Memo

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Prof. Dr. Dieter Scholz, MSME
Aircraft Design and Systems Group (AERO)
Department Automotive and Aeronautical Engineering
Hamburg University of Applied Sciences Hamburg
Berliner Tor 9, 20099 Hamburg, Germany

Phone: +49 - 40 - 42875 - 8825
E-Mail: info@ProfScholz.de
WWW: http://AERO.ProfScholz.de

Jet Engines – Bearings, Seals and Oil Consumption

Abstract

Purpose of this review is to understand how to find values for three input values for the calculation of the oil concentration in aircraft cabins. These are the number of bearings of the jet engine and the number of them upstream of the bleed air ports as well as the oil consumption per hour.

Methodology is an Internet review of related facts.

Findings: Jet engine schematics are available online and can be interpreted to find the number of bearings. Values for the CFM56 engine are 5 bearings with 3 of them upstream of the bleed port. Oil consumption should be assumed to be 0.3 L/h for the CFM56 engine. Rates for selected other engines are also given.

Research limitations are due to the fact that detailed company data is not available and own measurements can not be made on passenger jets.

1 Introduction

An attempt has been made to estimate the amount of oil leaving a jet engine into the bleed air. Bleed air is air taken from the engine compressor. It is used (among other tasks) for aircraft cabin air conditioning. In order to perform this calculation some jet engine parameters have to be known (**Scholz 2017**):

- number of engine bearings,
- number of bearings upstream of the first bleed port,
- engine oil consumption per flight hour.

This memo tries to provide these numbers. The method of investigation is a review of available information provided through the Internet.

Bearings are used to support engine shafts/rotos. Bearings are lubricated inside a bearing sump, which is sealed. Often labyrinth type seals are used together with air, which is also holding back the oil. Air and oil have to be separated and the air is eventually vented over board. Some oil is lost along various paths causing oil consumption. Only oil lost through bearing seals upstream of the bleed ports can contaminate the bleed air.

Chapters 2, 3 and 4 look at (the number of) engine bearings, their lubrication in a sump, its seals and the lubrication system of a jet engine as a whole. Focus is also on the mechanisms of oil losses.

Chapter 5 shows the position of the bleed ports in the high pressure compressor and their position with respect to the bearings with their potential oil losses.

Chapter 6 summarizes numerical values (in qt/h) collected of jet engine oil consumption. Details from the Internet are given in the Appendix. Chapter 7 looks at oil consumption monitoring to understand where these numerical values come from.

2 Jet Engine Shafts and Bearings

Main jet engine shafts are supported by a minimum of two bearings. At least one bearing has to be a thrust ball bearing that can take axial and radial loads. The other bearing can be a cylinder roller bearing that takes only radial loads. Bearings are located inside a bearing sump. "Oil sumps are part of the oil circuit, where oil must remain. Leakage outside the oil system could pollute the air bleeds or result in an engine fire." Two or more oil sumps are distributed along the engine shaft. (**Exxon 2016b**)

Bearings of the CFM56 engine are shown in Figure 1. The engine has 2 shafts called HP shaft and LP shaft. The rotors (shafts and discs) are supported by 5 bearings mounted in two engine sumps for lubrication. The engine rotors are supported by two frames via the bearings. The forward sump is in the fan frame and is the location of bearings No. 1, No. 2 (fan/booster shaft) and No. 3 (HP shaft forward part). The aft sump is in the turbine rear frame where bearings No. 4 (HP shaft aft part) and No. 5 (LP shaft aft part) are located. Seals of various types are provided to confine the oil. Pumps for oil supply, oil scavenge, seal pressurization and sump vent subsystems produce a system known as a dry sump. Engine sumps are vented to ambient pressure. (**Lufthansa 1999**) Note: Bearing number 3 consists of a double bearing. In numbering the bearings, it is considered as one bearing.

Bearings of the Rolls-Royce Trent 1000 engine are shown in Figure 2. The engine is used on the Boeing 787. Trent 1000 is a bleedless design, with shaft power off-takes from the IP shaft instead of the HP shaft found in other members of the Trent family. (**Wikipedia 2018a**). As a bleedless engine the Rolls-Royce Trent 1000 only serves here only as a further example of engine (bearing) technology. The engine has 3 shafts called LP, IP and HP shaft. The shafts are supported by 8 bearings as detailed in Figure 2. The 4 bearing chambers are: the front bearing housing (FBH) at the front of the engine; the internal gearbox (IGB), towards the centre of the engine; the HP-IP bearing chamber also towards the centre of the engine and the tail bearing house (TBH) towards the rear of the engine. Of these the two hottest chambers are those in the middle of the engine. Figure 3 shows the complicated air sealing in the HP-IP hub. (**Ademiyi 2015**)

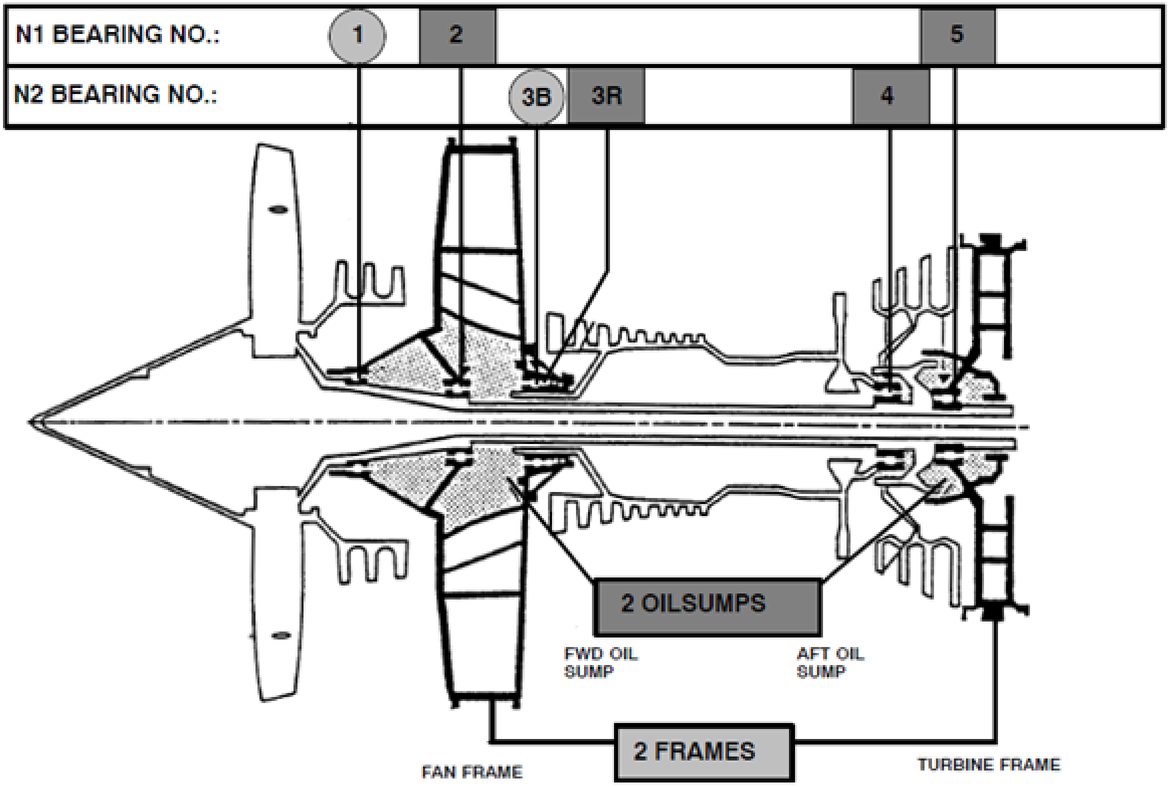

Figure 1: Location of the 5 bearings of the CFM56 engine (**Lufthansa 1999**)

