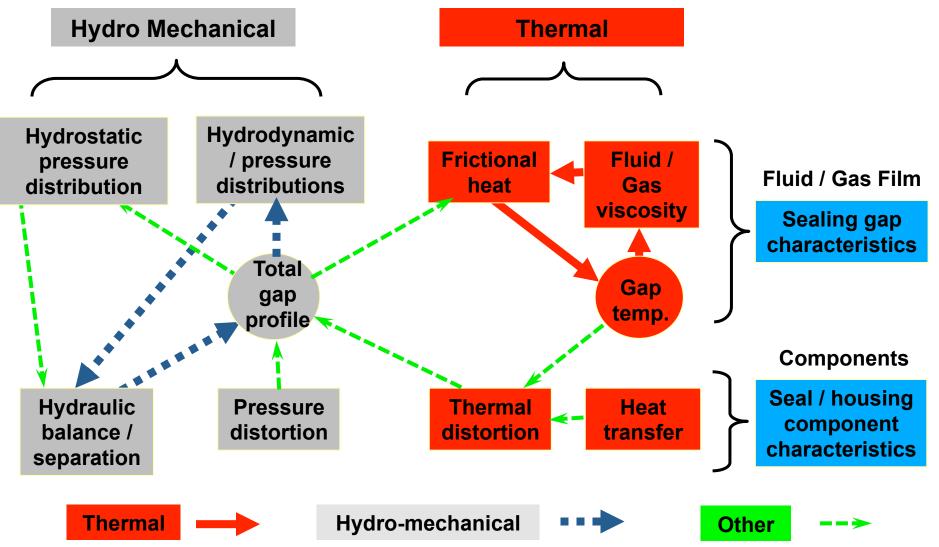




FACTORS AFFECTING SEALS



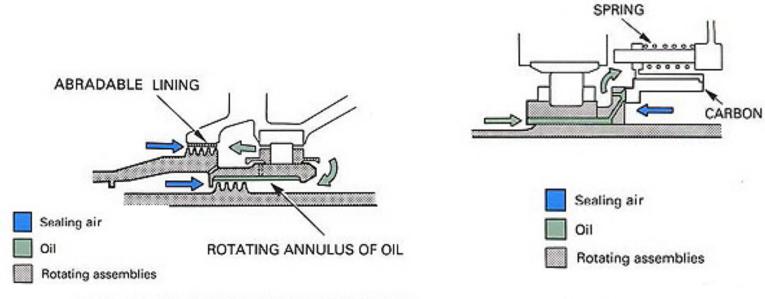
Seal leakage concepts



Typical seals

Labyrinth seal

Mechanical/ Carbon seal



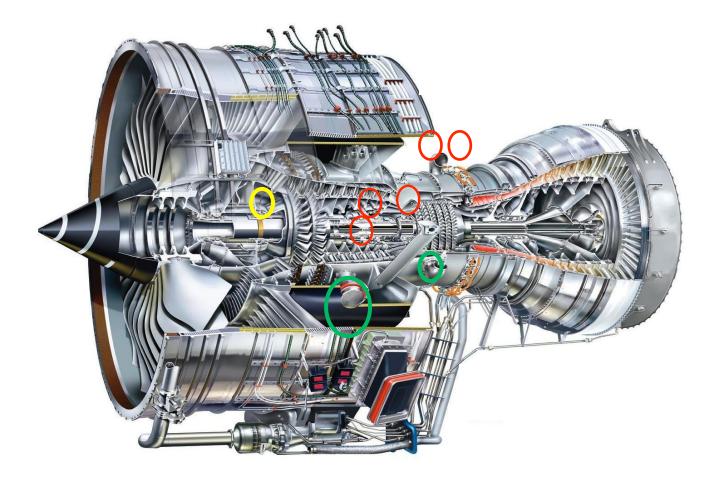
FLUID AND ABRADABLE LINED LABYRINTH SEAL







Seals and bearings / Air off-take











Oil leaks – 3 ways

- 1. Normal operations
- All dynamic seals leak very low levels (not absolute design)
 - Rely on pressurised air: seals have a clearance / lubricated surface
- Increased leakage:
 - Pressure changes (transients) \rightarrow Power air supply config changes
 - Thermal mechanical changes in engine
 - Low internal pressure e.g. start up, taxiing, descent
 - Oil hydrolysis (reaction with water) and thermal oxidation → release of carboxylic acids which <u>can escape</u> from oil system (associated with strong odour "dirty sock")
- 2. Operational: e.g. wearing seal; oil overfill
- 3. Failure conditions: bearing seal failure or component...





