

The Trailing Edge

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Why Is There Oil All Over My (Airplane) Belly?

My wife Tuki has a most unusual favorite hobby—cleaning the oil off the bottom of my airplane. Most aircraft owners consider this activity one of the worst parts of aircraft ownership, probably because of the mess and the uncomfortable position of rolling around on your back underneath the airplane. She claims it is wonderfully therapeutic because a single swipe of a paper towel can change the color from ugly black to brilliant yellow. It's cleaning with immediate visual progress.

The oil, of course, is coming out of the crankcase breather, and while most of it achieves its life-long goal of escaping the airplane into the freedom of the atmosphere, some of it strikes the bottom surface of the fuselage and becomes stuck there, accumulating dirt, until my wife comes along and wipes it off.

But this raises the question of why is the oil escaping the crankcase through a “breather”? Wouldn't it be better to keep the oil in the engine where it is supposed to be? Environmental issues aside, I paid good money for that oil and would like to keep it on the job!

Crankcase Volume (Non-)Variations

My first thought was that the volume of the crankcase was oscillating as the pistons happily reciprocated up and down, pushing air in and out the breather with each crankshaft rotation. Spoiler Alert: I was wrong. The total crankcase volume stays the same, even though the pistons move the air inside from one section of the crankcase to another and back with every rotation of the crankshaft. A bit of recreational maths is a fun way to prove this.

Let's do the analysis for my engine, a six cylinder Lycoming O-540. The displacement swept by any piston is 540/6, or 90 cubic inches. We will define zero incremental displacement for any piston as where it is halfway between top dead center and bottom dead cylinder. At this point the crankpin is 90 degrees to the axis of the cylinder. Top dead center would be +45 cubic inches incremental displacement from zero. Bottom dead center would be -45 cubic inches incremental displacement from zero. Cylinders 1 and 2 both reach top dead center together (Figure 1, blue curve). Cylinders 5 and 6 reach top dead center together 120 degrees of crankshaft rotation later (Figure 1, orange curve). Cylinders 3 and 4 reach top dead center together 120 degrees of crankshaft rotation after that (Figure 1, gray curve).

Note that at any crankshaft position, two pistons are on one side of zero and four pistons are on the other side of zero. If two pistons are at zero, then two pistons are positive and two pistons are equally negative. Note at zero degrees rotation, pistons 1 and 2 have a positive incremental displacement totaling 90 cubic inches. Pistons 3 and 4 have a negative incremental displacement totaling 45 cubic inches. Pistons 5 and 6 have a negative incremental displacement totaling 45 cubic inches. Adding up all of the incremental displacements gives a sum of zero cubic inches.

Let α represent the crankshaft position. Mathematically, we can represent the incremental displacement (ID) as

$$\text{Incremental Displacement} = 90\cos(\alpha) + 90\cos(\alpha - 120) + 90\cos(\alpha - 240)$$

From those halcyon days of trigonometry class, we remember...okay, we looked it up in a reference book:

$$\cos(A - B) = \cos A \cos B + \sin A \sin B$$

Using this identity for the phase shifted terms

$$\text{ID} = 90\cos(\alpha) + 90\cos(\alpha)\cos(120) + 90\sin(\alpha)\sin(120) + 90\cos(\alpha)\cos(240) + 90\sin(\alpha)\sin(240)$$

Substituting known values

$$\text{ID} = 90 \left(\cos(\alpha) - \frac{1}{2}\cos(\alpha) + \frac{\sqrt{3}}{2}\sin(\alpha) - \frac{1}{2}\cos(\alpha) - \frac{\sqrt{3}}{2}\sin(\alpha) \right)$$

Simplifying

$$\text{ID} = 90(\cos(\alpha) - \cos(\alpha)) = 0$$

Thus, the incremental displacement of the pistons moving is always zero, regardless of the position of the crankshaft. The same result can be shown for a four cylinder engine with a 180 degree phase angle.

