Aircraft Air Supply Contamination and Measurement Studies

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BHR 25th Conference on Fluid Sealing
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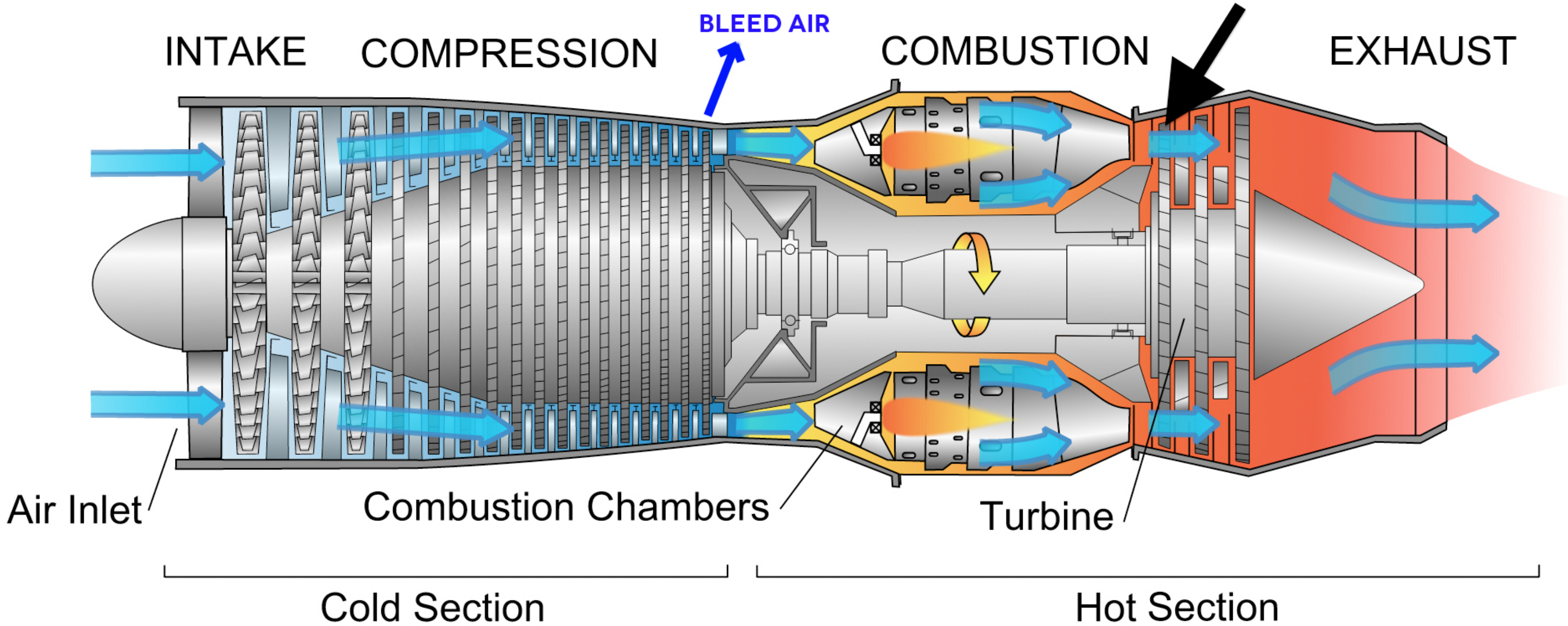
Who am I?

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

Jet engine and 'Bleed Air'



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History

How far back does this issue go?

2000? 1970?

Synthetic engine oil Specifications

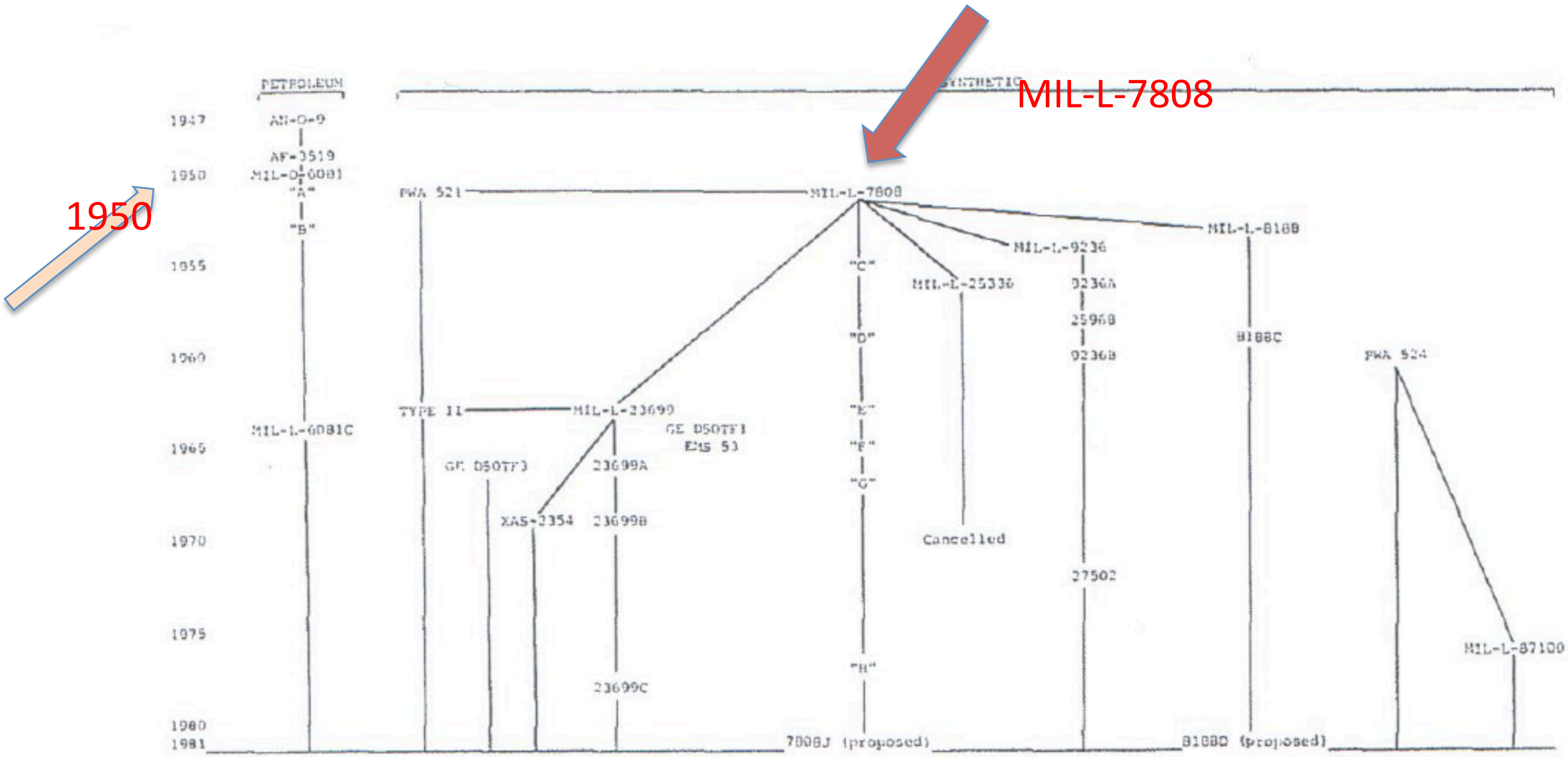


Fig. 2a - U. S. Military and commercial gas turbine engine lubricant specifications