Misconceptions about oil leakage

- Higher pressure in gas path than inside bearing chamber – Keeps oil in bearing chamber ×
- 2. Seals only leak when failure occurs ×
- 3. Reverse pressures to be avoided prevents leakage ×

Sealing bearing chambers at near ambient pressure is difficult – Chupp 2006 NASA/TM—2006-214341



Recognition of oil leakage in 'normal' conditions



Oil replenishment ('top up') maintains oil additives (Johnson 2018)

→ Oils designed to work in engine, limiting exposure (ExxonMobil, 2018)

Bleed system pressure fluctuations cause bearing seals to leak allowing oil to migrate into the cabin bleed air (ExxonMobil, 2018)

* "Shaft seals- must function as SEALS - NOT flow restrictors" (Bill, 1991)

→ "A zero seal leakage is an oxymoron" – (Chupp, 2006)

✤ Most engines might have a certain low level turbine oil leak rate (permanent oil entries) - (EASA 2017)





Differing viewpoints

- Low level oil leakage occurs in normal ops
- It is a controlled flow not a leakage
- Leakage only occurs during failure conditions
- In a normally operating engine, the seals should not leak but this does not include transient & low power conditions.
- Leakage over seals during transients would be a design failure





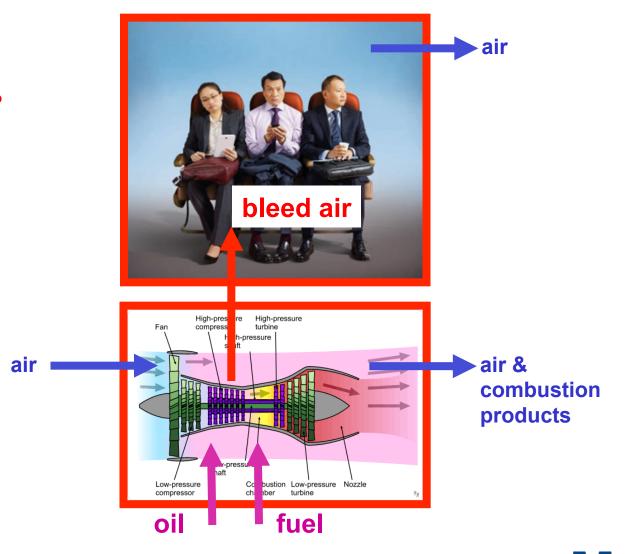
RR – Edge & Squires - 1969

Evaporation loss of oil "constitutes only a minor part of the oil onsumption in Rolls-Royce gas turbines, the major part of the consumption representing loss of liquid oil arising from permissible leakage past certain seals, escape of mist or aerosol through breathers" and losses incurred during inspections. These are made good by 'topping up' the system with fresh oil"



Aircraft cabin air and engine oil

How much Oil Gets into the Cabin?





Dieter Scholz, Aircraft Design and Systems Group (AERO), HAW University, Hamburg

Is this really happening?

Measurements

- Bleed air duct sampling
- Cabin and bleed air air monitoring
- Ultrafine particle sampling
- Swab sampling of cabin surfaces





Air supply ducting





Figure 4: Used aircraft air supply ducting [7].

Figure 3: Unused air supply ducting



VOC measurements

Appx A: Aircraft cabin & bleed air monitoring data

Study	Year	Country	Compound (CAS	Level Cor	nment
FOX (PhD)	2012	US	Acetaldehyde	75-07-0	51ppb	
Nagda/ASHRAE	2001	US	Acetaldehyde	75-07-0	70.2ug/m3	
Rosenberger	2018	Germany	Acetaldehyde	75-07-0	9ug/m3	
Rosenberger	2018	Germany	Acetaldehyde	75-07-0	234ug/m3	Deicing but no F/event
Spengler/Battelle/ACER/ ASHRAE	2012		Acetaldehyde	75-07-0	75.79 ug/m3	
Weisel	2017	US	Acetaldehyde	75-07-0	20ppb	
Fox/Ansett	2000	Australia	Acetaldehyde	75-07-0	26ug/m3	
Honeywell- SDRE	2000	Sweden	Acetaldehyde	75-07-0	91ug/m3	
EASA CAQ	2017	EU	Acetaldehyde	75-07-0	42ug/m3	
Fox/Malmo Engine test	1999	Sweden	Acetaldehyde (Ethanal / Acetaldehyde)	75-07-0	61.5ug/m3	
Rosenberger	2015	Germany	Acetaldehyde /acetylaldehyde	75-07-0	52ug/m3	
Rosenberger	2015	Germany	Acetaldehyde /acetylaldehyde	75-07-0	90ug/m3	
Rosenberger	2014	Germany	Acetaldehyde /acetylaldehyde	75-07-0	52 ug/m3	
Space	2017	US	Acetaldehyde /acetylaldehyde	75-07-0	225ppb	





