The Trailing Edge

December 2024

Being Advanced Isn't Always A Good Thing

Getting your comeuppance is never fun, or to say it another way, karma is a b****. For the last several years, when someone asked me how the Bearhawk was running, I would tell them that it had me worried. When they asked why, I would say I couldn't find a single squawk. I was very much in the "I love my airplane" state. You might think that would be the desirable state, but my assumption was that the normal status for an airplane was at least one thing is broken. However, if the fault is not known, it can't be fixed. It was meant as a joke, but this is the story of an unknown problem that slowly grew until finally noticed when it grounded the airplane.

The Context

One of the benefits of flying the same airplane over and over is that you learn what to expect. As built, Bearhawk Three Sigma has a cooling problem, but it is a problem that can be managed. I know what is causing it and what I would change if I were to rebuild the cowling, but the problem isn't bad enough to justify the effort of rebuilding and repainting the entire cowling. Some of the problem has to do with stuffing an O-540 into a cowling originally designed for an O-360. The updated design, as ships with Bearhawk kits, addresses these problems and from what I understand works just fine.

Rather than address the cooling problem through rebuilding, I have chosen to address it through procedure. This procedure has been shown to work reasonably well in ambient air temperatures up to 100°F. Takeoff is done at maximum power with 2700 RPM to get to a safe altitude and airspeed as quickly as possible. While best rate of climb airspeed is about 75 KIAS, I always climb at 100 KIAS to give more cooling airflow over the engine. At an altitude high enough to turn back in case of an engine failure, usually between 500 feet and pattern altitude, I will reduce the RPM to 2400. Reducing the RPM reduces the power produced and also reduces the excess heat produced. This procedure will usually keep the maximum cylinder head temperatures (CHT) between 400°F and 435°F steady state. Upon reaching cruise altitude, I reduce the RPM to 2100, which works well for economy while still at wide open throttle (WOT).

If all of the CHTs cool to around 360°F or below, I can close the cowl flap, which reduces drag an imperceptible amount. This will cause the CHTs to rise, with the happy zone being between 380°F and 400°F. This is cool enough to not worry, but hot enough to promote good lead scavenging.

Houston, We Have A Problem

After finishing the condition inspection in early May, I flew the Bearhawk several times and engine temperatures seemed normal. Having changed nothing mechanically or operationally, while climbing out on 10 August, one of the CHTs reached 442°F (above my threshold of 435°F) with several other CHTs close behind. I stopped the climb and reduced the throttle, flying level for about four minutes to let the CHTs come back below 400°F, then pushed the throttle in for climb power to complete the climb. I had done this before when the outside air temperature (OAT) was 100°F, and after rejecting the initial heating from takeoff power, the CHTs would remain reasonable for the rest of the climb. On this occasion, the OAT was 89°F, which isn't quite 100°F, but still warmer than normal, so I attributed the high CHTs to the high temperature of the cooling air.

On a flight on 24 August, the highest CHT in cruise was 411°F, but the OAT was colder at 62°F. This was a notably higher CHT than normally seen in cruise (usually below 400°F), and it clearly wasn't because of a hot atmosphere. This was still within "limits" so I didn't take any action.

Things started getting hot on 11 October, when shortly after takeoff, the CHTs rocketed through the threshold of 435°F, reaching 445°F before I could get the throttle back. Again, I let the temperatures cool below 400°F, but when I pushed the throttle back in, the CHTs started rising rapidly again. I reached my cruising altitude, but the hottest CHT remained high at 422°F. OAT was 77°F, cool enough that overheating should not have been a problem. I wondered in flight if the cowl flap linkage had failed and the cowl flap had been blown closed. Inspection on the ground showed that the cowl flap was still in the fully open position.

Thinking this was a cooling problem, I inspected the baffle seals around the engine and found that they appeared to be drooping with age, leaving a gap between the seal and the upper cowling, presumably letting the cold intake air escape, rather than being forced down around the cylinders. I spent about a month collecting materials and replacing all of the baffle seals around the engine.

Anticipating that this would solve my problem, I took off on 9 November, and while climbing to altitude, watched as the CHTs rapidly rose past 435°F, at which point I pulled the throttle back and immediately returned to the airport for landing. Replacing the baffle seals had no effect.

WTF, Over?