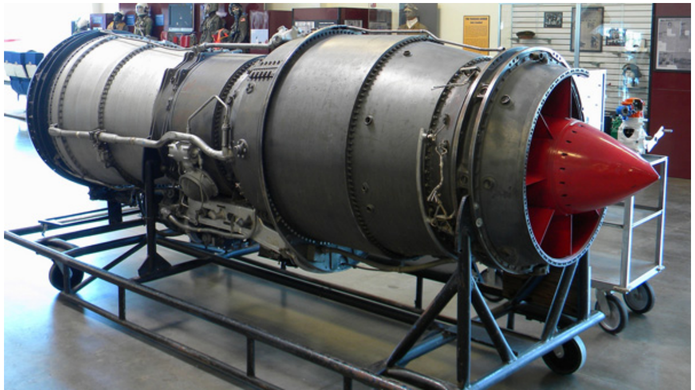
Knipple, R, Thich, J- The history of aviation turbine lubricants, SAE 810851

1952/53 – J57 Engine

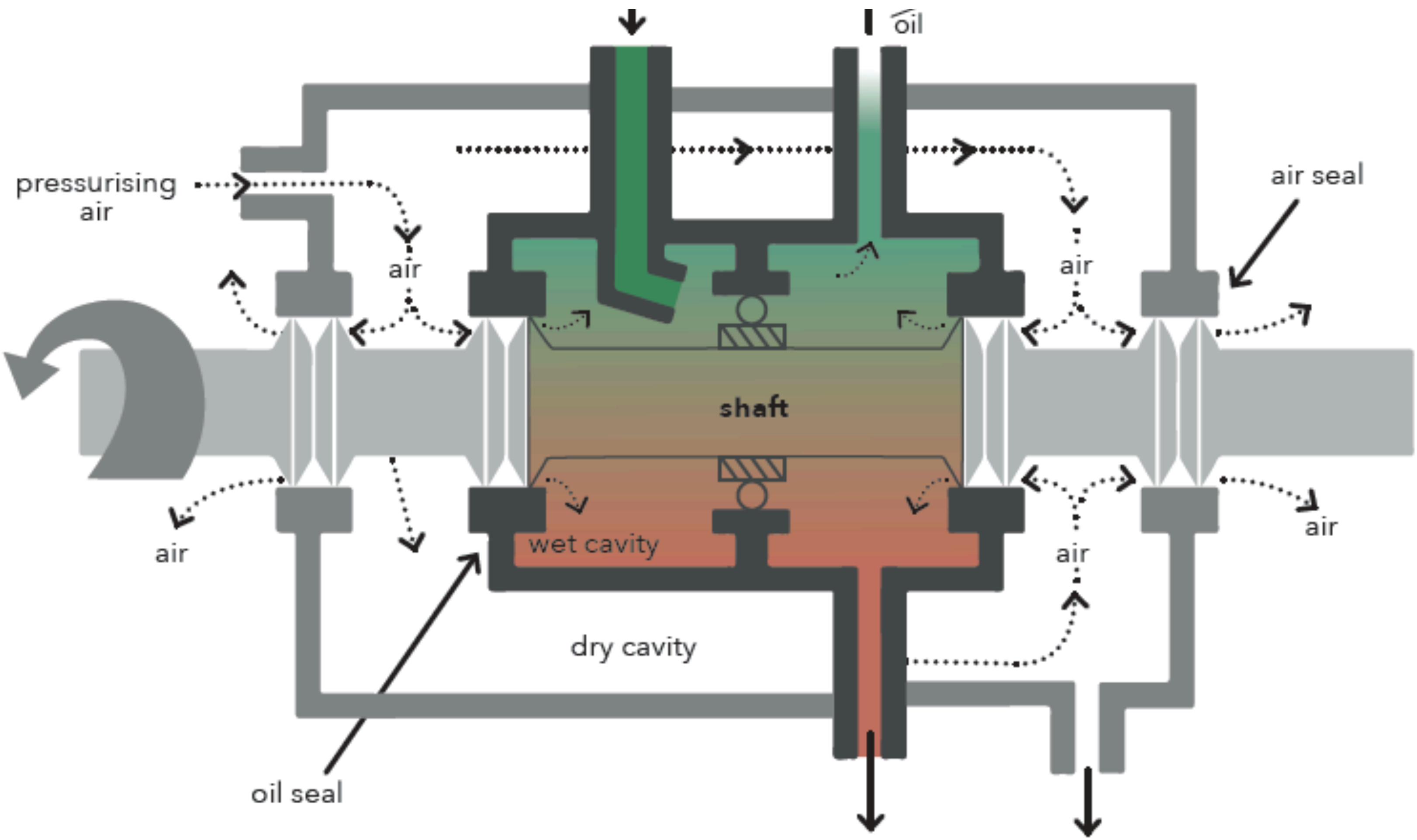
B-52 and the F-100 – Bleed Air

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



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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

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

Oil drips & drips…..

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Fume Event 2 – London-Valencia

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

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The outcome

BBC: 17/10/19
https://www.bbc.co.uk/news/business-50074402?fbclid=IwAR1WU32plqX_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

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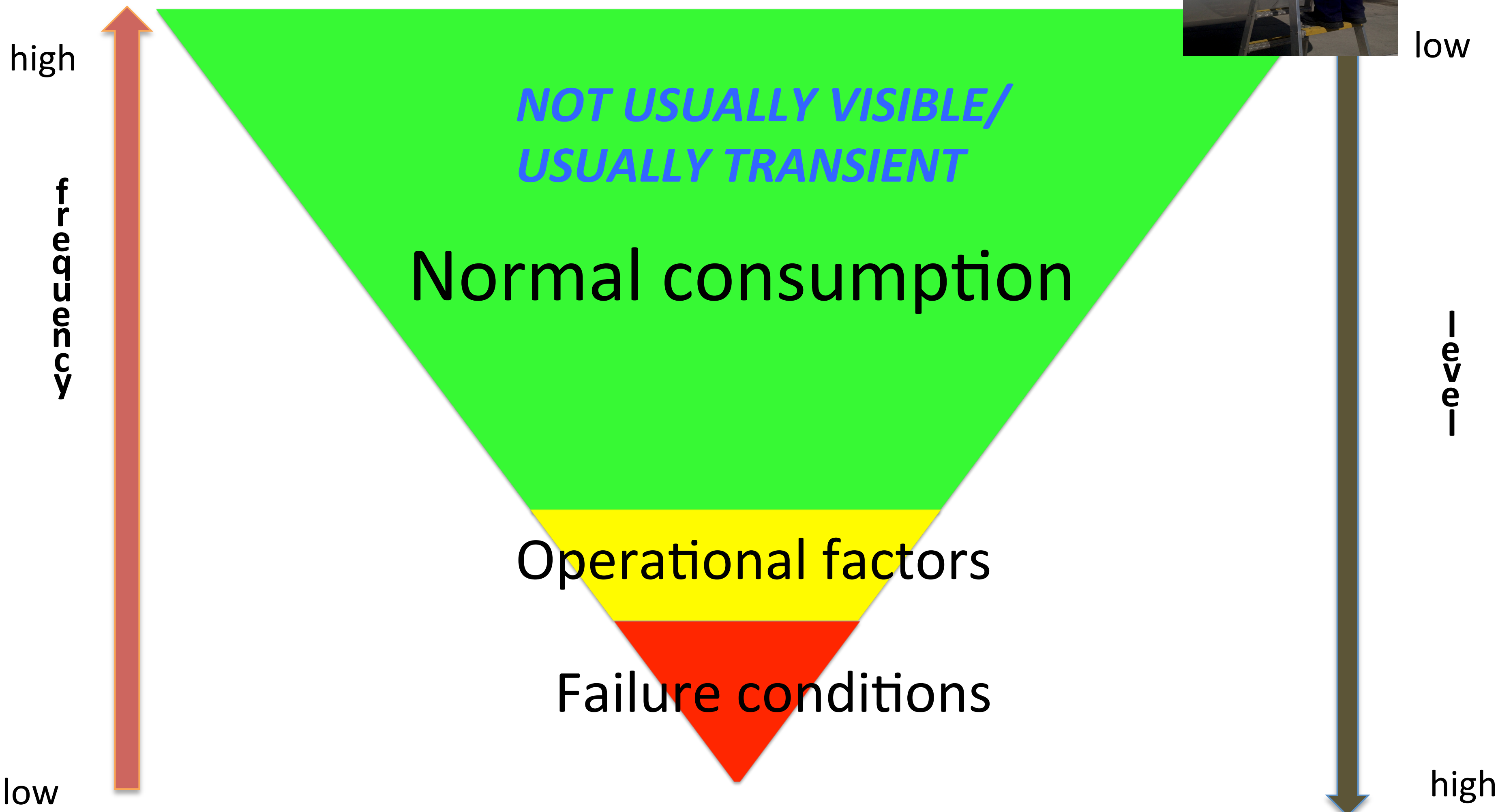
Oil consumption