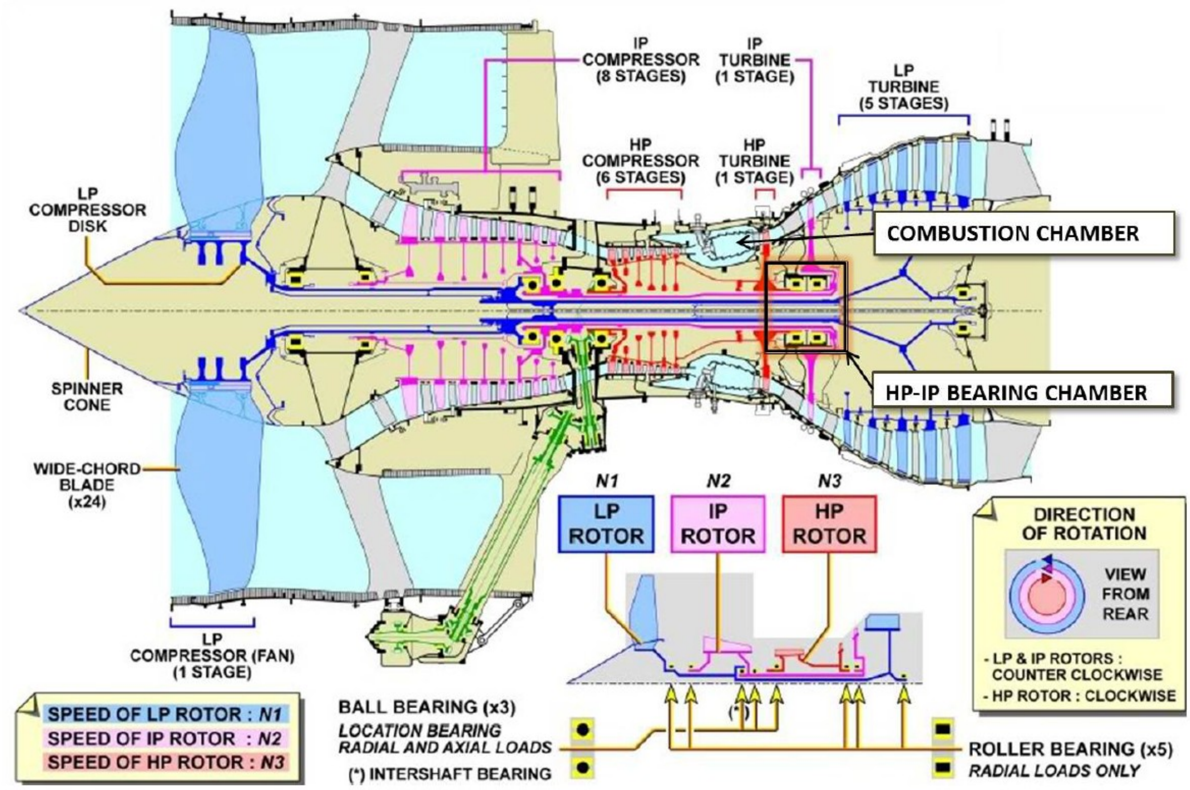

Figure 2: Location of the 8 bearings of the Rolls-Royce Trent 1000 engine (**Ademiyi 2015**)

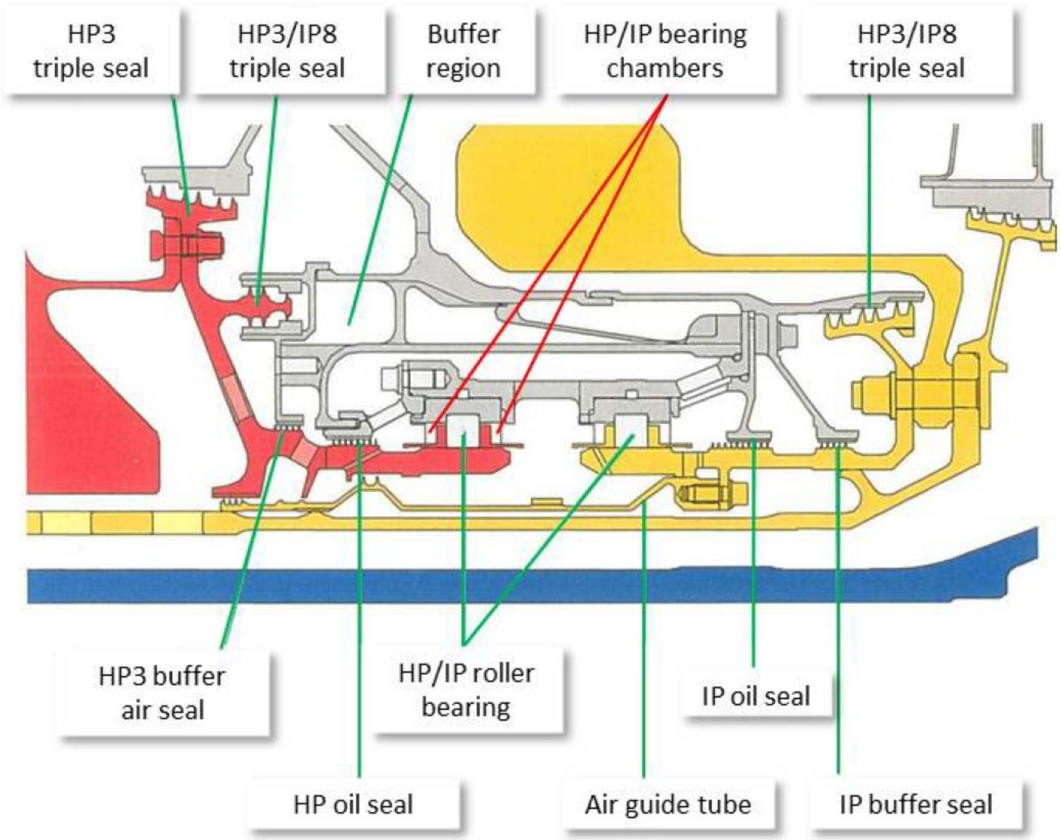

Figure 3: Details of HP/IP bearing chamber with two cylinder roller bearings of the Rolls-Royce Trent 1000 engine (**Ademiyi 2015**)

3 Bearing Sumps

Sumps are sealed usually by labyrinth seals. Less often carbon seals or brush seals are used. A sump (called a "wet cavity") with labyrinth type seals in hot areas (typically mid-sumps) are usually surrounded by a "dry cavity" that is sealed by a second labyrinth type seal. In this way a double wall design is achieved (Figure 4). Pressurized air enters the dry cavity and moves from the outside to the inside of the wet cavity to hold back the oil in the labyrinth seal. The air mixes with the oil in the sump (wet cavity) producing an oil mist (air and oil mixture). The oil mist is directed to an air/oil separator. (**Exxon 2016b**)

"The separation of the [scavenge] oil and air first occurs in the de-aerator. After [that] the mixture ... [is] sent to the centrifugal breather for further separation. Once the oil is separated from the air, the oil is sent back into the bearing chambers and gearboxes to provide lubrication, while the air is vented from the system." "Separating the oil and air is necessary because by separating the oil and air, the amount of oil that is vented outside the engine is minimized." (**Hehir 2016**)

Four different flows with an air/oil mixure need to be differentiated (see Figure 4):

1. The 'oil out to scavenge pumps' contains some air bubbles. This air has to be removed in a de-aerator located on the oil tank (Figure 5).
2. The 'vent to de-oiler' is an air/oil mist. The de-oiler can be an individual one for the bearing sump or it can lead to a central de-oiler as shown in Figure 6 and 7.
3. The 'drain (oil)' consist predominantly of oil. "In many applications, oil that crosses the [inner] oil seal is [drained,] collected and routed by a tube to an aircraft drain collector that is inspected from time to time and is used as a seal monitoring tool." (**Exxon 2016b**)
4. The 'Air & Oil' out the air seal consists predominantly of air, but some oil is also present as indicated in Figure 4. This flow enters the compressor.