So if the problem isn't with the cooling air, what else could it be? When we were student pilots, we were taught to put the mixture in the full RICH position when running at high power settings, such as takeoff and climb. The extra rich mixture reduces the peak temperature of the burning fuel because the carbon atoms and hydrogen atoms are all fighting each other trying to join up with oxygen atoms when there aren't enough oxygen atoms to go around. The leftover carbon and hydrogen atoms remain bonded, absorbing some of the thermal energy that the luckier atoms released as they broke apart and joined up with oxygen atoms. Since that thermal energy goes into just increasing the kinetic energy of the hydrocarbons, there is less thermal energy to increase the temperature of the surrounding cylinder walls. This protection breaks down if the fuel flow is insufficient, such that the fuel-air mixture is not as rich as it is supposed to be. I have read many times that fuel injection systems must be adjusted to provide more than a threshold fuel flow at full power, lest the engine overheat from running with too lean a mixture. However, my engine is carbureted, and the fuel flow at full power had not really changed from before the overheating to after the overheating. That didn't seem to be the problem.

One other possibility was that the ignition timing had changed and was now advanced too much. The burning of the fuel-air mixture is timed ideally so that the pressure in the cylinder reaches a maximum when the crankshaft is 15-20° past top dead center (TDC). This is sufficiently past TDC to provide meaningful torque on the crankshaft, but not so late that the pressure doesn't have sufficient time to push on the crankshaft. The burning of the fuel-air mixture takes about 6 milliseconds, which equates to about 90° of crankshaft rotation. To reach peak pressure at 15-20° past TDC, the spark must occur around 25° before TDC. The peak temperature that the burning mixture reaches depends on the pressure (compression) that the burning occurs at. The higher the pressure, the higher the peak temperature. A subtle point is that as the burning continues past top dead center, the temperature starts decreasing as the piston starts moving down, with the increasing volume reducing the pressure. This keeps the peak temperature under control and controls the amount of thermal energy that goes into the cylinder walls.

If the timing is too advanced, the spark occurs earlier, and the fuel-air mixture is burning as the piston is still going up, and reaches its peak pressure closer to TDC, and thus at a higher pressure. Because the pressure of the burning is higher, the peak temperature is also higher. When the peak temperature is higher, there is more thermal energy going into the cylinder walls, increasing the CHTs. Additionally, because the burning is complete earlier in the crankshaft rotation, it has more time to cool as the cylinder volume expands, resulting in a lower exhaust gas temperature (EGT), even though the peak temperature was higher.

Beware of Your Assumptions

This theory of overheating because of excessively advanced timing is all well and good if your engine uses magnetos. It is easy to understand how magnetos can get out of timing. It could be as simple as the little clamp holding the magneto in place is a little too loose and the magneto turns a few degrees, which advances the timing a few degrees. Also, there are a lot of plastic parts (non-conductive) in a magneto that could wear or break. Many an engine has gone from smooth running to scarily rough just because one gear tooth broke in a magneto, upsetting the timing.

However, such a problem could never occur in my airplane, because my engine has dual Lightspeed Engineering Plasma III electronic ignition. There are no adjustments on the ignition boxes that I could mis-set to cause a timing problem. I checked the pickup behind the flywheel to see if it had moved, and it was still securely lined up right where it should be. With no way to adjust the timing, how could the timing be out of adjustment?

Time to Call In the Cavalry

Having now eliminated every conceivable problem that could cause overheating (leaking cooling air, insufficiently rich mixture, excessively advanced ignition timing), I still had an engine that was overheating in spite of my analysis.

I hadn't signed up for any aviation maintenance service in the past, because having an experimental, I did my own maintenance, so I didn't need someone to represent me when dealing with the mechanic's shop. I didn't think I needed the consultation of an expert, because having studied internal combustion engines in great detail since 1993, I considered myself an expert in engine diagnosis. I've made computer models of engines and written and published many articles about engines. However, something was wrong, and I was at an impasse, unable to make progress. I had slipped all the way over into the "I hate my airplane" state. It was so depressing that I didn't want to think about it. Fortunately, I was able to see that it was time to seek some outside help.