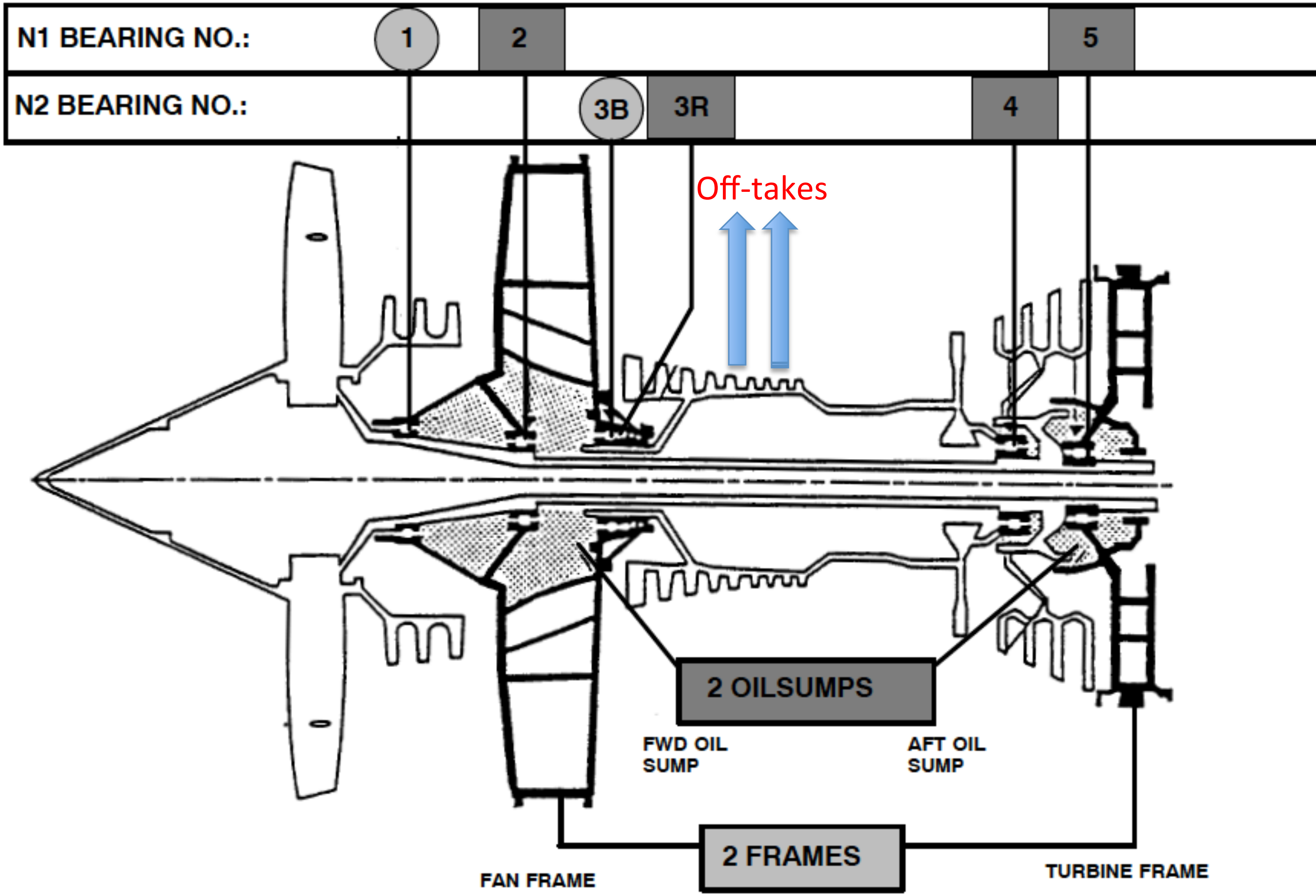


Figure 11 Engine Construction

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 → core airflow
  - Oil leaks

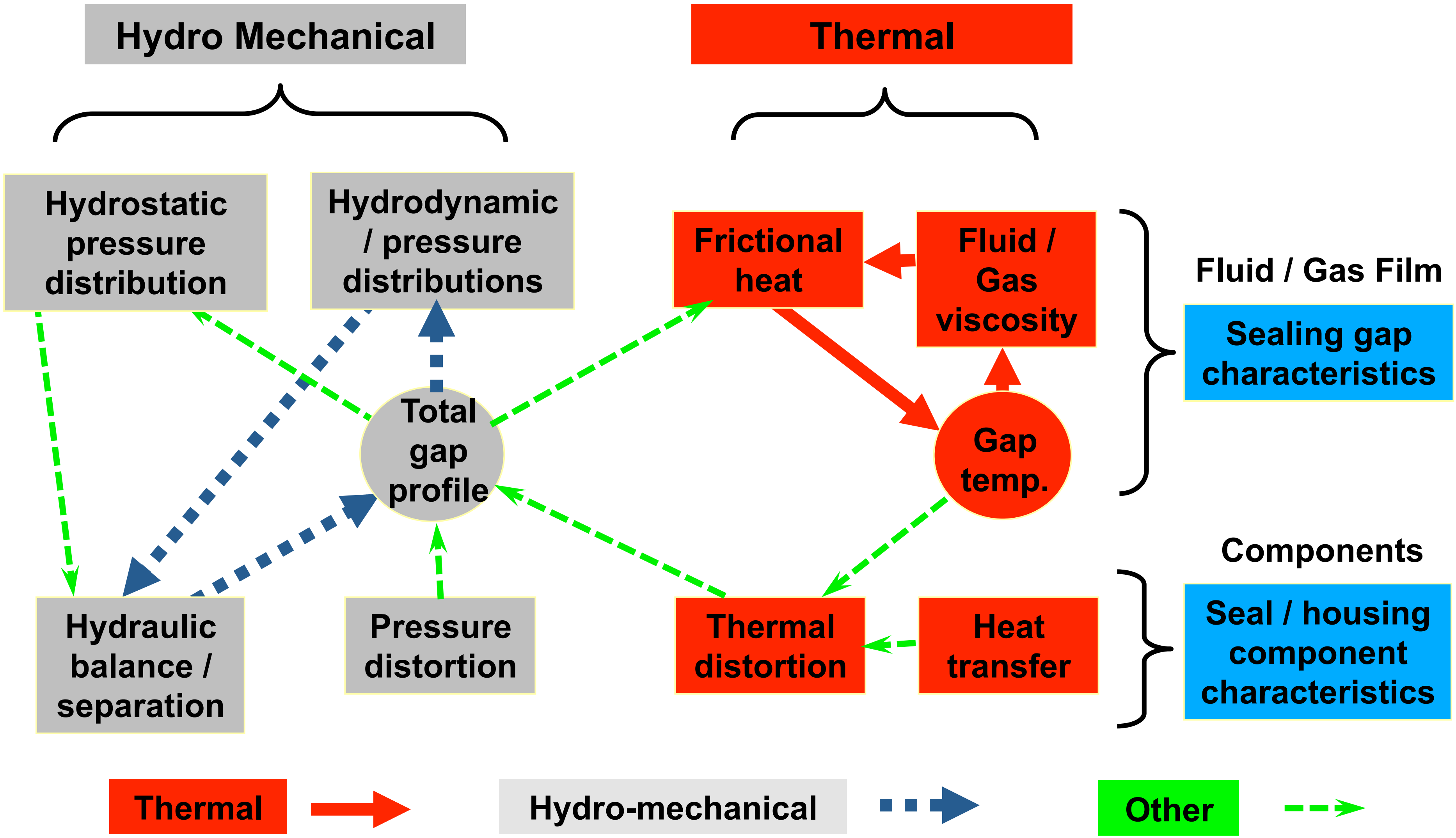
- Rate of loss affected by various factors
  - Style of seal, balance ratio, Lubricating regime, operating conditions (speed, temp, pressures), component condition, wear life, distortion…