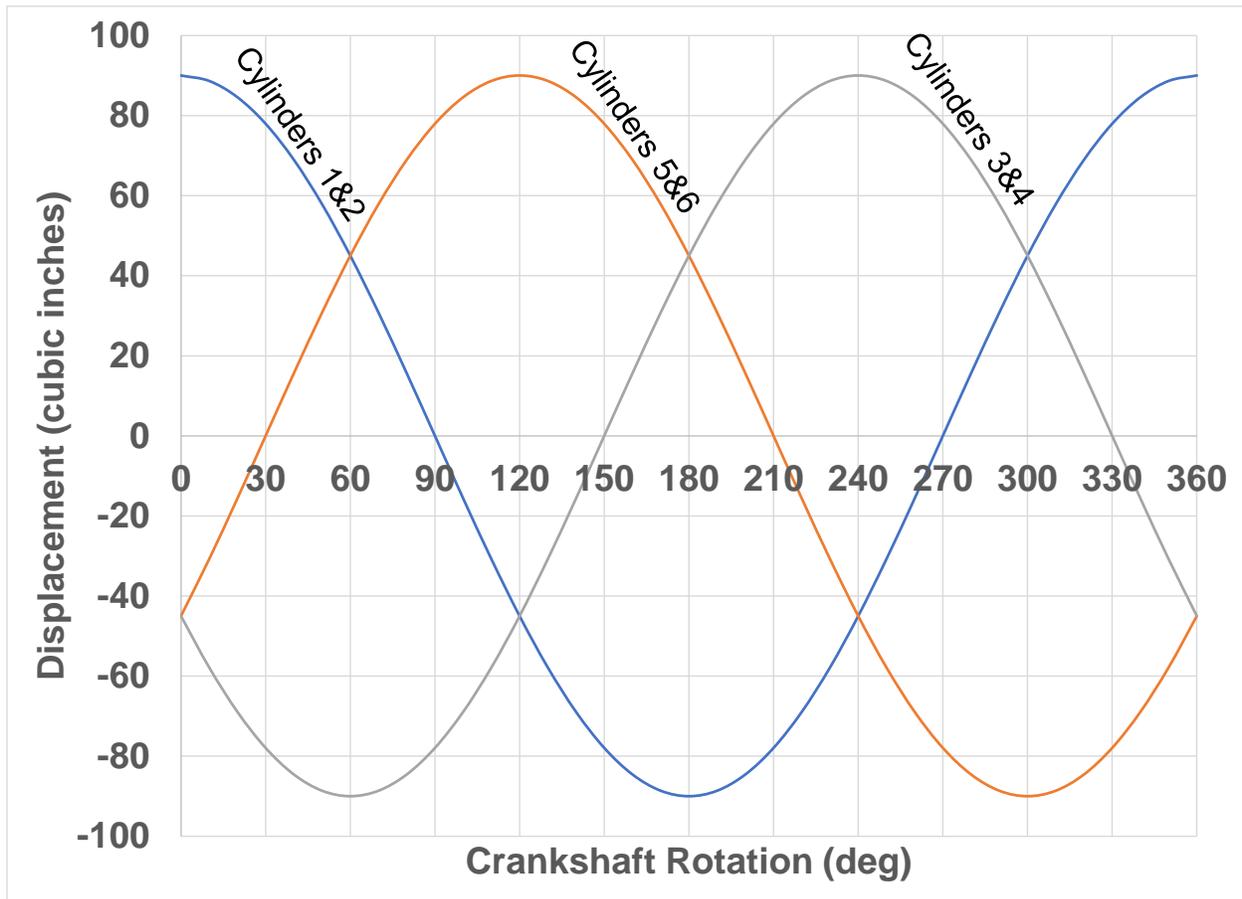


Figure 1. Six Cylinder O-540 Incremental Displacement

Where The Pressure Comes From

Piston engines create their power by burning fuel with air in the cylinders to produce high pressure. The piston sliding in the cylinder is sealed by the piston rings. While the piston rings make an amazing seal, the seal is not perfect. The high pressure in the cylinder forces tiny amounts of unburned fuel plus products of combustion (including water) past the piston rings into the crankcase. While it is not much, with over 7000 combustion events per minute, a tiny bit here and a tiny bit there eventually add up to a significant amount of gas that wasn't in the crankcase before, raising the pressure and looking for a path to escape. If the blow-by gasses remain in the crankcase, they may condense, forming sludge and diluting the oil with unburnt fuel.

If the crankcase is sealed, this pressure will grow until it creates a way to escape, usually by busting through a gasket or other seal. Said seal was probably installed with the intention of keeping the oil in the crankcase, and this new gas escape path also provides an avenue for the oil to escape as well, creating undesirable leaks.

In many applications, such as automobiles, an escape path for the crankcase gasses is provided to the intake manifold. The pressure in the crankcase is generally above atmospheric, and the pressure in the intake manifold is less than atmospheric, especially during partial throttle operation, which for cars is most of the time. This pressure difference moves the blowby gasses from the crankcase to the intake manifold, where they then pass through the cylinders and out the exhaust pipe. Of course, a tiny amount squeezes past the rings into the crankcase and gets to make the trip again! This flow is regulated by a valve known as the Positive Crankcase Ventilation (PCV) valve. At low power settings, the intake manifold pressure is very low and would draw in excessive crankcase gasses, which would lean the mixture and make the engine run rough. In this condition, the PCV valve closes to restrict the flow. A PCV valve also acts as a flame arrester to prevent positive pressure, such as from a backfire, from entering the crankcase by acting as a check valve.