I have long been a fan of the work of Mike Busch, having read his books, read his articles, listened to his webinars, and listened to his podcasts. His company, Savvy Aviation, offers a subscription service for aircraft maintenance advice and representation, which is great for owners of certified aircraft that are forced to have someone else fix their problems. I didn't need the representation, but Savvy does offer a service where you can upload engine monitor data and ask their experts to look at it and make recommendations about what problems the data might indicate. After all, they look at thousands of data sets, so they get pretty good at reading the data. I decided that this was probably my best option, so I signed up for the service for $189 a year.

At this point, it seemed like a reasonable deal, since the only idea I had was to replace the carburetor, which would have cost around $1334, and I had low confidence that would solve the problem, since the fuel flows hadn't really changed. I uploaded the full set of engine data that my engine monitor had, which went back to the last condition inspection. I opened a trouble ticket, described my problem, and waited for a response, hoping desperately that someone would see something that I wasn't seeing.

After the standard welcome messages, my analyst asked a few establishing questions, like had any work been done on the airplane (No), was I flying at a slower airspeed than before (No), do the baffles look good (Yes, just replaced), do you have cowl flaps (Yes, they are full open), and has the mag timing been checked (what mags?). I told him "Mag timing is NA. The engine has dual Lightspeed Plasma III ignition. The ignition modules do connect to Manifold Pressure. He did some more research, looked at the data in detail, and asked some more questions. I responded to his questions, and asked if there was possibly a problem with the carburetor that would cause it to deliver less fuel flow at full rich. He said that the carburetor maximum fuel flow is determined by the orifice size. While there are shops that can adjust the orifice size, that wouldn't explain an increase in CHT over time. After all of this discussion, he said "After talking with a colleague with lots of experimental knowledge, we do recommend looking towards the ignition timing."

Time To Talk To Lightspeed Engineering

At this point, I started to realize that my assumption that the problem could not be in the ignition boxes might be invalid. I sent an email to the contact at Lightspeed Engineering, manufacturer of my ignition systems, which happened to be Klaus Savier, the President of the company. I described my problem, and included that the Savvy analysts suggested that my problem might be excessively advanced ignition timing.

I waited for his reply, desperately afraid he was going to say what I had assumed, that there was no way the box could get out of adjustment.

But that's not what happened. Klaus replied "Your systems are 18 years old. I recommend that you send the two boxes for upgrades and repair. Then we know for sure that there is no problem with the system."

Since Lightspeed Engineering is at the Santa Paula airport, about a 1.5 hour drive from home, I decided to drive the boxes down there rather than shipping them. While there, I asked about how the timing could possibly change. Klaus said that electronic components can degrade with time. For example, consider a capacitor that you expect never to see more than four volts, so you install a capacitor with a six volt rating. Over time, that capacitor degrades until it cannot handle four volts, and thus fails. You don't know which components are going to fail with time, so you build it and wait for it to happen. When it happens, you replace the part with a better part, such as a ten volt capacitor. Now I understood that there was a mechanism for the boxes to fail.

A few days later, I went back to pick up the repaired boxes, and Klaus mentioned that while testing before making repairs, he had indeed found that one of the boxes was firing with excessively advanced timing. Just what I wanted to hear. There was a New Hope, and it had nothing to do with Luke Skywalker or his sister Princess Leia.

Why Didn't I Think of That

Sometime, long after I had the airplane disassembled, I realized that I could have done a simple test in flight to indicate if ignition timing was the problem. Assuming that only one of the two boxes would have failed, I could have tried turning off one ignition box at a time while in flight. The engine temperatures should have returned to normal when running on the good system, and increased when running on the bad system. Of course, that would have required me to accept that there could be a problem in the ignition system.

Yep, That Was Your Problem!

After assembling all of the parts I needed, I finally reinstalled the ignition boxes and carefully reassembled the airplane. On the morning of 23 December I made a test flight, climbing according to my normal procedures to 5000 feet AGL. This time the CHTs behaved themselves, with none of them exceeding 400°F. I flew for 1.2 hours, and the engine behaved just like it did before the overheating problem reared its ugly head.

Hindsight Really Is 20/20

Now knowing what I am looking for, I can see the problem developing in the engine monitor data. Because of funding constraints, flying this year was very constrained, so there aren't a lot of flights to look at. It didn't help that I spent the month of September and part of October with a bum foot that made me concerned about being able to get the airplane out of the hangar safely. Here is a summary of data pulled from the engine monitor.