All dynamic seals are designed to leak

https://www.exxonmobil.com/en/aviation/knowledge-library/resources/categories/tech-topics
https://gavinpublishers.com/admin/assets/articles_pdf/1537165462new_article_pdf69025564.pdf

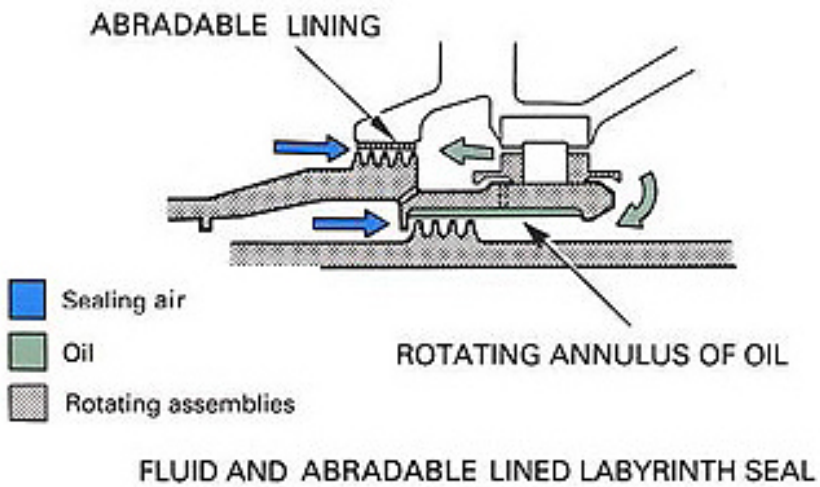
FACTORS AFFECTING SEALS

- Seal leakage concepts

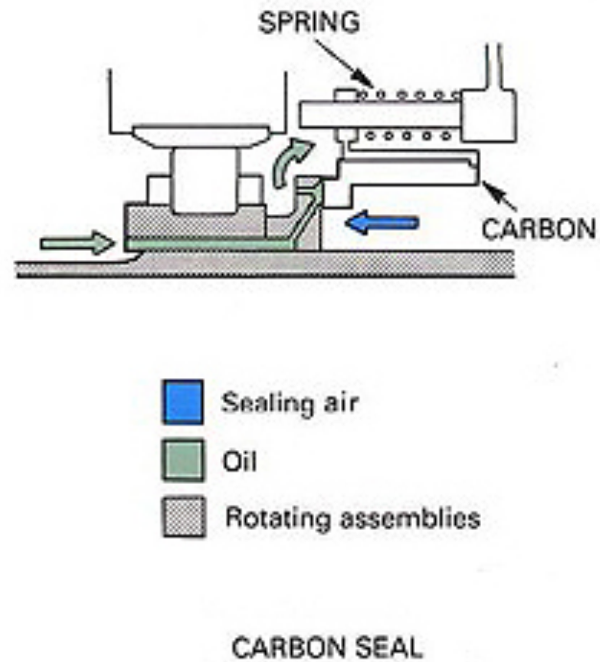


Typical seals

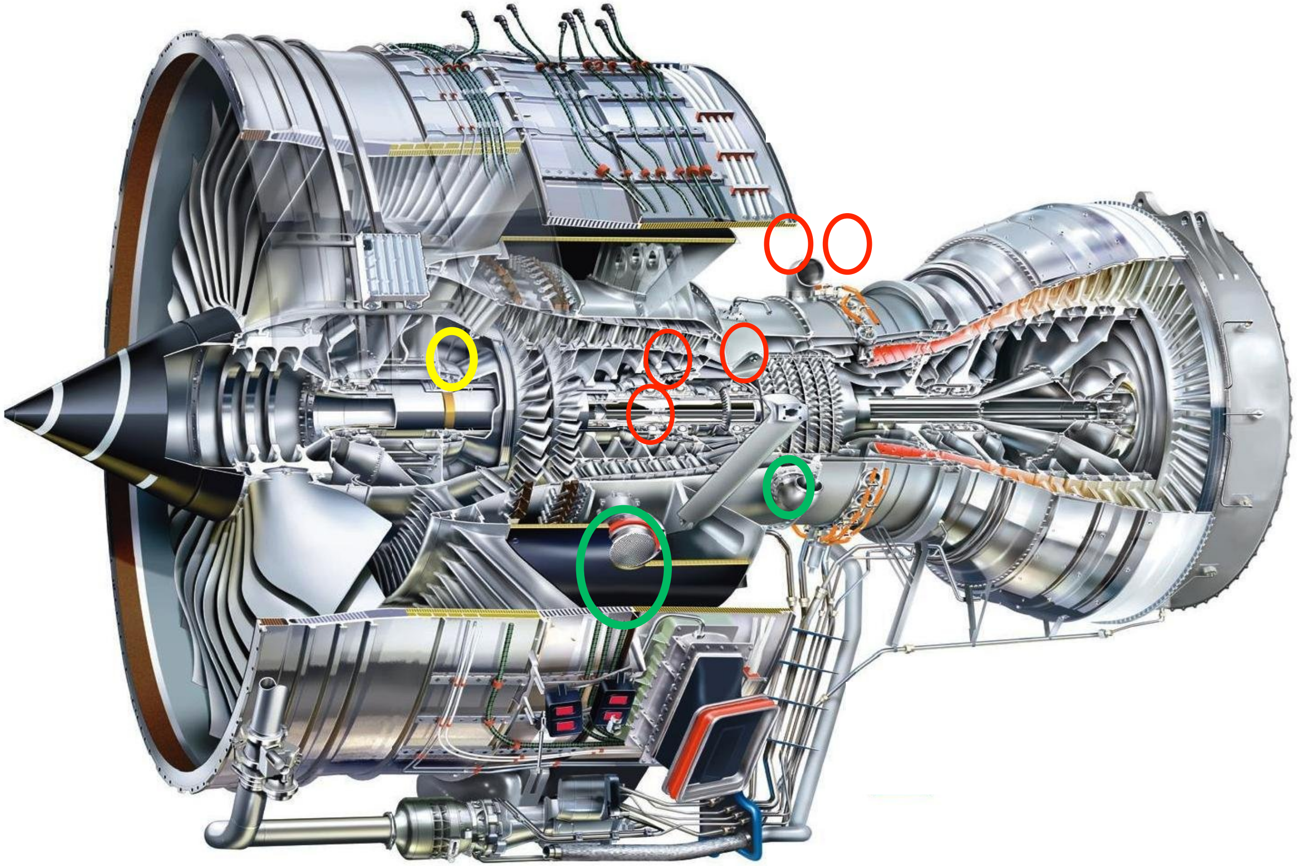
Labyrinth seal

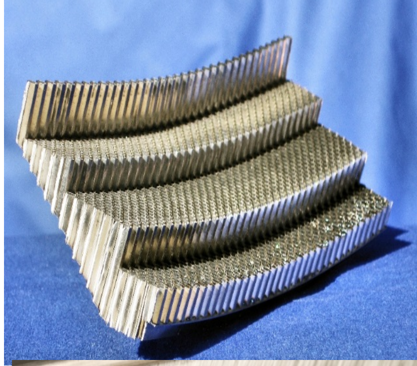


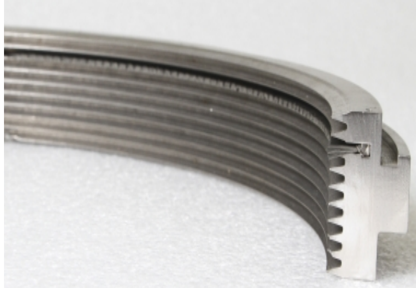
Mechanical/ Carbon seal



Seals and bearings / Air off-take







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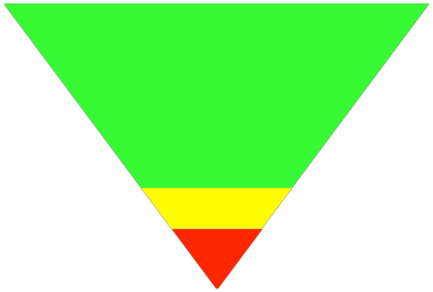
Oil leaks – 3 ways



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) → 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 can escape 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

1. 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

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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

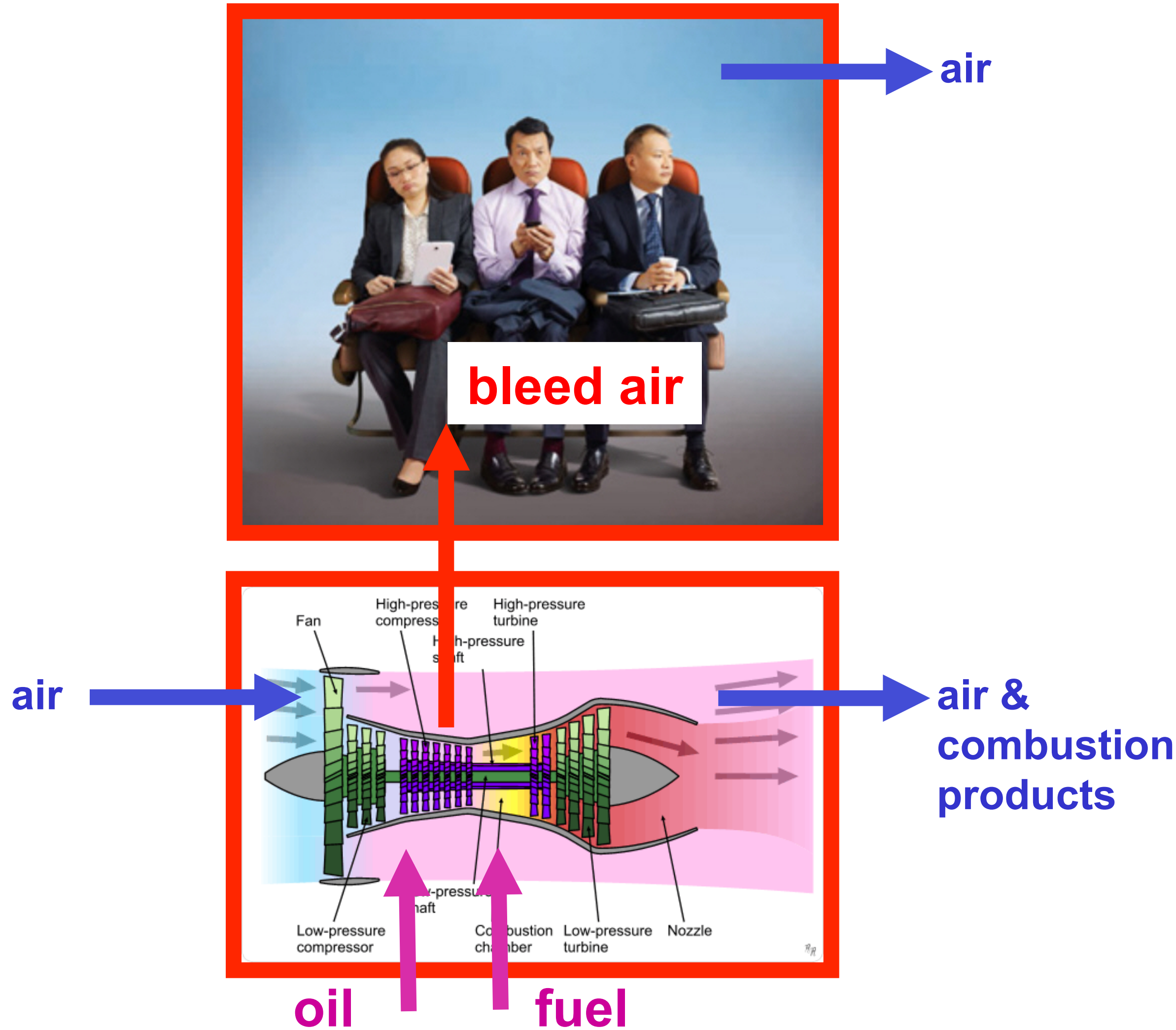
RR –Edge & Squires - 1969

- 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"

Edge, R. and Squires, A. (1969) SAE 690424. Lubricant Evaluation And Systems design For Aircraft Gas Turbine Engines. Warrendale: SAE.

Aircraft cabin air and engine oil

How much Oil
Gets into the Cabin?



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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