Appx B: Aircraft cabin and bleed air monitoring data air compared to threshold limits

SUBSTANCE	CAS	STUDY	YEAR	MAX LEVEL	OEL UK-8 HRS	OEL UK-ST	OSHA- USA 8	IOSHA-USA- ST	GERMANY/DFG 8 HRS	GERMANY DFG- ST
Legend		No limits available								
1-butanol	71-36-3	EASA CAQ	2017	0.0315mg/m3	n/a	154mg/m3	300mg/m3	n/a	310 mg/m3	310 mg/m3
1-Butene	106-98-9	Fox/Malmo Engine test (engine generated	1999	0.0032mg/m3						
1-chioro-1-fluoroethane	1615-75-4	Fox/Ansett	2000	0.005mg/m3						
1-dichloromethyl-2,6- difluorobenzene	;	Fox/Ansett	2000	0.02mg/m3						
1-Methoxy-2-propylacetate	108-65-6	EASA CAQ	2017	0.0097mg/m3	274mg/m3	548mg/m3	n/a	n/a	270mg/m3	270mg/m3
1-Propanol	71-23-8	EASA CAQ	2017	1.524mg/m3	500 mg/m3	625mg/m3	500 mg/m3	n/a	n/a	n/a
1,1-Dichloroethene (vinylidene chloride)	75-35-4	ASHRAE/Battelle	2004	0.0002ppm	10ppm	n/a			2ррт	4ppm
1,1-Dipropane-1,2-diol ether	;	EASA CAQ	2017	0.124mg/m3						





Appx C: Oil pyrolysis studies

TNO/KLM/ASHRAE2013decanoic acidTNO/KLM/ASHRAE2013pentadecaneTNO/KLM/ASHRAE2013TBPTNO/KLM/ASHRAE2014triphenyl phosphateTNO/KLM/ASHRAE2014di-cresyldiphenyl phosphateTNO/KLM/ASHRAE2014TCP (meta)TNO/KLM/ASHRAE2014TCP (meta)TNO/KLM/ASHRAE2014TCP (m,m,p)TNO/KLM/ASHRAE2014TCP (m,n,p)TNO/KLM/ASHRAE2014TCP (m,p,p)TNO/KLM/ASHRAE2014TCP (Para)EASA2017Tris(2-butoxyethyl)phosphateEASA2017Triethyl phosphateEASA2017Triethyl phosphateEASA2017Cresyl diphenyl phosphateEASA2017Cresyl diphenyl phosphateEASA2017Di-cresyl phenyl phosphateEASA2017Di-cresyl phenyl phosphateEASA2017Di-cresyl phenyl phosphateEASA2017TCP (meta)EASA2017TCP (meta)EASA2017TCP (meta)		•	
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	EASA	2017	Di-cresyl phenyl phosphate
EASA 2017 TCP (mmn)	EASA	2017	TCP (meta)
	EASA	2017	TCP (mmp)





