HAW HAMBURG

Oil Leakage Paths within Compressors of Jet Engines and Oil Concentration in Aircraft Cabin Air

Engineers selected a fundamentally wrong solution for air conditioning of passenger aircraft.

Air from the engine's compressor (bleed air) is used for ventilation and pressurization. As such, all engine related problems leading to contaminated compressor air also contaminate the air, passenger and crew must breathe.

PURPOSE

Investigation of oil leakage paths from the engine seals into the gas path of jet engine compressors and the estimation of oil concentration in aircraft cabin air based on fundamental aircraft and engine parameters.

METHODOLOGY

Real jet engine illustrations were collected and used for a detailed investigation of possible paths of oil-contaminated air into the main gas stream of the jet engine compressor before the extraction of bleed air. Furthermore, an equation was analyzed to calculate the oil concentration in the cabin air. Required aircraft and engine and parameters were collected for five engines: CF34, V2500, CFM56, PW4000, and GE90 on typical aircraft.

FINDINGS

Based on the illustrations it is evident that the oil finds a path into the compressor airstream and into the cabin, once it has left an oil sump (Figure 1 and Figure 2). Regarding the oil concentration in normal operation, it could be shown that larger engines tend to produce lower oil concentration in the cabin air (Figure 3). One reason is that they have a lower oil consumption per thrust. The initially unknown parameter, x_{seal} (ratio of oil out of all seals versus the total oil consumption) was later identified based on the concentration of total volatile organic compounds (TVOC) measured inside aircraft cabins. The difference of TVOC measured in cruise in 31 conventional aircraft and the TVOC measured in four bleed-free B787 is 285 µg/m³ (based on the mean values over all aircraft in a group and all flights). For the identification, parameters of the Airbus A320 with CFM56 engines were used and an oil consumption of 0.28 qt/h per engine. Based on this, $x_{seal} \approx 28\%$. The number of engines, n_{eng} has no effect and cancels out of the equation, when oil consumption is given per engine. The flow of oil into the cabin can be calculated from the oil consumption and a ratio of compressor air for air conditioning to total core flow. If this is assumed to be $x_{CA} \approx 3\%$, the oil into the cabin would be 3 l per year or 60 l in 20 year (as for an older aircraft). The oil concentration in the cabin in a cabin air contamination event (CACE) is given in Figure 4. It can be estimated from the visibility in the cabin, when the visibility is reduced by smoke.