CAA (2004) CAA PAPER 2004/04. Cabin Air Quality. Gatwick Airport South, UK.

VOC measurements
Appx A: Aircraft cabin & bleed air monitoring data

Study	Year	Country	Compound	CAS	Level	Comment
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 I	OSHA-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-chloro-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			2ppm	4ppm
1,1-Dipropane-1,2-diol ether	?	EASA CAQ	2017	0.124mg/m3						

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Appx C: Oil pyrolysis studies

TNO/KLM/ASHRAE	2013	decanoic acid
TNO/KLM/ASHRAE	2013	pentadecane
TNO/KLM/ASHRAE	2013	TBP
TNO/KLM/ASHRAE	2014	triphenyl phosphate
TNO/KLM/ASHRAE	2014	di-cresyldiphenyl phosphate
TNO/KLM/ASHRAE	2014	TCP (meta)
TNO/KLM/ASHRAE	2014	TCP (m,m,p)
TNO/KLM/ASHRAE	2014	TCP(m,p,p)
TNO/KLM/ASHRAE	2014	TCP (Para)
EASA	2017	Tris(2-butoxyethyl)phosphate
EASA	2017	Triethyl phosphate
EASA	2017	Diphenyl (2-ethylhexyl)phosphate
EASA	2017	TPP
EASA	2017	Cresyl diphenyl phosphate
EASA	2017	Cresyl diphenyl phosphate
EASA	2017	Di-cresyl phenyl phosphate
EASA	2017	Di-cresyl phenyl phosphate
EASA	2017	TCP (meta)
EASA	2017	TCP (mmp)

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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/TNO	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/TNO	2017	Holland	Tricresyl phosphate -TCP	1330-78-5	17ng/m3	0.017	sampling in FD in flight- cruise
de Ree- KLM/TNO	2017	Holland	Tricresyl phosphate -TCP	1330-78-5	66 ng/m3	0.066	sampling in FD in flight- TOD- shutdown