Because aircraft engines run mostly near Wide Open Throttle (WOT), the pressure in the intake manifold is only slightly less than atmospheric pressure, meaning there is little difference in pressure between the intake manifold and the crankcase. The PCV system on automotive engines relies on an intake manifold pressure lower than the crankcase pressure to draw the blowby gasses out. With little difference in these pressures, the benefit of a PCV system is lost. In the case of a supercharged engine, the intake manifold will probably be at a greater pressure than the crankcase, so a typical PCV system would pressurize the crankcase, which is the reverse of the desired result. Thus, aircraft engines typically use a crankcase breather, which is mostly just an open vent to the atmosphere to let gasses out of the crankcase.

This breather is usually connected to a tube which ends where the engine cooling air exits the cowling, which releases the gasses into this generally low pressure area. One concern with this configuration is in icing conditions, when ice can build up in this tube and eventually block it, causing the crankcase to pressurize and sprout new oil leaks in random locations. To mitigate this, manufacturers typically put a small hole or slot in the breather tube up inside the cowling in an area which should not ice as an emergency pressure relief.

If The Crankcase Breather Is There To Release Blowby Gasses, Why Is There So Much Oil On My Belly?

To answer this question, we need to understand the lubrication system in the crankcase. What follows is a description of the lubrication system in a typical Lycoming engine and specific to the engine in my Bearhawk. Text that is indented is quoted directly out of a Lycoming engine manual (Ref 1).

The lubrication system is of the pressure wet sump type. The main bearings, connecting rod bearings, camshaft bearings, valve tappets, push rods and crankshaft idler gears are lubricated by means of oil collectors and spray. The oil pump, which is located in the accessory housing, draws oil through a drilled passage leading from the oil suction screen located in the sump. The oil from the pump then enters a drilled passage in the accessory housing where a flexible line leads the oil to the external oil cooler. In the event that cold oil or an obstruction should restrict the flow of oil to the cooler, an oil cooler bypass valve is provided. Pressure oil from the cooler returns to a second threaded connection on the accessory housing from which point a drilled passage conducts the oil to the oil filter adapter, which is located on the accessory housing below the tachometer drive.

A thermostatic valve (trade name Vernatherm) is installed in the oil filter adapter. When the oil temperature is below 185°F, an open port (the oil cooler bypass valve) allows oil to pass directly from the oil pump to the oil filter, bypassing the oil cooler. This allows the oil to come up to operating temperature quicker by not passing through the oil cooler. The lines to the oil cooler remain open, so that a small amount of oil is continually directed to the oil cooler to keep oil circulating through the cooler to keep it from going dry.

When the oil reaches a temperature of 185°F, the plug at the end of the Vernatherm extends up to 0.194 inches and closes the bypass port, forcing all oil from the oil pump to be routed to the oil cooler. If a pressure drop greater than 75±15 psi develops in the oil cooler, such as by congealed oil or an obstruction, a spring on the Vernatherm will compress to open the bypass port, allowing oil to continue flowing to the engine.

A flexible line leads the oil to the remote full-flow oil filter. The oil filter is provided to filter from the oil any solid particles that may have passed through the suction screen in the sump. The Champion CH48108 or CH48109 full flow oil filters are equipped with an internal bypass valve which will allow lubricating oil to bypass the filter in the event the filter becomes plugged, or the oil temperature is extremely cold.

After being filtered in the oil filter, the oil is returned to the oil filter adapter and passes over the oil temperature sensor. From there

the oil is fed through a drilled passage to the oil relief valve, located in the upper right side of the crankcase in front of the accessory housing.

This relief valve regulates the engine oil pressure by allowing excess oil to return to the sump, while the balance of the pressure oil is fed to the main oil gallery in the right half of the crankcase. During its travel through this main gallery, the oil is distributed by means of separate drilled passages to the main bearings of the crankshaft. Separate passages from the rear main bearings supply pressure oil to both crankshaft idler gears. Angular holes are drilled through the main bearings to the rod journals. Oil from the main oil gallery also flows to the cam and valve gear passages, and is then conducted through branch passages to the hydraulic tappets and camshaft bearings. Oil enters the tappets through indexing holes and travels out through the hollow push rods to the valve mechanism, lubricating the valve rocker bearings and valve stems. Residual oil from

the bearings, accessory drives and the rocker boxes is returned by gravity to the sump, where after passing through a screen it is again circulated through the engine. Pressure build-up within the crankcase is held to a minimum by means of a breather located on the accessory housing.