It is important "to avoid [oil] leaks due to too low Δp through the oil seals." The differential pressure Δp across the oil seal is the difference between the pressurized air entering the dry cavity (equal to the pressure in the compressor) and the vent pressure. "The vent tube must remain wide open" to ambient air (at ambient pressure) to achieve low enough vent pressure for sufficient Δp. In other words, "to be leak free [and to enable the flow of air into the wet cavity (to hold back the oil)], the pressure must always remain lower inside than outside the sumps." (**Exxon 2016b**)

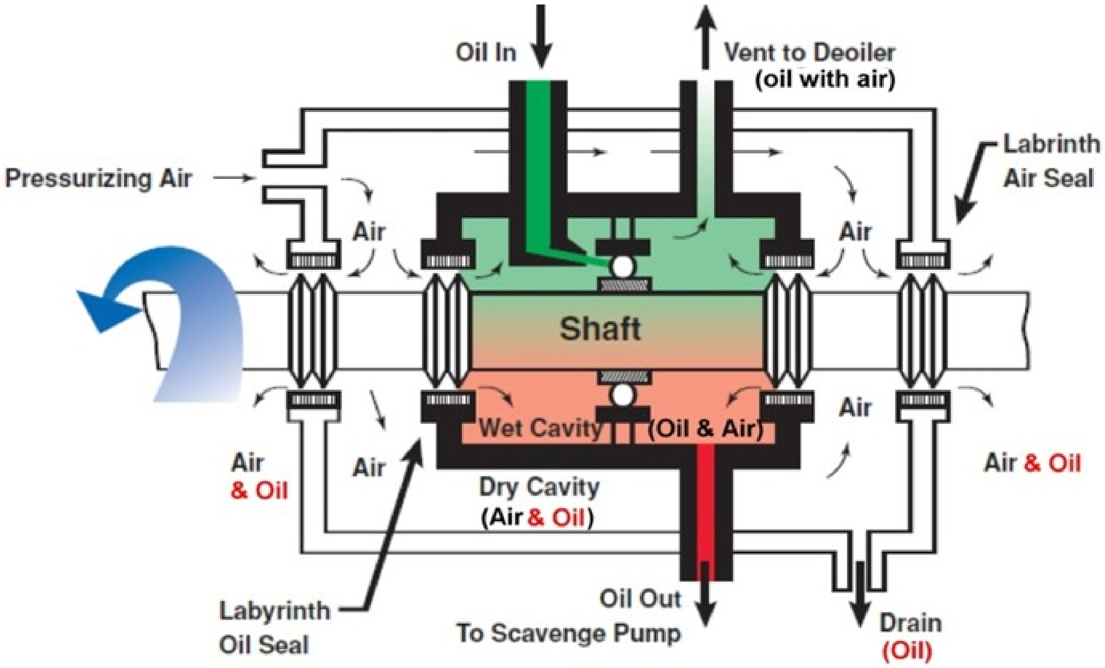

Figure 4: Typical bearing lubrication and sealing in a jet engine. The Figure is based on **Exxon 2016b**. A double walled seal design is illustrated.

4 Jet Engine Oil System and the De-Aerator

Fresh oil flow is constantly supplied to jet engine components like bearings. The flow rate to components is based on lubrication and cooling requirements. The oil also protects against corrosion, transports contaminants and acts as sealant. (**Exxon 2016a**)

"After lubricating and cooling the components in the bearing sumps (or compartments), the oil flows to the bottom of sumps, carrying heat, air bubbles, wear particles and debris. Oil is scavenged by a dedicated ... pump." (**Exxon 2016a**)

The oil flows past an oil cooler and the de-aerator into the oil tank from where it is pumped back to the sumps. Figure 5 depicts a generic oil system that vents the air overboard via the de-aerator on the tank.

Figure 6 (closely resembling the V2500 engine) gives more details with respect to the vent lines and shows an oil system with a central de-oiler installed on the accessory gearbox (Figure 7).

Figure 8 shows the oil system of the CFM56 engine. "Air entrained in the scavenge oil is separated in the tank by a de-aerator and is vented to the Forward Sump through the Transfer Gearbox and Radial Drive Shaft. The Sumps are vented overboard through the Low Pressure Turbine Shaft to prevent overpressure in the sump. Air entrapped in the scavenge oil pressurizes the tank and provides adequate oil pressure to the supply pump." (**Lufthansa 1999**)

"Scavenged oil flow is slightly lower than the supply flow due to normal oil consumption through the

- de-oiler [air/oil separator, de-aerator],
- oil seals and
- oil leak". (**Exxon 2016a**)

The amount of oil consumption is highest due to the air vented overboard with some oil left due to limited efficiency of the de-aerator, followed by the amount of oil leaving through the drain or through the seals of the outer wall. External oil leaks have to be very small to prevent an engine fire. (**Gassart 2015**)

"Means must be provided to separate the oil from the air to retain the oil within the system and vent almost clean air into the atmosphere." Figure 7 shows the de-oiler and its vent air outlet on the gearbox of a V2500-A5. "A small amount of oil is released with the air leaving the system. It represents the normal oil consumption of the engine (0.1 qt/h to 0.5 qt/h)." (**Linke-Diesinger 2010**)

An air-oil separator (also called a de-aerator) (Figure 9) is a component in a gas turbine lubrication system in which air is removed from scavenged oil before its return to the oil tank. The scavenged oil is churned, resulting in air coming to the surface, which is then bled out before returning the oil to the tank. (**FreeDictionary 2005**)

Figure 10 "shows a cross sectional view of the de-aerator in which the oil flow can be seen in green and the air flow can be seen in orange. The oil and air both enter the de-aerator from an inlet pipe at the top of the cylinder. Then the oil circulates along the side of the vertical cylinder. As the oil circulates down the side of the de-aerator, it reaches the pedestal. There is a gap between the pedestal and the de-aerator wall. The gap allows only the oil to flow beneath the pedestal and then out the oil vent. The air circulates downward within the inner section of the de-aerator until it hits the pedestal. The pedestal reverses the axial velocity of the air and creates an air vortex moving up the de-aerator and out the air vent. Once the air comes out of the air vent, there is still small amount of oil mixed in the air. This air and oil mixture is then sent to the centrifugal breather where the oil and air are separated further." (**Hehir 2016**)

"The de-oiler recovers oil and dircts air overboard. Mist volume is more than 10 times greater with labyrihth seals than carbon seals, creating a higher air velocity in the de-oiler." (**Exxon 2016c**)

"Gear installations allow for high de-oiler rotational rates. As de-oiler speed increases, oil loss decreases. De-oiler speeds on the main engine shafts are set by the engine operating cycle and can be very low, particularly on high-bypass turbofan low-pressure spools. This makes recovering very small droplets much more difficult." (**Exxon 2016c**)

"Engines with carbon seals for oil sumps and de-oilers installed in gearboxes usually have lower consumption that those using labyrith seal and deoilers in main engine oil sumps." (**Exxon 2016c**)

"Labyrinth seal clearances naturally increase as an engine ages. As this occurs – due to rubbing under vibration, gyroscopic torque, rough landings or any g-load factor – the engine airflow incrases, reuslting in even higher oil consumption. If seals are assembled and installed properly, and not abnormally worn or damaged, the high oil consumption is essentially due to inefficient de-oilers installed in the engine air breathing system." (**Exxon 2016c**)

A monitoring system provides information to the aircraft avionics about engine health. The engine oil level (EOL) in the tank is one such parameter. The oil level depends on many other parameters and is normalized by the Health and Usage Monitoring Systems (HUMS) for Condition-Based Maintenance (CBM). (**Exxon 2016a**)

The main parameters having an effect on the oil level are (**Gassart 2015**):

- engine oil temperature (EOT),
- engine shaft rotation speed (n)
- flight altitude (h).