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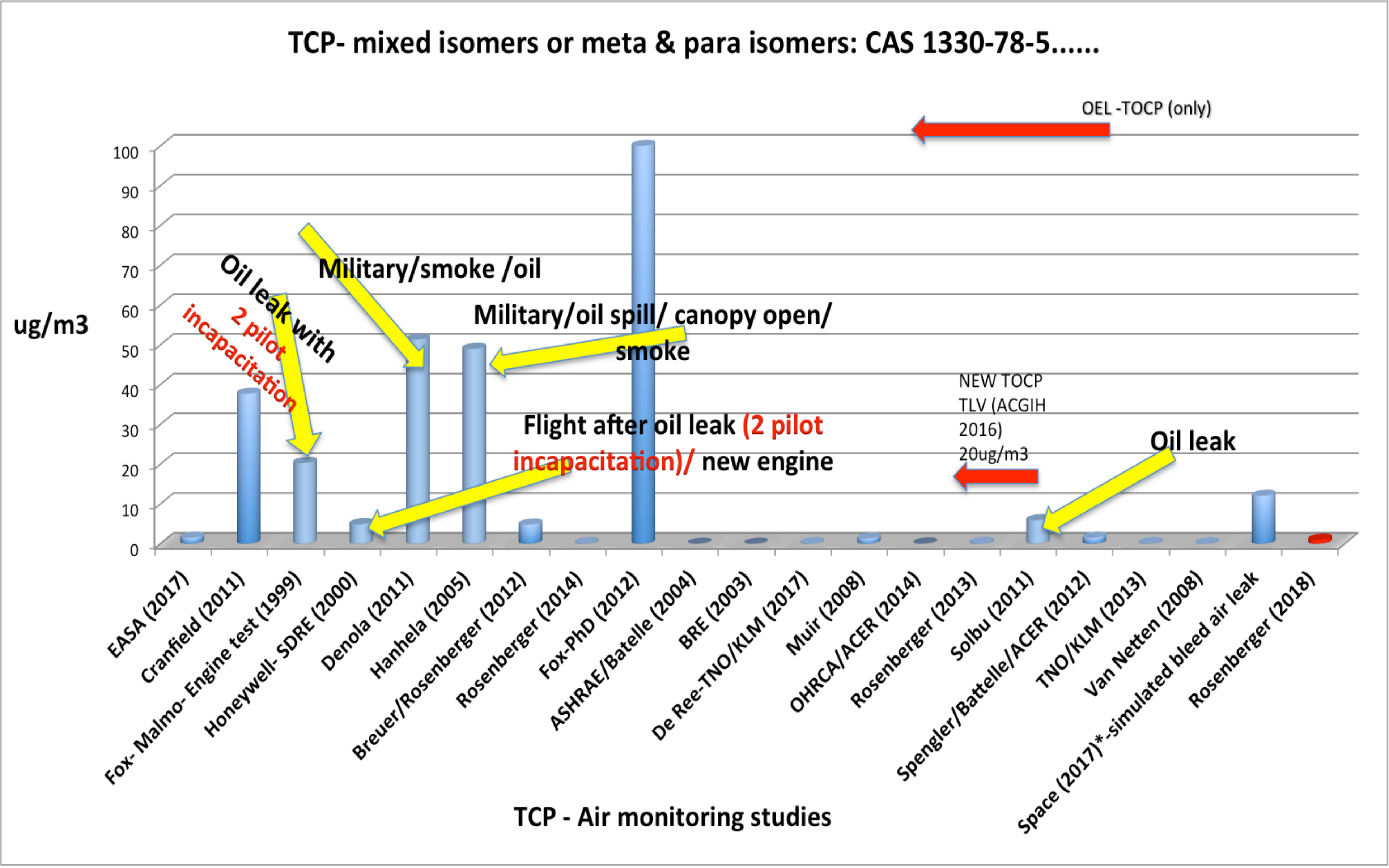

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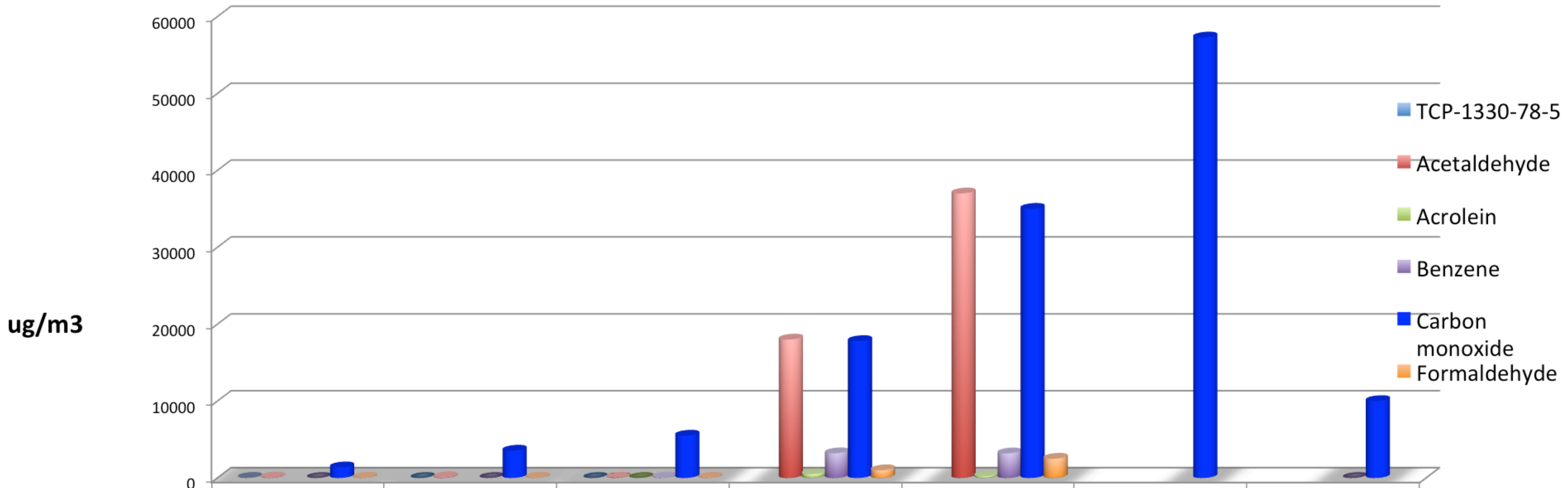
2 pilot incapacitation incident V threshold limits



	MALMO engine test-1999	Honeywell-SDRE cabin air test-2000	EASA CAQ 2017	SAE 4418A/ EN 4618 - limit	UK OEL- 8 hrs	FAA/EASA	EU AQ standard (8 hrs)/annual*
TCP-1330-78-5	20.3	4.9	1.51				
Acetaldehyde	61.5	91	42	18000	37000		
Acrolein			1	500	230		
Benzene	4.9	1.95	53.4	3200	3190		5
Carbon monoxide	1374	3550	5500	17800	35000	57280	10000
Formaldehyde	40.9	58	48	1000	2500		