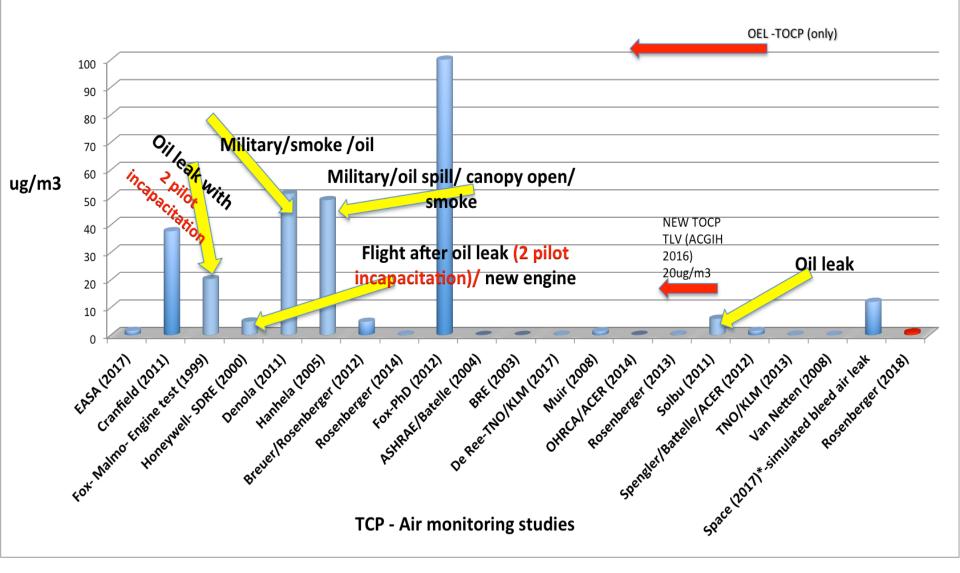
Appx D: Air monitoring studies: TCP

Study	Year	Country/region	Chemical	CAS	Level	Level -ug/m3-	- Al Notes
CRANFIELD	2011	UK	Tricresyl phosphate (mixed isomers- excl TOCP)	1330-78-5	28.5 μg m3	28.5	
Denola	2011	Australia	Tricresyl phosphate - avg	1330-78-5	<5 µg/m3	<5	
Denola	2011	Australia	Tricresyl phosphate - max	1330-78-5	51.3 μg / m3	51.3	Military - visual smoke
FOX (PhD)	2012	US	Tricresyl phosphate - non TOCP isomers	1330-78-5	6.8ppb	100	
CRANFIELD	2011	UK	Tricresyl phosphate - Total TCP	1330-78-5	37.7 µg m3	37.7	fumes reported in 38% of flights 26% oil smell/ 4% reported symptoms
ASHRAE/Batelle	2004	US	Tricresyl phosphate -TCP	1330-78-5	ND	ND	
BRE	2003	UK	Tricresyl phosphate -TCP	1330-78-5	ND <130 ug/m3	ND <130	Descent/trace amt present
de Ree- KLM/TNC	2017	Holland	Tricresyl phosphate -TCP	1330-78-5	155 ng/m3	0.155	
							sampling in FD in flight- engine start to TOC
de Ree- KLM/TNC	2017	Holland	Tricresyl phosphate -TCP	1330-78-5	17ng/m3	0.017	sampling in FD in flight- cruise
de Ree- KLM/TNC	2017	Holland	Tricresyl phosphate -TCP	1330-78-5	66 ng/m3	0.066	sampling in FD in flight- TOD- shutdown





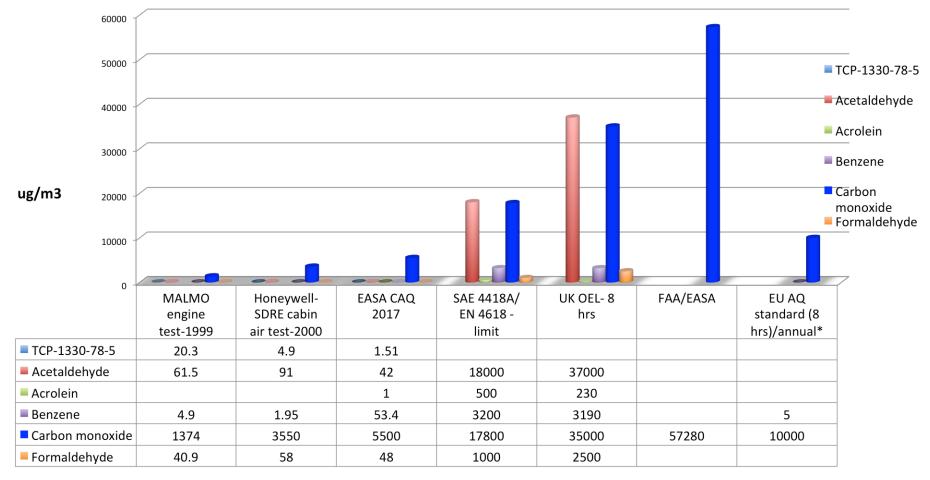
TCP- mixed isomers or meta & para isomers: CAS 1330-78-5.....