Oil from the main galleries sprays on the camshaft through Ney nozzles.

The main bearings and connecting rod bearings on the crankshaft are fed pressurized oil, but these bearings are not sealed. In fact, the oil is smeared around the bearings by their relative motion and eventually the oil is pushed out the sides of the bearings. Because the crankshaft that these bearings are on is spinning rapidly, that oil is slung all over the inside of the crankcase, much like a Jackson Pollock painting. With all of the movement in the crankcase, oil is slung everywhere, creating an atmosphere of oil mist. This oil mist provides the primary form of lubrication for everything not served by the pressure oil system, including the cam lobes and cam followers, cylinder walls and pistons, connecting rod small ends and wrist pins, and the gear teeth of accessory gears.

Besides providing lubrication, oil is also the primary cooling medium for internal engine parts. These internal parts, including the pistons, transfer heat to the oil they come in contact with. That oil takes the heat away, cooling the part, with the oil eventually making its way to the oil cooler to reject that heat into the atmosphere.

Back To The Blowby Gasses

So, the blowby gasses are pushed past the piston rings by the high pressures in the combustion chamber, and these gasses need to escape the crankcase through the crankcase breather. As we have just seen, to get to the breather, these gasses have to travel through an atmosphere laden with a heavy oil mist. Thus, some of that oil mist is going to get carried along with the blowby gasses and forced out of the crankcase breather. The crankcase breather outlet is located at the top of the accessory case so that gravity can help minimize the amount of entrained oil.

From there, the gasses and entrained oil make their way down the breather tube and out into the atmosphere, with some of the oil striking and sticking to the bottom of your airplane. Some installations place the end of the breather tube near an exhaust pipe, in hopes that the oil mist will hit the hot exhaust pipe and burn away. In my case, this has not worked effectively. I think the exhaust pipe is too cool at this point after the exhaust has passed through the muffler. I have heard of other installations that vent the breather to the inside of the exhaust pipe, again, hoping to burn the oil mist before it gets on the belly. However, this can lead to problems if sludge builds up in the breather tube and blocks it.

Some aircraft are equipped with an air-oil separator, which attempts to capture the oil and either hold it or return it to the oil sump, while allowing the gasses to pass on. In my Bearhawk, I have a centrifugal separator. The oil-laden gasses are released tangentially into a cylindrical section, where their velocity induces a vortex. The gasses are extracted from the center of the vortex, while the oil stays at the outside of the cylinder, eventually draining back into

What's Up With Ney Nozzles?

As mentioned in the main text, the primary lubrication of the cam lobes and followers is through splash lubrication, that is, the oil mist in the crankcase. This works perfectly fine after the engine has run long enough for the oil mist to build up, but it takes a finite amount of time for the oil mist to build.

In Lycoming engines, the camshaft is at the top of the crankcase, far from the oil sump. When the engine is not running, the oil on the cam shaft can slowly drip off and return to the oil sump. Thus, when starting, especially after days or weeks of sitting, the cam lobes and followers may be very dry and devoid of oil. Because of the shape of the interface between the cam lobe and follower, the pressure between the parts can be very high, sufficient to damage the metal without an oil film present.

In my engine, I use two approaches to minimize wear to the cam lobes and followers on startup. I use the oil additive CamGuard, which through the magic of chemistry that I don't fully understand, strongly encourages the oil film to stay on the cam lobes when not running.

When I rebuilt my engine in 2009, I had the crankcase refurbished by Chuck Ney Enterprises. They installed the Ney Nozzles, which are connected to the main pressure oil galleries and spray oil directly onto the cam lobes and quickly fill the crankcase with the oil mist, much faster than the output of the crankshaft bearings, especially in an engine turning at slow speeds at idle.

These methods seem to be working, as in 13 years of operation and over 800 hours on the engine the regular oil analysis does not show any excessive wear.

Sadly, Chuck Ney passed away, and the former web site for his shop has disappeared. Rumor has it that Crankcase Services Inc.

(<http://crankcaseservices.com/>) can install the Ney nozzles, but I can't confirm this because their web site has very little information.

the oil sump. The operating principal is similar to the household vortex (bagless) vacuum, where the air with little mass can make the tight turn to the center of the vortex, while the more massive dust can't make the tight turn and stays at the outside. It's a great concept, but it doesn't seem to work very well in my case, as evidenced by the amount of oil that shows up on the belly. I suspect the problem is that the velocity of the gasses coming out of the breather is too slow to set up a meaningful vortex in the air-oil separator, and without a fast vortex the centrifugal separation doesn't happen.