Substance

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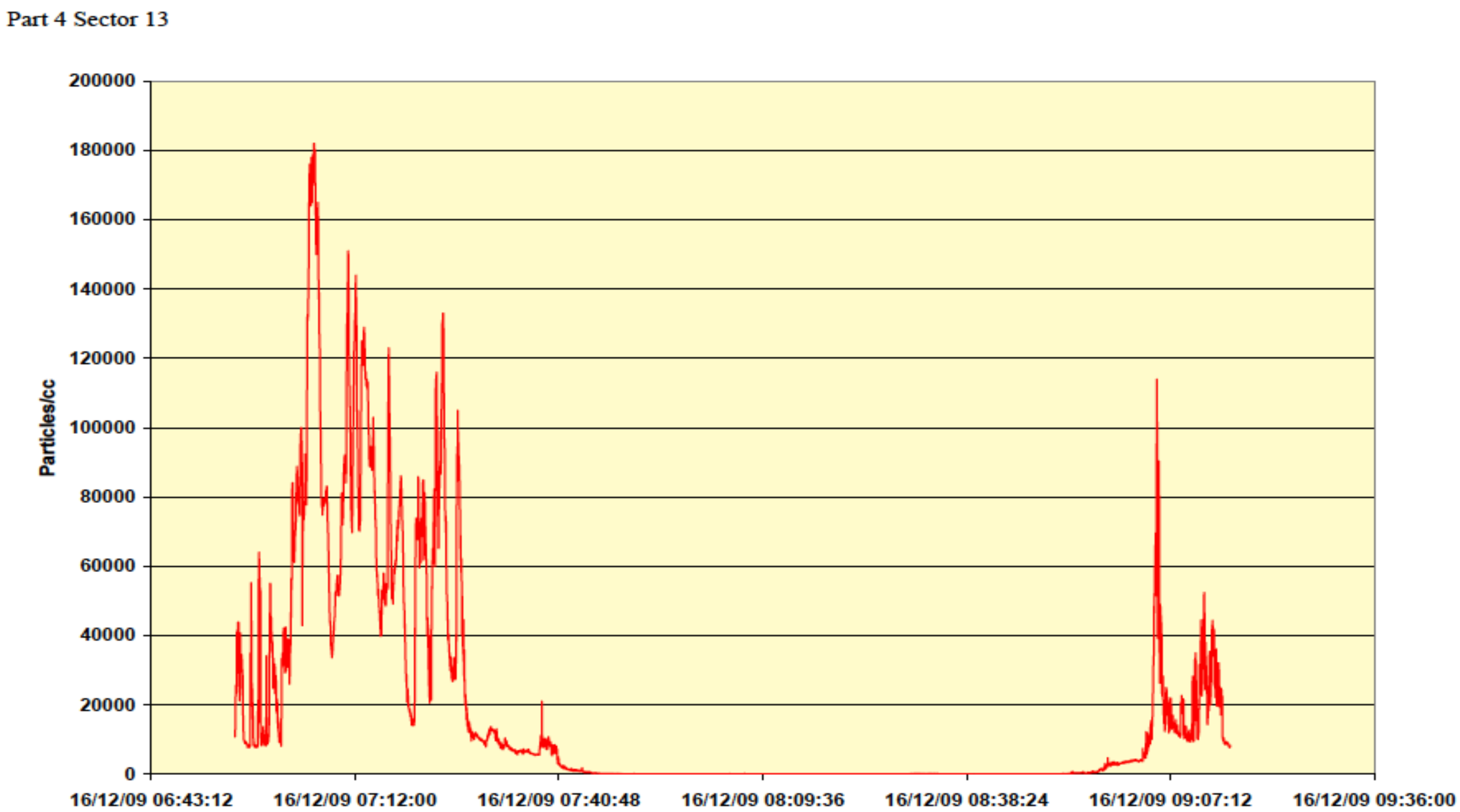
Results

- 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



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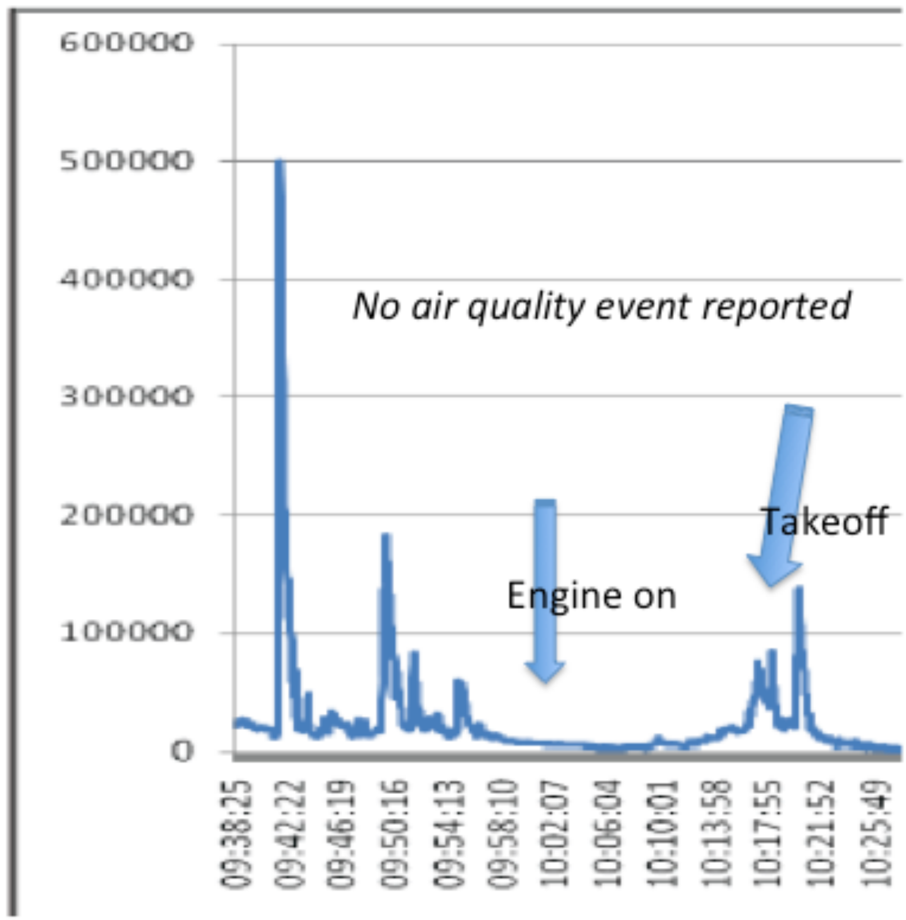
UFP:Cranfield, 2011