2 pilot incapacitation incident V threshold limits



Substance





Results

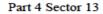
- 38+ cabin and bleed air studies
- >279 VOCs and other substances
- Levels found are far below OELs/TLVs
- ✤ 100+ substances consistent with oil pyrolysis

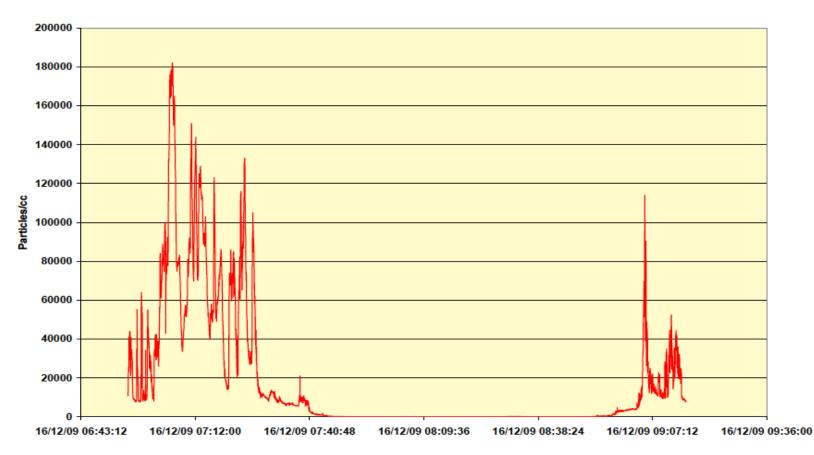
→ EASA (2017) – Permanent Low level oil leakage





UFP:Cranfield, 2011

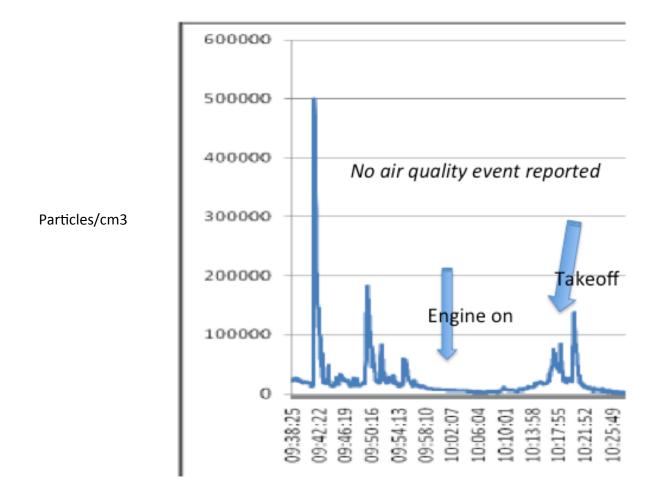








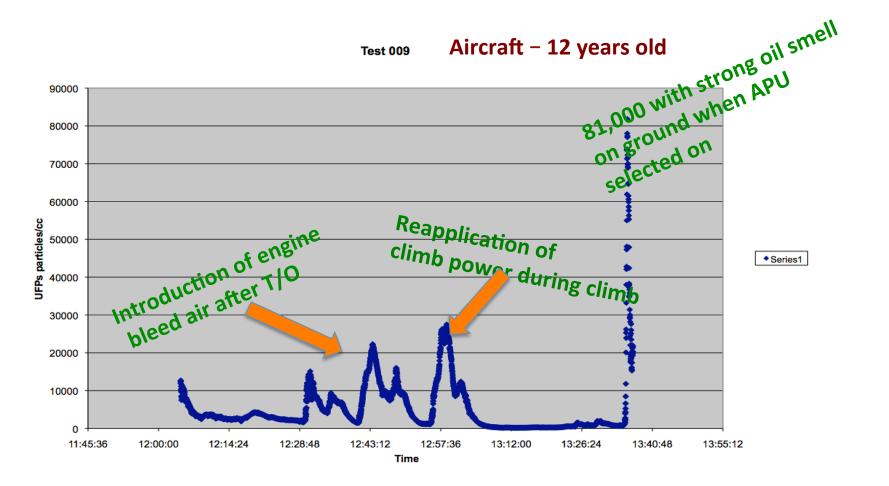
UFP:Cranfield, 2011







GCAQE – Flight 3







Compared to other locations

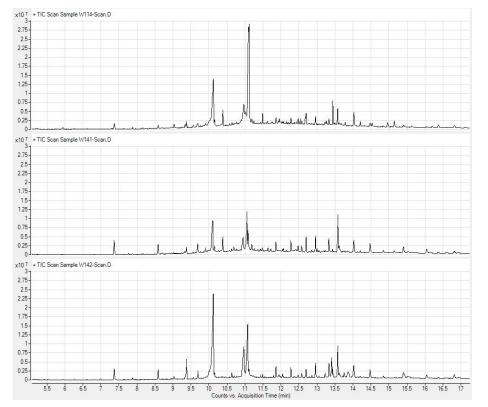
LOCATION	AVREAGE LEVELS RECORDED: Particles/CM3
Beach- beside water- English channel	2428
Train compartment – moving train	3242
Household kitchen – Not cooking	3661
Street outside Victoria station, London	24428







Swab samples Airbus A380



Regulator response

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



Positive for tricresyl phosphate and/or tributyl phosphate



GCAQE presentation for EASA workshop 30/31 January, 2020



What are the implications?