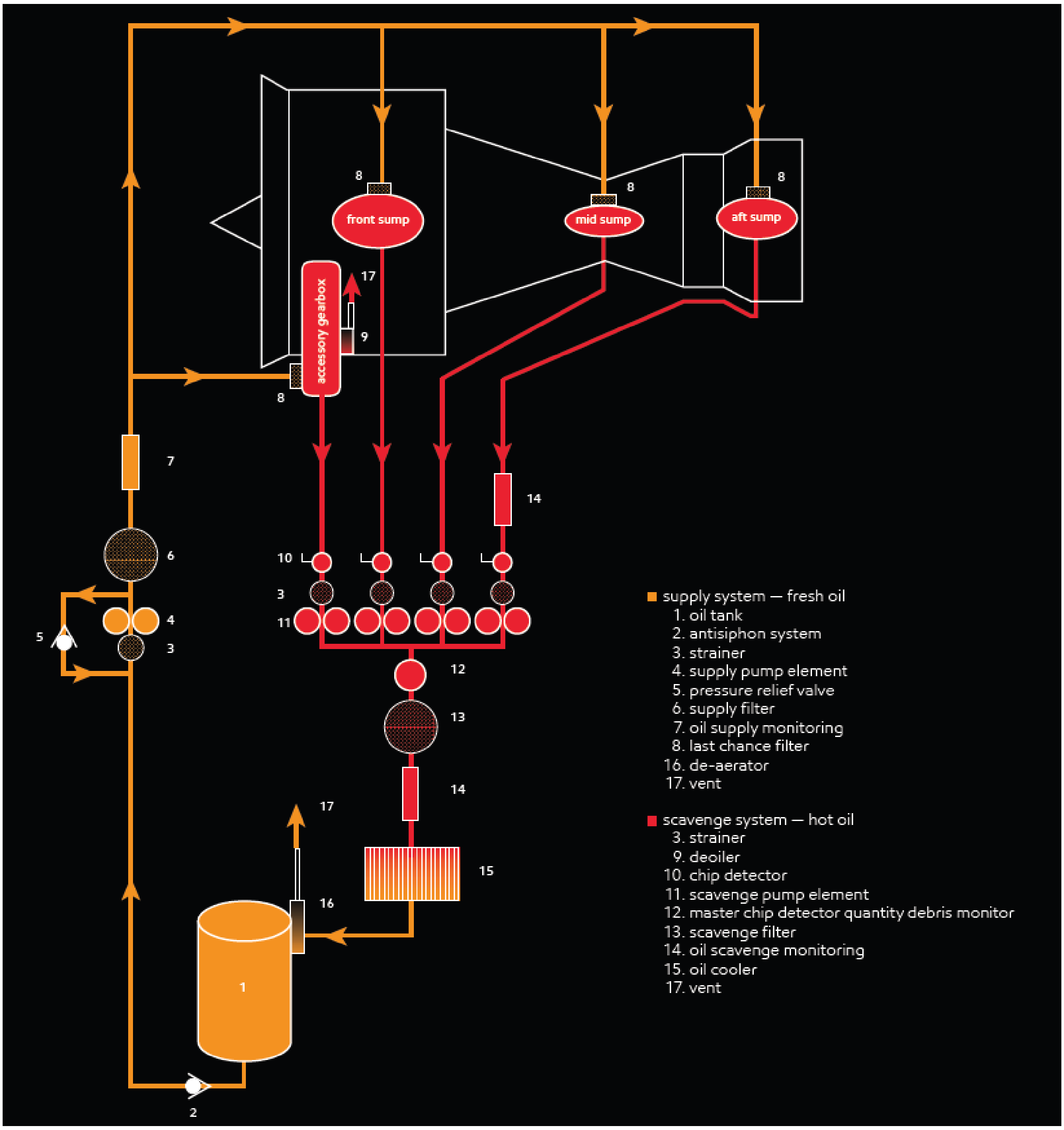

Figure 5: Typical jet engine oil system. The vents from the bearing sumps (wet cavities) are not shown or not present. Air is vented overboard via the de-aerator on the tank. **(Exxon 2016a)**

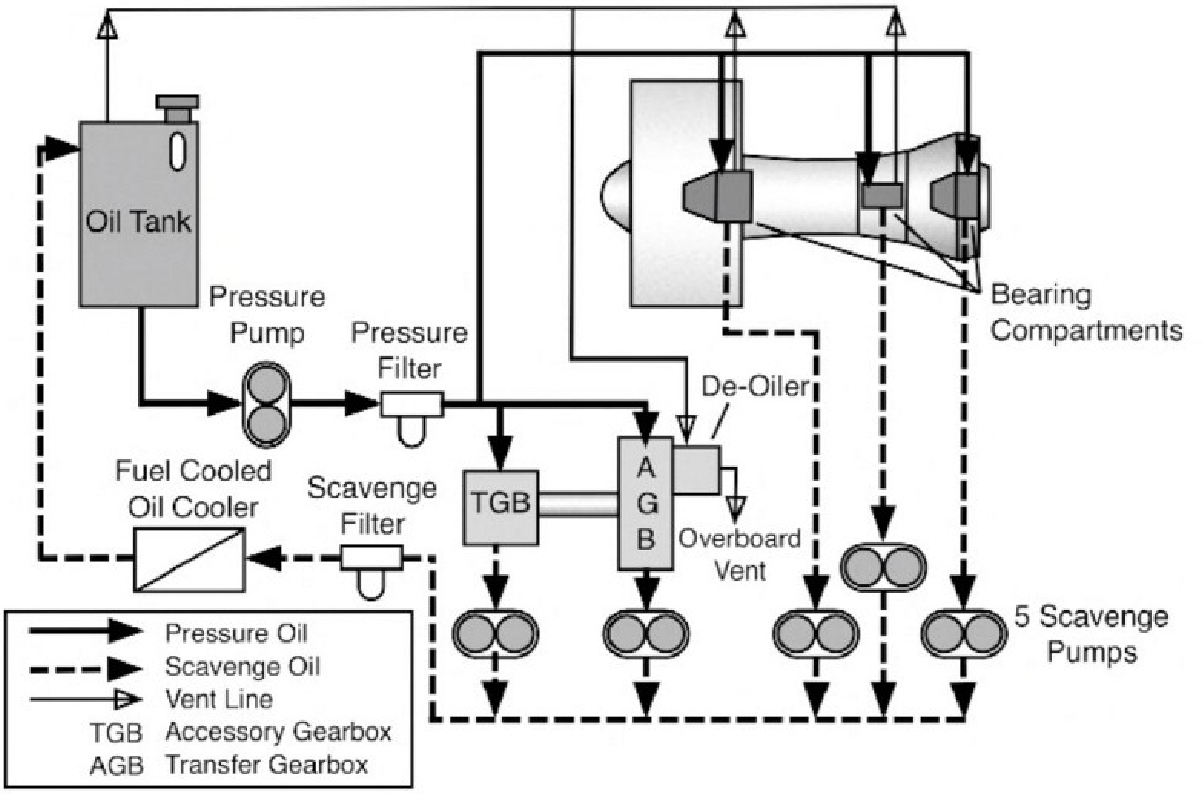

Figure 6: Typical jet engine oil system with a central de-oiler on the accessory gearbox (AGB). The air is vented overboard via the de-oiler on the AGB. (**Linke-Diesinger 2010**, © LTT)