Particles/cm3



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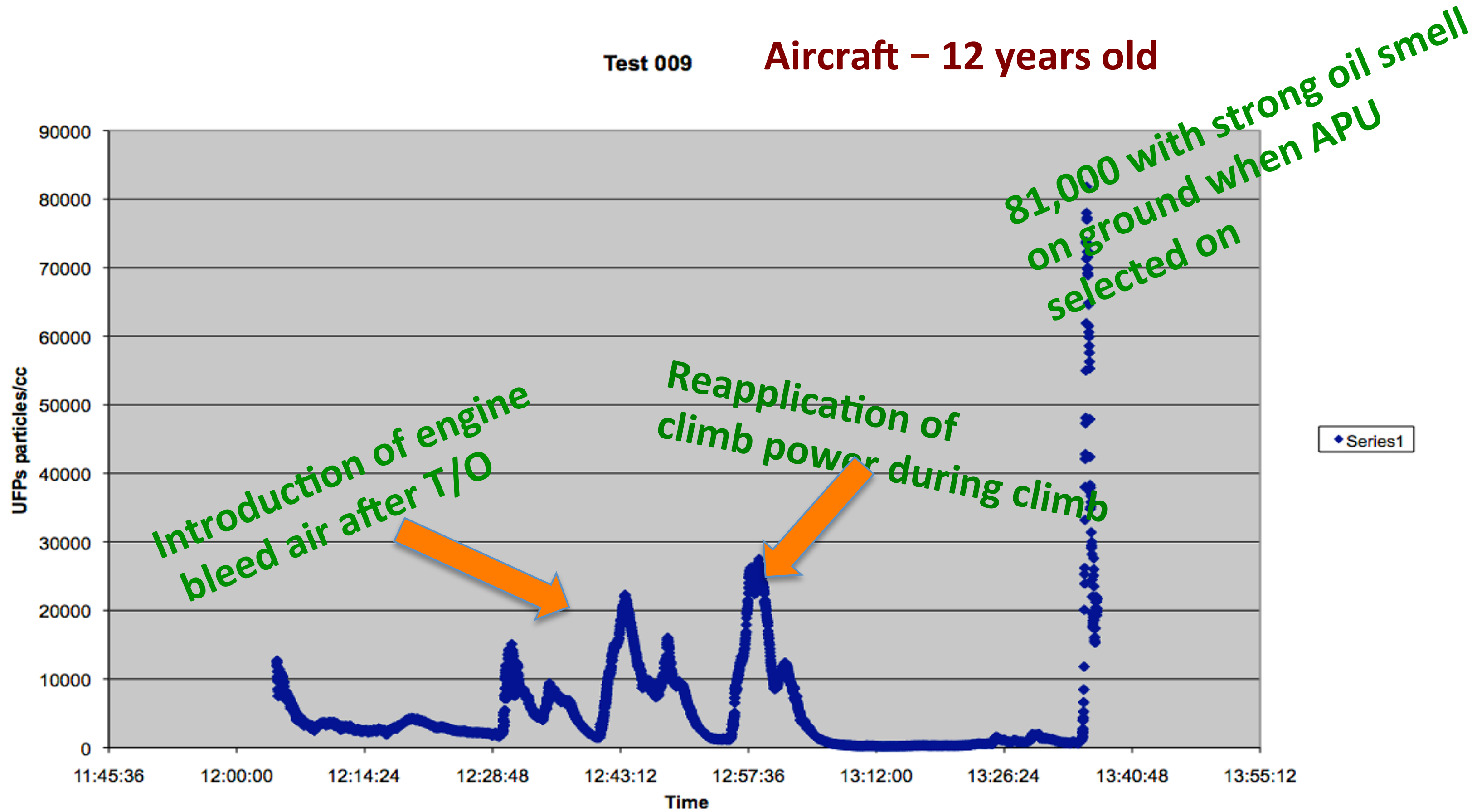
GCAQE – Flight 3



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Compared to other locations

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

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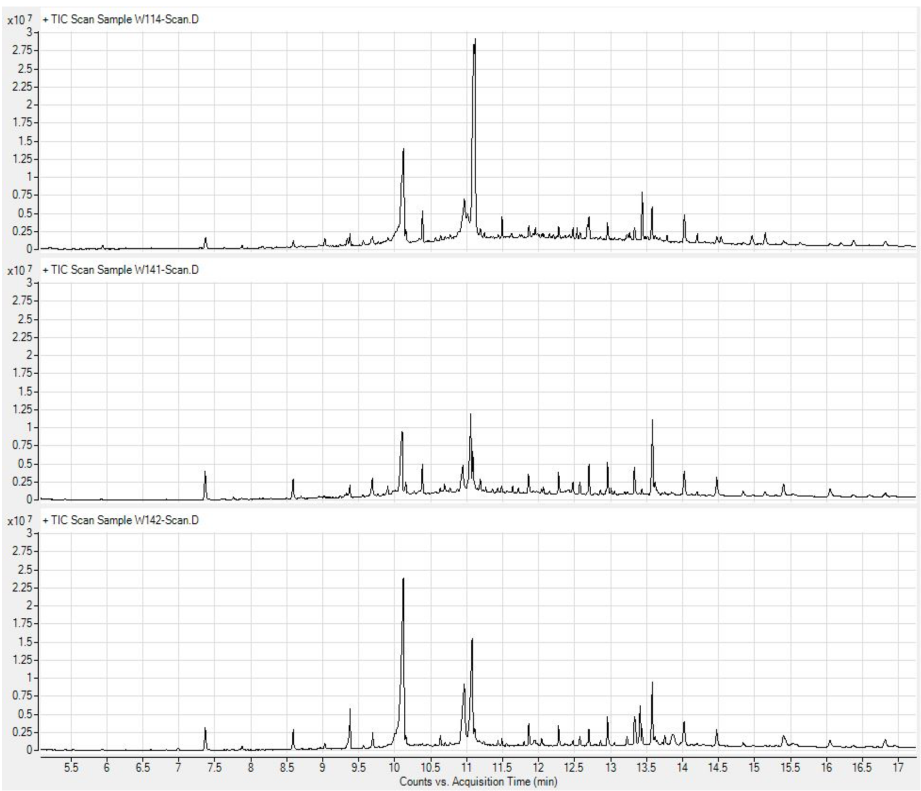
Swab samples Airbus A380



Regulator response

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

Positive for tricresyl phosphate and/or tributyl phosphate

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. - <u>NOT AIRWORTHY!</u> (Michaelis, 2016)**
- **Focus on <u>failure</u> conditions**

ExxonMobil

Product Name: MOBIL JET OIL II
Revision Date: 06 Sep 2017
Page 1 of 11

SAFETY DATA SHEET

SECTION 1	PRODUCT AND COMPANY IDENTIFICATION

PRODUCT

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

oils

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 & throat irritation</u>;
- Not expected under normal conditions of use. *(engine)*

Eastman 2197

- Do not breathe mist or vapor from heated material;
- Inhalation of thermal decomposition products may lead to <u>adverse 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**

European Commission

United Nations

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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)

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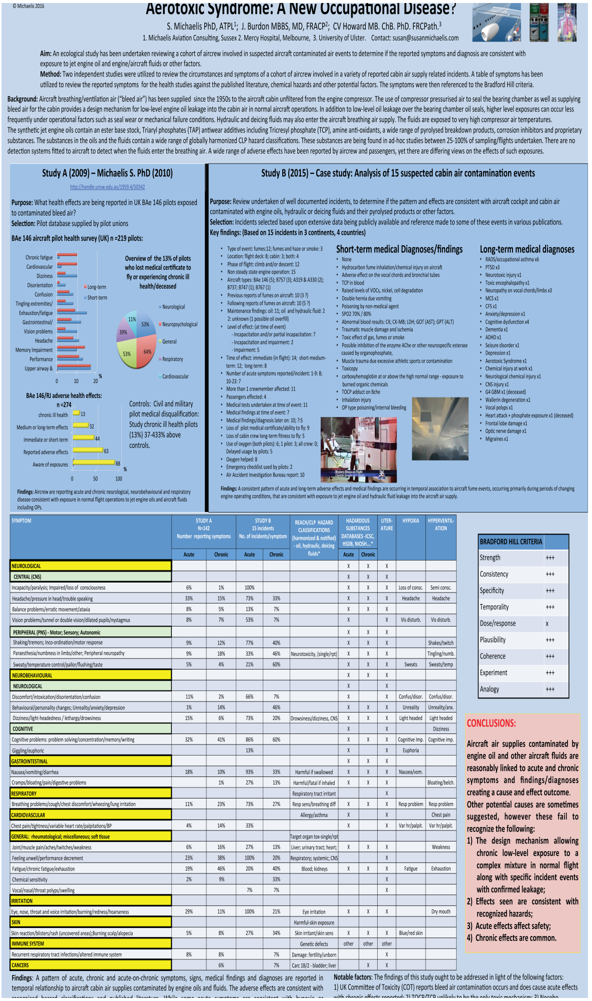
HEALTH

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

New occupational disease?



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

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Flight Safety

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

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

ICAO

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https://www.local10.com/news/local/fort-lauderdale/sick-people-on-flight-fll?fbclid=IwAR15B0pni9rxu7BTh-Ggl4ZBR_V1b2cm9uptNGdc14_NfIunTTvA4-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 design, NOT reporting.

Thank you

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