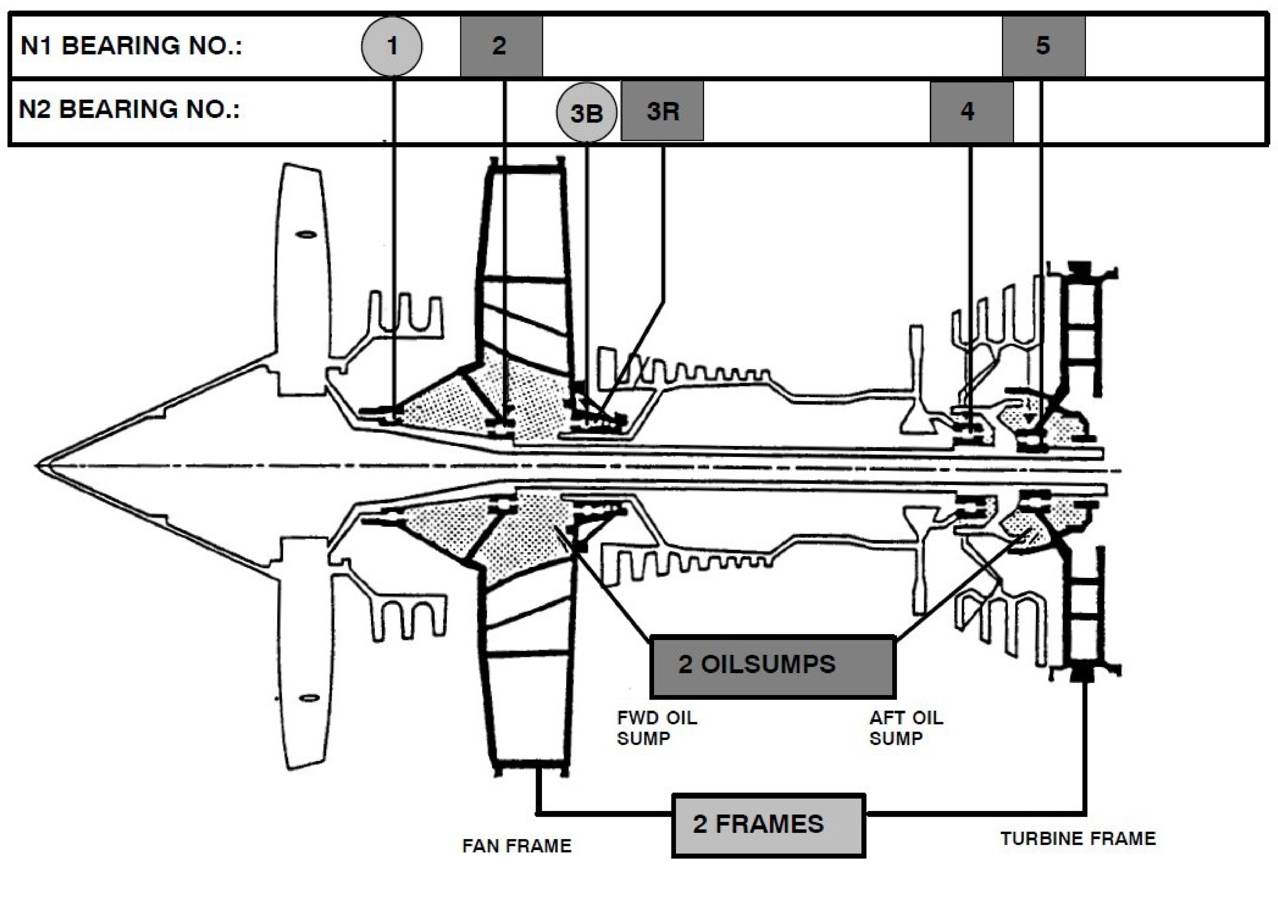

Figure 1: Bearing, seals and oil sumps in the CFM International CFM56 engine (LTT 1999).

RESEARCH LIMITATIONS

All investigations are based on common sense. The oil concentration in the cabin was calculated based on the assumption(!) that 1% of oil consumption leaves the engine via the seals.

PRACTICAL IMPLICATIONS

The influence of fundamental aircraft and engine parameters on oil concentration in the cabin is better understood. These parameters are engine air intake diameter, by-pass ratio, total number of seals and their number upstream of the bleed port, oil consumption, cruise Mach number, and cruise altitude.

SOCIAL IMPLICATIONS

People concerned about aircraft cabin air contamination can better argue their case with the information in this project.

ORIGINALITY

It is an important step in the argument to show how the oil can find its way into the compressed air path. Before, it was just assumed that leaking oil from the engine seals will "somehow" make its way. The usefulness of the equation for oil concentration in the cabin air is shown now with an increased number of five engines instead of just one engine as before. This gives increased credibility to the equation.

From Oil Consumption to Hydrocarbon Concentration in the Cabin? Yes, possible

$$\boxed{\frac{m_{oil,cab}}{V_{cab}} = \frac{\dot{m}_{oil}\ x_{bear,up}\ x_{seal}}{S_{eng}\ n_{eng}\ M_{CR}\ a(h_{CR})} \cdot \frac{\rho_{cab}}{\rho_{CR}}(\mu+1)}$$

Engine with increasing size

Parameter	CF34	V2500	CFM56	PW4000	GE90
$\dot{V}_{oil}$	0,2 qts/h [a]	0,28 qts/h [a]	0,3 qts/h [b]	0,5 qts/h [a]	0,34 l/h [c]
$\dot{m}_{oil}$	0,1115 g/s	0,1516 g/s	0,1673 g/s	0,5241 g/s	0,1895 g/s
$x_{bear,up}$	3/5 [d]	3/5 [e]	3/5 [b]	3/5 [f]	4/6 [g]
x_{seal}			0,01 [h]		
S_{eng}	1,42 m^2 [i]	2,06 m^2 [j]	2,35 m^2 [b]	4,48 m^2 [f]	8,3 m^2 [k]
n_{eng}	2 [l]	2 [l]	2 [l]	4 [l]	2 [l]
M_{CR}	0,78 [l]	0,78 [l]	0,76 [l]	0,85 [l]	0,84 [l]
$a(h_{CR})$			295 m/s [h]		
ρ_{cab}			0,963 kg/m^3 [h]		
ρ_{CR}			0,364 kg/m^3 [h]		
μ	5,4 [i]	4,5 [j]	5,7 [b]	4,8 [f]	9 [k]
$\frac{m_{oil,cab}}{V_{cab}}$	17,3 $\frac{\mu g}{m^3}$	14,4 $\frac{\mu g}{m^3}$	16,9 $\frac{\mu g}{m^3}$	10,7 $\frac{\mu g}{m^3}$	8 $\frac{\mu g}{m^3}$

[a] (Scholz 2018), [b] (LTT 1999), [c] (Transportation Safety Board of Canada 2012), [d] (SmartCockpit 2020), [e] (MTU Maintenance 2020), [f] (Sumner 1997), [g] (Aviation 2016), [h] (Scholz 2017), [i] (GE Aviation 2010), [j] (IAE 2016), [k] (MTU Aero 2020), [l] These parameters may vary due to engine/aircraft configuration.

On the ASSUMPTION that 1% of consumed oil leaves through the seals:

Oil concentration in the cabin decreasing with engine size

Figure 3: Calculating the (average) oil concentration in the cabin air during normal operation based on x_{SEAL} = 1%. With larger x_{SEAL} (e. g. 28%) the results can be scaled.