The other form of air-oil separator passes the oil laden gasses through a sponge that looks like coarse steel wool. The theory of operation is that tiny drops of oil will hit the sponge and stick to it, while letting the gasses pass by. As the oil drops get bigger, they eventually fall off and drain back to the oil sump.

Air-oil separators are controversial, with the advocates saying that they keep the belly cleaner and cut down on oil consumption. The nay sayers claim that the air-oil separator returns contaminated oil into the oil sump. I don't think this is a valid argument, since the oil did not become contaminated in the air-oil separator. It was already contaminated before it left the crankcase, so returning it in the same condition shouldn't be an issue.

About That Contamination

With the blowby gasses coming around the piston rings into a crankcase filled with oil mist, the gasses interact with that oil mist. Water vapor is a product of combustion of hydrocarbon fuels, and that water vapor can condense and mingle with the oil mist. Because the water droplets and oil droplets are so small, they can mix together in an emulsion instead of separating. Generally, this is not a problem, since the oil passing through the engine will reach temperatures well above the boiling point of water, driving the water out of the emulsion. An indicated oil temperature of 180°F is generally sufficient to boil off the water. As mentioned before, the oil temperature is measured after the oil passes through the oil cooler and oil filter, but before entering the engine. Thus, the oil temperature is measured at the point where the oil is the coolest. At other places in the engine, the oil will be as much as 50°F hotter than the indicated oil temperature. If the indicated oil temperature is 180°F, then at some point the oil will be 230°F, which is more than enough to boil off the water. Any water accumulation in the oil usually happens at engine shutdown, when the water condenses while still in the crankcase. Generally, this water is boiled off the next time the engine comes up to operating temperature. This is one reason why it is good to run aircraft engines frequently.

Raw fuel can be part of the blowby, because during the compression stroke, the contents of the cylinder are fuel and air. Other combustion byproducts are acidic and can accumulate in the oil. To combat this, new engine oil is rather alkaline, such that it can neutralize the acids in the blowby before they can attack the structure of the crankcase. This is why one of the measured properties of oil is the TBN, or Total Base Number. This is a measure of how alkaline the oil is, and can indicate how much longer the oil can be run without becoming acidic.

It is easy to understand why it is recommended to change the oil after so many hours of operation. All of that constant lubricating and shearing eventually breaks the long chain polymers in the oil down into shorter chain polymers, and these shorter chain polymers don't lubricate as well.

However, there are reasons to change the oil based on calendar time even when operating hours are not that much. When the raw fuel gets into the oil, the gasoline will evaporate away at operating temperature like the water, but the lead in the gasoline gets left behind, remaining in suspension in the oil. This is a primary reason that aircraft engines use conventional oil and not synthetic oil. Lead will remain in suspension in conventional oil, but will precipitate out of synthetic oil, leaving sludge in the crankcase. However, excessive lead in conventional oil may eventually precipitate out, leaving sludge, if left too long. Also, the accumulation of acids in the oil creates a corrosion risk if left too long. Many oil manufacturers recommend changing aircraft engine oil at 50 hours if using a full flow oil filter, and 25 hours if using an oil screen. They also recommend changing the oil after 4 calendar months, but they also stand to make money if you change oil more often. I usually change the oil after 6 calendar months, but if operating hours are very low, there aren't many contaminants in the oil, so I may let it go 12 months.

Great, But I Still Have To Go Clean My Belly

So, the condensed answer to the original question is that piston rings don't seal perfectly, so some of the stuff from the combustion chamber makes it into the crankcase. This stuff from the combustion chamber, known as blowby gasses, has to be released through a hole (the crankcase breather) into the atmosphere so that pressure does not build up in the crankcase. If pressure did build up, it would blow out all of the seals, creating oil leaks everywhere. An oil mist is necessary in the crankcase for the lubrication of many critical parts. As the blowby gasses make their way out of the crankcase, they intermingle with the oil mist in the crankcase. The blowby gasses make friends with some of the oil mist and carry the oil out the crankcase breather, where some of it sticks to the bottom of your airplane so that you have something to do at the airport when the weather is not suitable for flying.

- Russ Erb

Reference

1. *Operator's Manual, Lycoming TO-360 Series*, 2nd Edition, Part No. 60297-20, Lycoming, Williamsport PA, 2008.