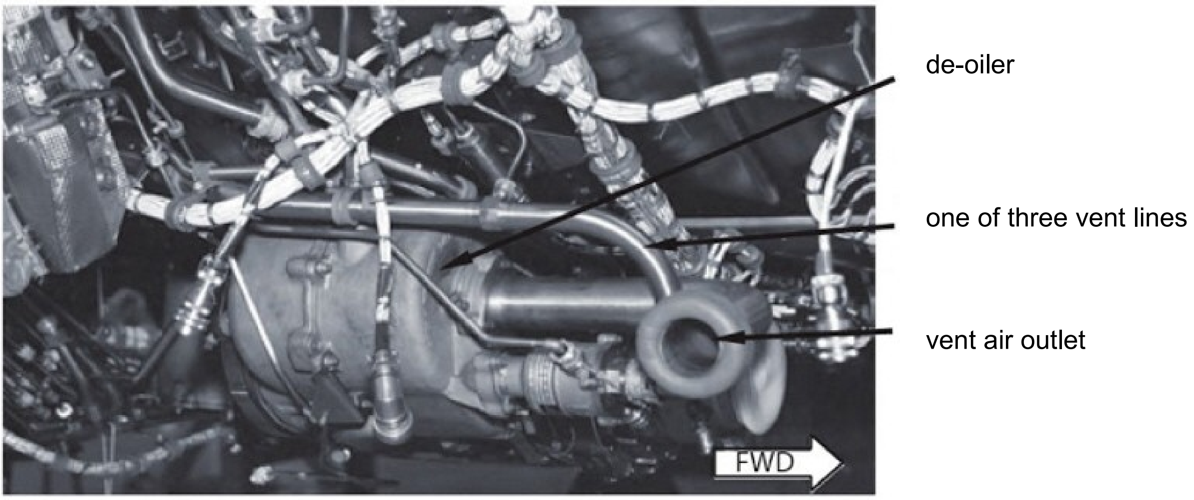

Figure 7: The de-oiler of the V2500-A5 on the front side of the accessory gearbox (**Linke-Diesinger 2010**, © LTT)

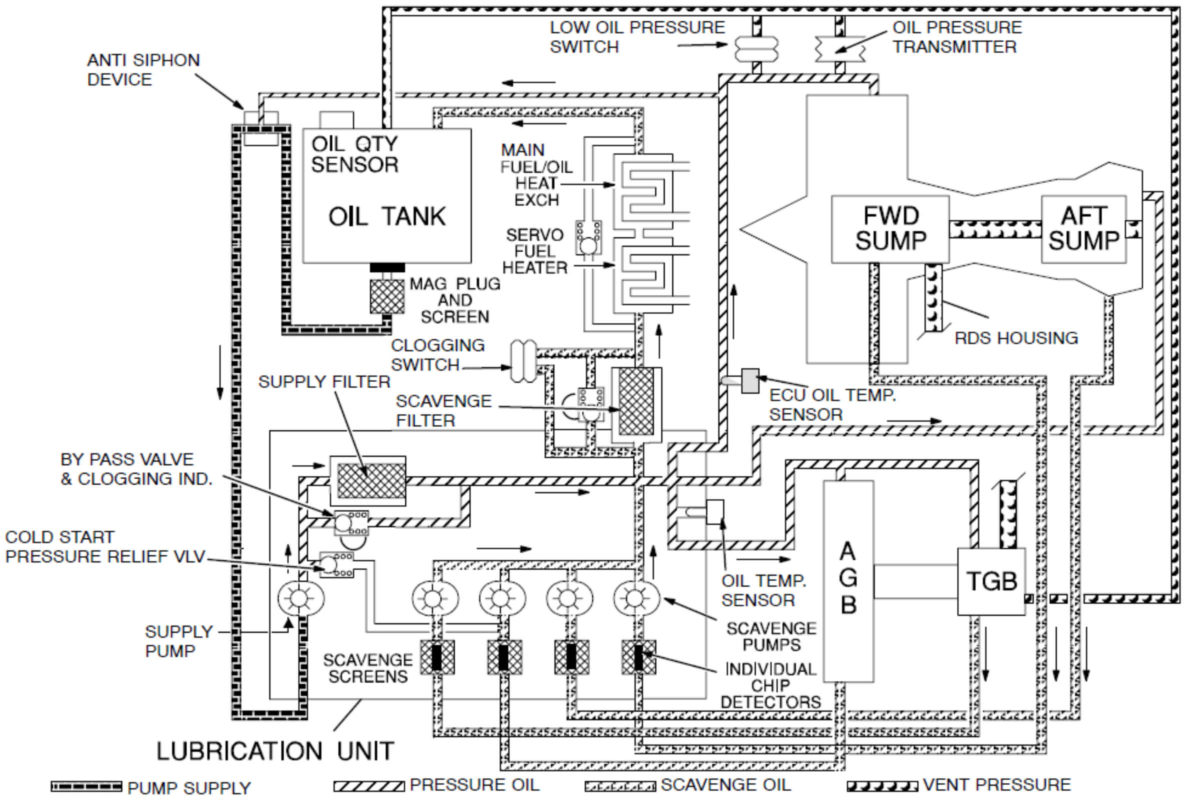

Figure 8: Oil system schematic of the CFM56-5A engine. There is a connection of the vent line between the transfer gearbox (TGB) and the radial drive shaft (RDS). The air is vented overboard through the LP turbine shaft. (**Lufthansa 1999**)

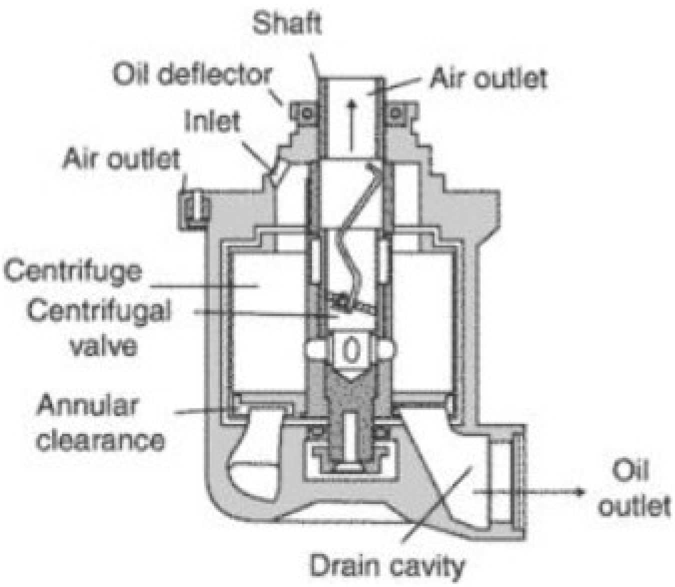

Figure 9: Air-oil separator (**FreeDictionary 2005**)

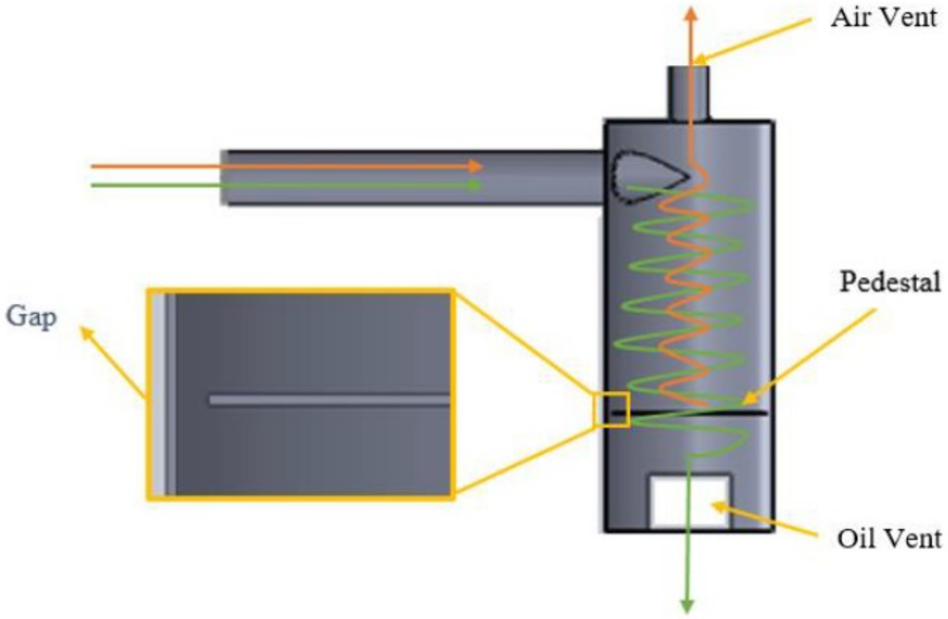

Figure 10: De-aerator (**Hehir 2016**)