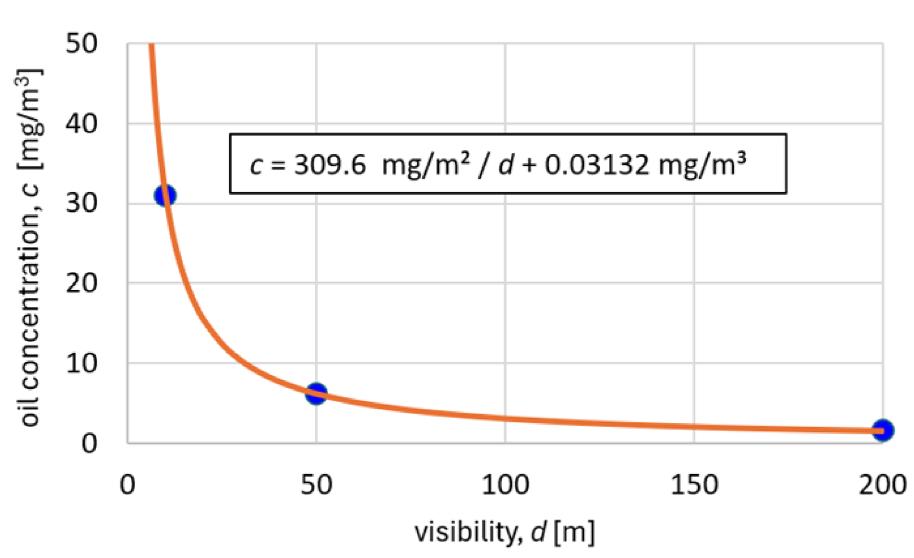

Figure 4: Oil concentration in the cabin during a cabin air contamination event (CACE). It can be estimated from the visibility in the cabin. The visibility in a CACE can be reduced due to smoke. The three points are given in NRC (1997).

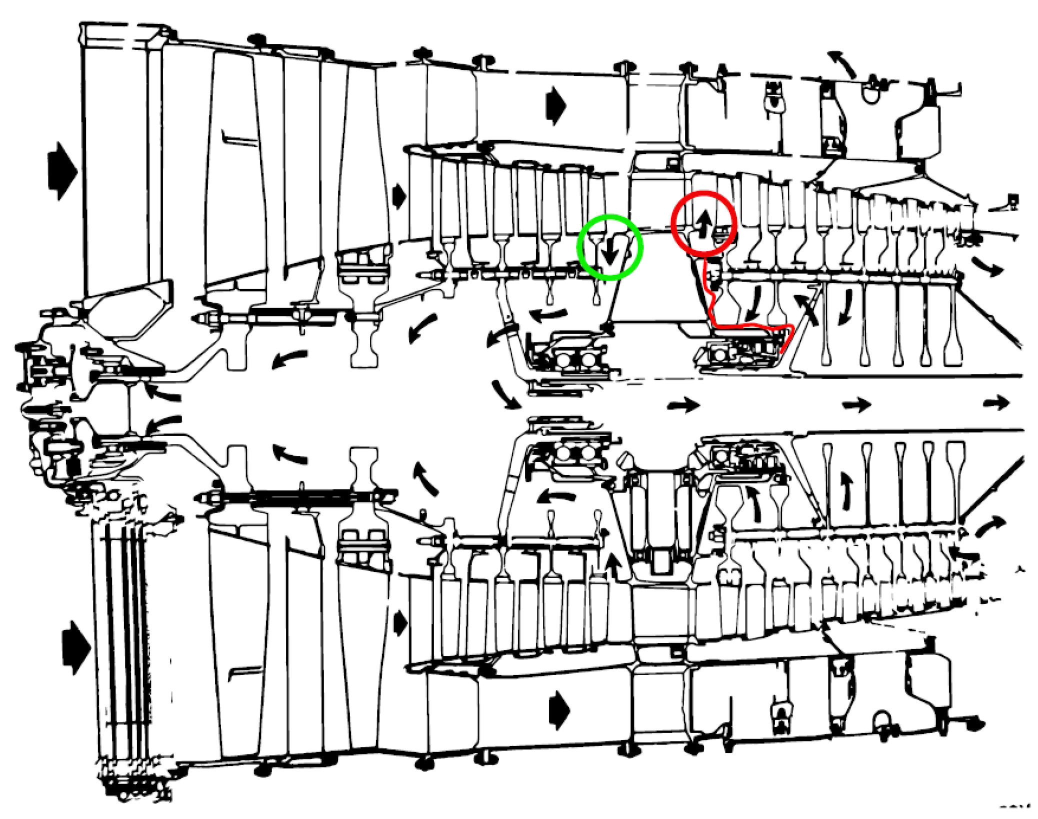

Figure 2: Air paths in the engine Pratt & Whitney JT8D (adapted from Treager 1995).

All details (including picture sources) in the Project:
https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2020-03-25.017

Associated research data (Harvard Dataverse):
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Dennis Tietke

Prof. Dr. Dieter Scholz, MSME

HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFTEN HAMBURG
Hamburg University of Applied Sciences