Health and safety

- →Safety
- Regulatory

→Health





Regulatory

- Certification process is insufficient to ensure to ensure breathing air (bleed air) will not lead to impaired crew efficiency / degraded performance / adverse effects to occupants. There is a gap between the bleed air system regulatory process and the supply of clean air in aircraft. - NOT AIRWORTHY! (Michaelis, 2016)
- Focus on <u>failure</u> conditions





oils

SAFETY DATA SHEET

PRODUCT AND COMPANY IDENTIFICATION

SECTION 1

Name: MOBIL JET OIL II

Product Name: MOBIL JET OIL II Product Description: Synthetic Esters and Additives Product Code: 201550101020, 430207-00, 970570 Intended Use: Aviation lubricating oil, Turbine oil

Mobil Jet Oil II

✤ May cause damage to organs through prolonged or repeated exposure. (Blood, Kidney); suspected to damage fertility;

Symptoms of acute exposure to decomposition products: <u>headache; nausea; eye nose &</u> <u>throat irritation;</u>

Not expected under normal conditions of use. (engine)

Synthetic Lubricant Oil Statistication of the performance Capabia Peri

Eastman 2197

Do not breathe mist or vapor from heated material;

✤Inhalation of thermal decomposition products may lead to <u>adverse</u> <u>effects</u>;





EU/UN Hazard Classifications (CLP /REACH) Oil, hydraulic, deicing fluids: HAZARDS

Harmful if swallowed/dermal:	Eye/skin irritant & ? Respiratory irritant	
May (suspected) cause damage fertility or harm the unborn child	Skin sensitizer	
Single exposure & repeated target organ toxicity - nervous system	Very toxic by inhalation	
May cause genetic defects	May cause allergy/asthma or breathing difficulties if inhaled	
May (Suspected) of causing cancer	May cause drowsiness or dizziness	

TXP – Substance of Very High Concern (SVHC) – REACH

May cause harm to the unborn/Impair fertility





United Nation

Oils are hazardous

→ "Jet oils do not pose a hazard when used as intended... Mobil jet oils are intended to be used in the lubrication of engine oil systems" - (ExxonMobil 2018)

"We do not believe that Mobil jet turbine oils pose any significant toxicological risk to individuals <u>accidentally</u> exposed to aerosols or vapors in aircraft cabins. Such exposures are not what we would refer to as "normal use" (Mobil, Australian Senate Inquiry, 1999/2000)

"Ortho –TCP is a known hazard; but <u>exposure is controlled.</u>" - (ExxonMobil 2018)

✤ "Oil leaking from an engine entering the customer off-take is "classified as HAZARDOUS"" (Rolls Royce 2003)

"Oil vapors and coking smells are obnoxious at best and health hazards at worst to the customer" (NASA, 1995)





HEALTH

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

New occupational disease?

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D, ATPL1; J. Burdon MBBS, MD, FRACP2; CV Howard MB. ChB. PhD. FRCPath





Flight Safety

Oil: Do not breathe heated vapour/mist Mostly fumes



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





https://www.local10.com/news/local/fort-lauderdale/sick-people-on-flight-fll? fbclid=IwAR15B0pni9rxu7BTh-Ggl4ZBR_V1b2cm9uptNGdc14_NflunTTvA4-un_nU



Safety - London to Nice



Regulation - Impairment not > 1 per 100,000 flight hours

➔ e.g. London to Nice - 2 hours

Regulatory approach: impaired efficiency/degraded performance should not be occurring > 1 in 50,000 London to Nice flights.

Reality ?







Where to next?

Future designs should be bleed-free;

✤ Air cleaning technology (filtration, catalytic convertors) to be provided for supply air (bleed and non bleed aircraft);

Sensors to be fitted;

Better designs: seals, improved oil reservoir, other design features;

Improved clean air regulations/standards & compliance;

Understanding low-level oil leakage occurs in normal operations, not just failure scenarios;

Better procedures, training, education: crew, maintenance & management;

Frequency seen in terms of <u>design</u>, NOT reporting.





Thank you

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