5 Bleed Air Valves Positioned with respect to Engine Bearings

"Bleed air is compressed air that is extracted from the engine compressor." "Most bleed-air systems have at least two extraction ports, one near the end of the compressor to get the highest possible pressure when the engine is operating at low speed and an intermediate stage where the pressure is adequate during normal cruise and at high-power conditions. The bleed-air extraction from the high-pressure stage is automatically turned off when the pressure at the intermediate stage is adequate and is automatically turned on when the pressure from the intermediate stage is not adequate. The high-pressure port is used only during taxi and descent." (**NRC 2002**)

Figure 11 shows typical positions of the bleed air valves (ports) with respect to the engine bearings.

Figure 12 shows the bleed air valve position in more detail for the CFM56 engine. The engine has 5 bearings of which 3 bearings are upstream of the bleed air valves.

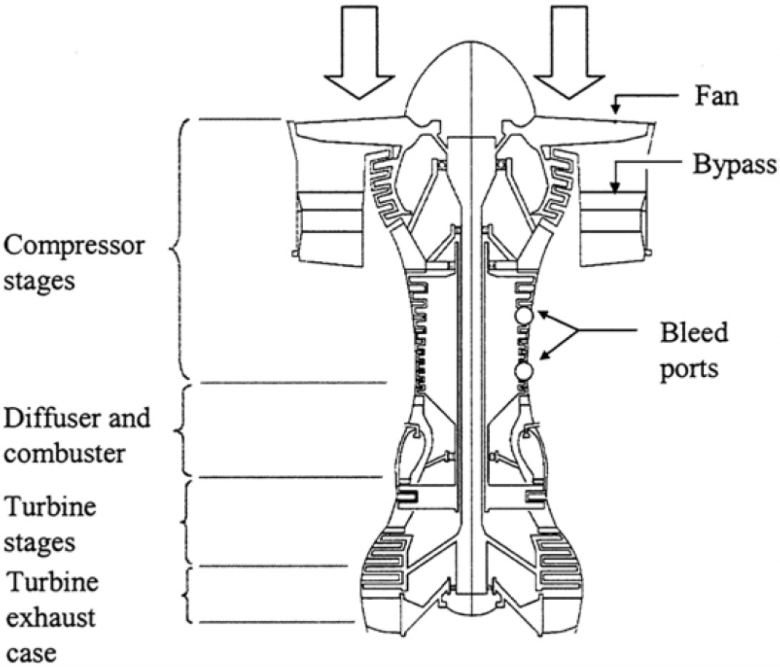

Figure 10: Bleed air valves positioned with respect to engine bearings. The engine has 5 bearings of which 3 bearings are upstream of the bleed air valves. (**NRC 2002**)

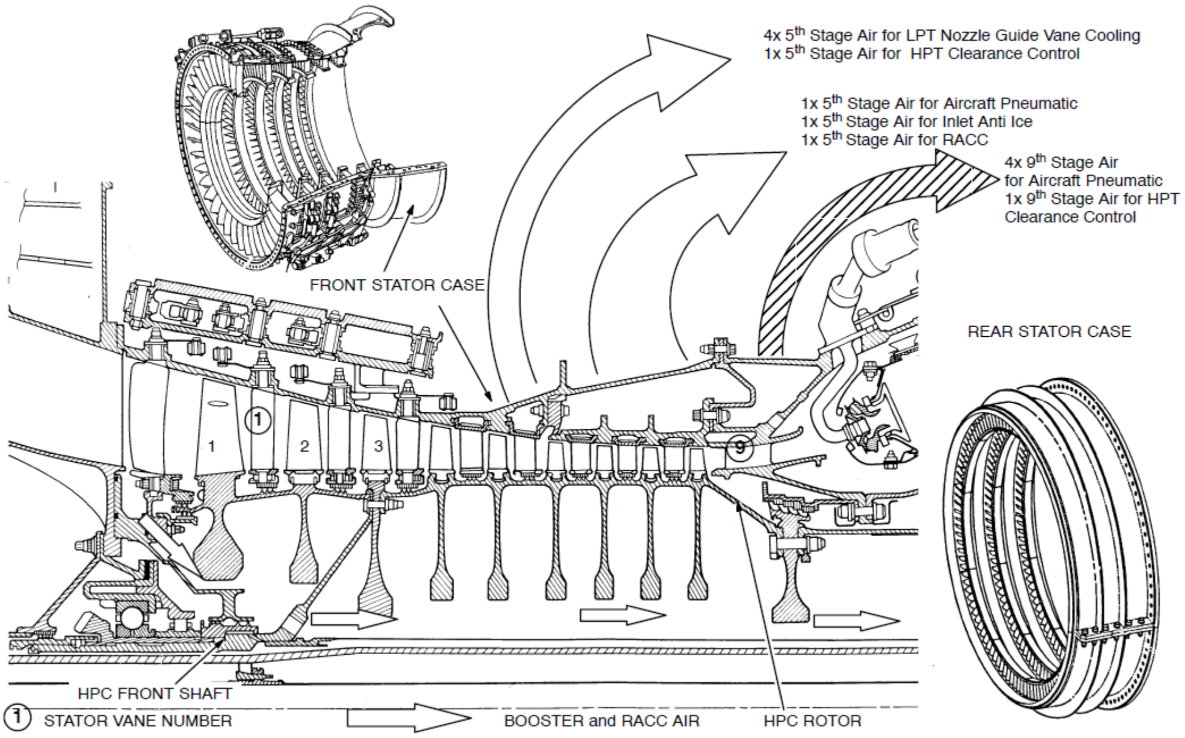

Figure 11: CFM56 HP compressor with bleed air off-takes. IP bleed from 5th stage and HP bleed from 9th stage. Bearings 1, 2 and 3 are upstream of both IP and HP bleed valves. Bearing 3 is visible in the lower left corner of the Figure. (**Lufthansa 1999**)

6 Summary of the Jet Engine Oil Consumption Review

Jet engine oil consumption was collected from two Internet discussions on the topic, industry jet engine lecture notes and a book. The results are given in Table 1. Details from the discussion are given in the Appendix. In the USA oil consumption is reported in quarts/hour (qt/h). One qt is 0.946 L. With rough numbers as discussed here, the difference between qt and L can be neglected.

On average, jet engine oil consumption is between 0.2 qt/h and 0.45 qt/h. Older engine types seem to have/had a little higher oil consumption. When engines on these older aircraft (B707, B727, DC8, Gulstream II) are excluded, oil consumption is between 0.2 qt/h and 0.38 qt/h on average.

"In modern, high-efficiency engines, oil consumption is likely to be lower." (**Exxon 2016c**)

Table 1: Summary of collected jet engine oil consumption in qt/h, thrust in kN

		oil consumption						
Aircraft	Engine	medium low	medium	medium high	limit	thrust	Source	Remark
A340	CFMI CFM56-5C	0,250		0,500		143	airliner.net 2016	
A340	CFMI CFM56-5C	0,250		0,500		143	airliner.net 2016	
B747	RR RB-211	0,125		0,250	1,100	279	airliner.net 2016	
many	GE CF6		0,125	0,250	0,550		airliner.net 2016	
B747	GE CF6	0,125		0,250		279	airliner.net 2016	
many	PW4000				0,500		airliner.net 2016	
(B757)	PW2000				0,600		airliner.net 2016	
many	PW JT9				1,000		airliner.net 2016	
B727/DC9	PW JT8D				0,500		airliner.net 2016	
B727	PW JT8D		1,000				airliner.net 2016	
Gulfstream II/III	RR Spey RB.163 Mk 511-8		0,900				airliner.net 2016	
Bombardier CRJ200	GE CF34-3B1				0,200	39	airliner.net 2016	
PC-12	PW Canada PT6		0,250				airliner.net 2016	turboprop
B787	RR Trent 1000		0,100			320	airliner.net 2016	
B787	GE GEnx	0,330		0,500		320	airliner.net 2016	
A320 / MD90	IAE V2500		0,300			120	airliner.net 2016	
DC9	PW JT8D				0,900		yahoo.com 2008	normal use
DC9	PW JT8D			0,300			yahoo.com 2008	ETOPS limit
B707 / DC8	P&W TF33 / JT3D			1,000			yahoo.com 2008	
A320	CFMI CFM56		0,300			120	Lufthansa 1999	
A320	IAE V2500	0,100		0,500		120	Linke-Diesinger 2010	
average		0,197	0,425	0,450	0,669			
Selected Data Items								
A320	IAE V2500		0,300				airliner.net	
A320	CFMI CFM56		0,300				Lufthansa 1999	
A320	IAE V2500	0,100	0,300	0,500			Linke-Diesinger 2010	
			0,300					
A340	CFMI CFM56-5C	0,250	0,375	0,500			airliner.net	
A340	CFMI CFM56-5C	0,250	0,375	0,500			airliner.net	
			0,375					

When only reported extreme values are excluded, oil consumption ranges from 0.1 qt/h and 0.5 qt/h. This yields an average oil consumption of 0.3 qt/h. These values are also reported in the two reliable sources.

Gassart 2015 reports about engine oil consumption at Safran (Snecma). Fig. 50 and 51 in his thesis show about 0.5 L/h, Fig. 52, 53, 54, 56 show 1 L/h. This reported oil consumption seems to be quite high and is not considered further.

Engine manufacturers specify limit values for the oil consumption. Once reached, the engine needs to be inspected for the cause of the higher than normal consumption. Limit values range from 0.2 qt/h for a smaller engine (CF34) to 1.1 qt/h for a larger and older engine (RB-211). On average the consumption limit is at 0.67 qt/h.

Relative oil consumption correlates with engine size (expressed by the engine's nominal thrust) as can be seen in Figure 12. Larger engines have less relative oil consumption.

Absolute oil consumption correlates less well with engine size. There is not sufficient data available to determine, if absolute oil consumption increases continuously with engine size (Figure 13). From given data it could even be concluded that larger engines have less absolute oil consumption than smaller engines. This is not an intuitive result. What can be learned, however, from the data is that individual engine design (layout principles and design philosophy) can influence oil consumption more than simply the size of the engine.

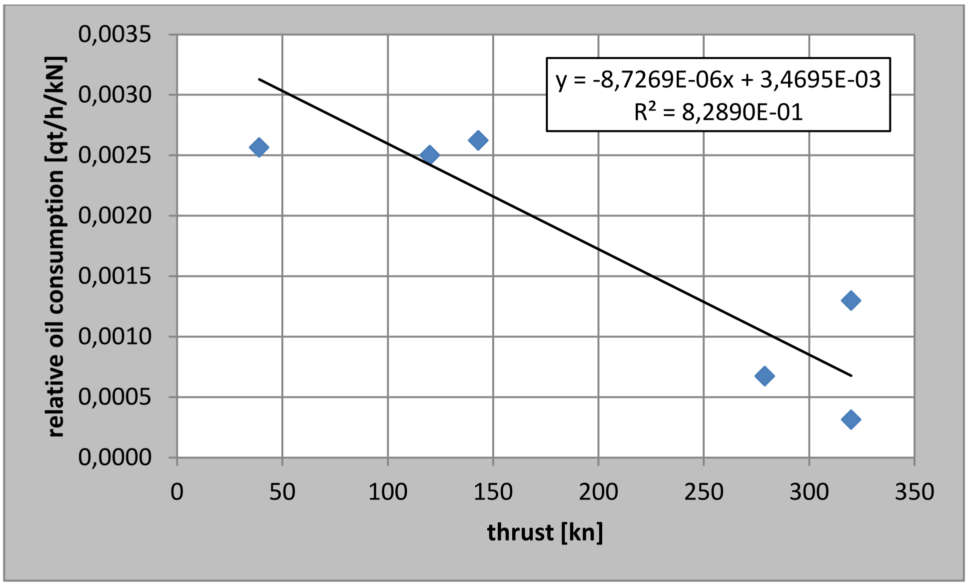

Figure 12: Relative oil consumption correlates well here with size.

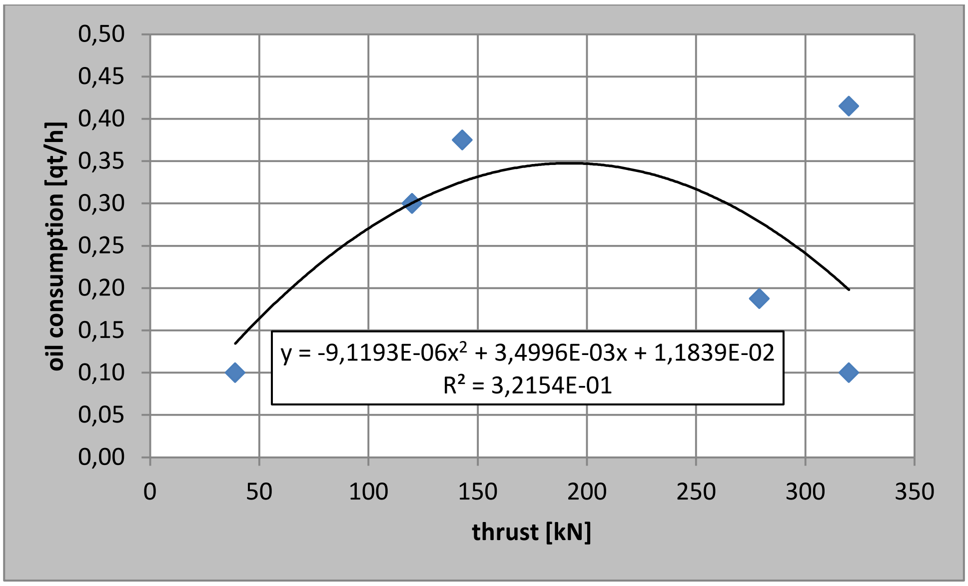

Figure 13: Absolute oil consumption does not correlate well with size. Up to 200 kN absolute oil consumption seems to increase with thrust, but for larger engines no clear trend can be seen here with limited data.

7 Oil Consumption Monitoring

A monitoring system provides information to the aircraft avionics about engine health. The engine oil level (EOL) in the tank is one such parameter. The oil level depends on many other parameters and is normalized by the Health and Usage Monitoring Systems (HUMS) for Condition-Based Maintenance (CBM). (**Exxon 2016a**)

The main parameters having an effect on the oil level are (**Gassart 2015**):

- engine oil temperature (EOT),
- engine shaft rotation speed (n)
- flight altitude (h).

"A typical maintenance program requires checking engine oil before every flight ... and the auxiliary power unit (APU) oil less frequently (such as every 100 hr). The quantity of oil added and flight hours for each leg should be noted in the maintenance logbook. The oil consumption rate, the amount of oil used per hour of operation on the previous flight leg, should be calculated for both engines and the APU during ETOPS before dispatch. The resulting number [in qt/h] provides a better indication of oil usage or loss than the quantity of oil added [in qt]. If the rate is acceptable, the flight can be released; if not, the cause of the increased usage must be addressed before dispatching the airplane on an ETOPS flight. This increase can frequently be caused by an oil leak." "The consumption rate data is also logged to track longterm variations in consumption rates." (Figure 14) "This allows the operator to determine if problems are developing so they can identify and implement solutions before serious engine or APU degradation occurs." (**Kinnison 1999**)

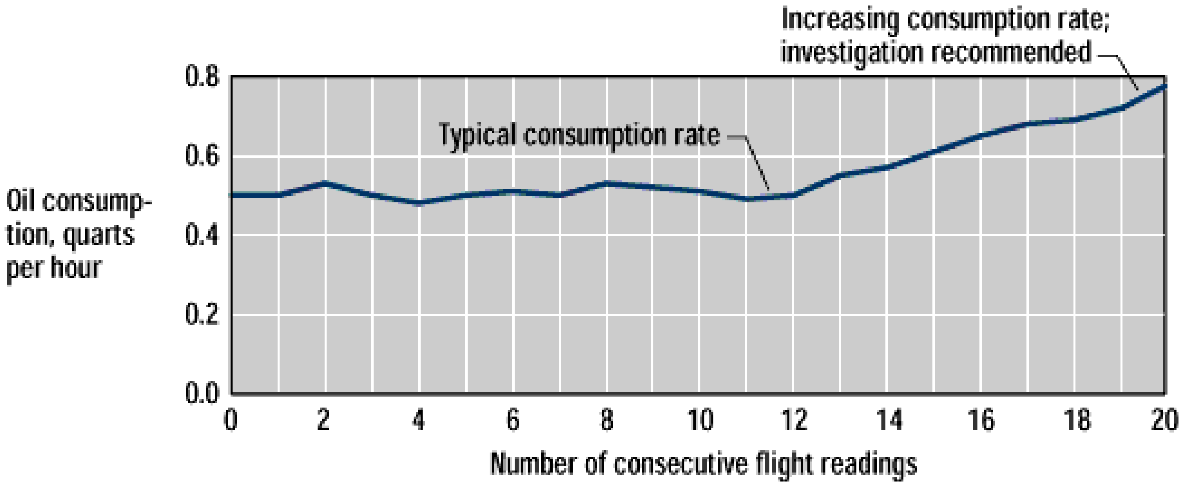

Figure 14: Oil consumption as it can possibly increase with an engine malfunction developing. Engine health monitoring can spot such developments. (**Kinnison 1999**)

8 Discussion and Summary

Based on Chapter 2 it should be possible to find the number of bearings of a jet engine, if an engine drawing or detailed diagram is given. Based on the same engine drawing and with help of Chapter 5 it is possible to find the number of bearings upstream of the bleed ports. The oil system was discussed in detail. Most of the oil consumption is caused by the inefficiency of the de-oilers or de-aerators. Only a small percentage of oil (e.g. 2%, **Scholz 1997**) is expected to go through the seals into the compressor. However, this small percentage can drastically increase when labyrinth seal clearances have naturally grown as engines age or if the engines get damaged under high g-loads (as explained by **Exxon 2016c** in Chapter 4). Figure 14 shows that oil consumption can double. If worn seals are the cause of doubling oil consumption, the percentage of oil loss through seals will go up from 2% to 50%. For the calculation of a generic jet engine, the absolute oil consumption can be estimated to be 0.3 qt/h ≈ 0.3 L/h.

Nomenclature

APU	Auxiliary Power Unit
CBM	Condition-Based Maintenance
EOL	Engine Oil Level
EOP	Engine Oil Pressure
EOT	Engine Oil Temperature

ETOPS	Extended-range Twin-engine Operational Performance Standards
HP	high pressure
HUMS	Health and Usage Monitoring Systems
IP	intermediate pressure
LP	low pressure
LTT	Lufthansa Technical Training
N	shaft rotational speed (RPM)
RPM	revolutions per minute

Units

L	litre. 1 L = 1/1000 m^3
gal	gallon. 1 gal = 3.785411784 L
qt	quarts. 1 qt = ¼ gal = 0,946353 L
pt	pint. 1 pt = ½ qt
oz fl	fluid ounce. 1 oz fl = 0,03125 pt

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Appendix:
Evaluation of Internet Discussions on Jet Engine Oil Consumption

Two Internet discussions are analyzed numbered here i) and ii).

Text shaded grey was added to the original text – mostly due to conversion to qt/h to allow comparison of numbers.

i) "Turbine Engine Oil Consumption"

http://www.airliners.net/forum/viewtopic.php?t=765437

Collection of text from the discussion:

... should be well below a quart an hour.

The CFM's on A-340's almost always required 2 or 3 quarts of oil each at the end of a 7-8 hour flight, sometimes even four quarts.
0.25 qt/h ... 0.5 qt/h
The RB-211's on 747's usually took 1 to 2 quarts. **0.125 qt/h ... 0.25 qt/h**
Trent 500's and 700's often did not require any uplift.
CF6's usually took a quart. **0.125 qt/h**

Oil Consumption Limits

Our PW4000 engines have a **.5qt/hour** limit.
Our CF6 engines are limited to **.55qt/hour**. We start looking for a problem at **.25qt/hour**.
Our PW2000 engines are limited to **.6qt/hour**.
Our RB211 engines are limited to 2.2pints/hour. (**1.1 qt/h**)
To contrast, our JT9 engines were limited to **1qt/hour**
CFM's on our 340's use the most, never less than 2 quarts, sometimes up to 3 or 4 over a 7-10 hour flight.
0.25 qt/h ... 0.5 qt/h
CF6's on our jumbo's usually take a can, sometimes 2.
0.125 qt/h ... 0.25 qt/h

JT8D: ... I think we are at a **.5qt/hr limit**.

RR Spey Mk 511-8 ... normal oil loss is **.9L per/hr**.

The **limit** on a cf-34 3b1 (crj-200) is 6.4 oz per hour **(0.2 qt/h)**

The oil consumption rate of a turbine engine is usually affected by changes in engine speed.
A two hour flight to the remote airfield and the engines needed 1 can of oil (**0.5 qt/h**), two hours of touch & go flying it needed six cans! **(3 qt/h)**

PC-12it was one quart every 4 hours in my plane. **(0.25 qt/h)**

The B787 with the Trent uses no oil, same as the Trent on the B777. Just one can now and then
But the B787 with the GENX is much the same as any CF6. It has the oil breather down the centre of the engine, and after shurdown oil drips onto the ground behind the engine. This means that we filled oil every time. The aircraft flew for 6 hrs to get to us and I filled 2 or 3 cans in each engine. **(0.33 ... 0.5 qt/h)**

Back in the 727 days, our engines were not put on H.O.C. watch until they burned more than **1 quart an hour**.

IAE V2500 burns **0.3Qt an hour**.

ii) "I am looking for an oil consumption rate formula for a turbofan P&W engine, can you give me some references?"

https://answers.yahoo.com/question/index?qid=20070626043236AAPa5Vp

Collection of text from the discussion:

I know on dc 9s the highest we where aloud was **.9 per hr**. and etops a/c where **.3 per h**/r. In the manual there WILL BE A MAX. If they are using hrs it will be **below 1**
Source(s): designated line release authority dc9 ,757, 757 etops, 319,320. 330,dc10,747

P&W TF33-100A
must have .25 Gallons per hour of intended flight (**1 qt/hr**)
I believe the TF33 is just military version of the JT8
Source(s): USAF Flight Engineer
(4 qt = 1 US gallon)