Date	Maximum CHT During Climb (°F)	OAT (°F)	Takeoff Fuel Flow (gal/hr)
12 May 2024	406, 403	66	23.5
27 May 2024	402	66	21.3
7 June 2024	393	83	21.9
10 June 2024	396	75	22.2
20 June 2024	423	72	21.8
6 July 2024	424	94	21.4
6 July 2024	427	76	21.5
3 August 2024	441, 410, 408	86	21.6
10 August 2024	442	89	21.9
10 August 2024	420	73	20.8
24 August 2024	411 (cruise)	62	21.4
11 October 2024	445 (422 cruise)	77	21.8
9 November 2024	437	55	21.5

The first flight after the condition inspection was on 12 May. The flights from 12 May through 10 June all fall within expected ranges based on prior operation of the airplane. The problem seems to have first expressed itself in the flight on 20 June. The maximum CHT is significantly higher than the previous flight, but at a similar OAT. It wasn't noticed at the time because it didn't exceed the warning threshold. The next two flights on 6 July showed a similar issue, even though the OAT on one flight was significantly higher.

The problem really grew on 3 August. On this day, we were taking photos from the ground of takeoffs and landings, so this flight consisted of three separate patterns, each to a full stop landing. Because each of the flights only climbed to pattern altitude, I did not notice the temperature exceedance on the first flight. Strangely, the second and third flights did not get as hot, but Klaus had said that the problem I was having can be intermittent. Even so, the temperatures were still higher than they should be at pattern altitude.

Finally, the problem was hinted at on 10 August, and clearly identified on 11 October.

Looking at the fuel flows, we see no real change with time, which eliminates concern that there might be a problem with the carburetor.

Bonus Analysis

I posted the engine monitor data from the 23 December test flight to Savvy Analysis so that my analyst could see that everything was back to normal. To explain a sudden spike in the EGT trace, I mentioned to him that I had done an in-flight "mag check" at that point. Being the excellent analyst that he is, he looked at the traces to see if EGT increased when one of the ignitions was turned off. (EGT would increase because it takes longer for the whole fuel-air mixture to burn than when each spark plug only has to burn half of it. Because it takes longer, it hasn't cooled as much before going out the exhaust valve.) He noted that for one ignition, the EGT on cylinder #3 dropped when it should rise. He recommended that I check the spark plug for that ignition in cylinder #3. Since I didn't know which one it would be, I started with the lower plug, since I have only seen lead fouling on the lower plugs. Sure enough, the lower plug on cylinder #3 was heavily fouled, as seen in these pictures. Rather than try to clean the plug, I simply replaced it with a new plug.

Added Instrumentation

On the Lightspeed Engineering web site, the list of products includes a small display that can be ordered that will give a readout of manifold pressure, RPM, and the current spark advance for each ignition system. As this is the only way I found to measure the spark advance (especially airborne), I requested to purchase such a display. I found out that this display was no longer available for purchase, because many EFIS displays and engine monitors now available can accept and display those inputs. Also, the millivolt meter displays that he had been using were getting more expensive and harder to obtain.

Unfortunately, my EFIS displays and engine monitor are old enough that they don't accept external inputs. As a compromise, I asked him to add the necessary wires for these data to my connectors. The DSub connectors required soldering and had many other wires already in the way. I figured that rather than struggle with doing it myself, I would just pay the man who already knows how to do it instead.

I ran these wires to another DSub connector behind the panel where I can plug in a diagnostic harness for checking the spark advance with a multimeter. This will be available on the ground or in flight. If I suspect the timing has shifted in the future, this will allow me to measure it directly. At a minimum, the spark advance can be checked as part of the annual condition inspection.

Epilog

If you don't already, I highly recommend that you listen to the "Ask the A&Ps" podcast, sponsored by AOPA. It is released on the 1st and 15th of the month. Mike Busch, Colleen Sterling, and Paul New answer call-in questions about people's thorniest aircraft maintenance problems. It's a great way to learn about diagnosing problems, and will certainly help when you find yourself trying to diagnose your own problem.

One of the things they say over and over is that your airplane should have an engine monitor. All of the analysis I have talked about was possible because there were data available recorded by the engine monitor. If I didn't have an engine monitor, the problem I had could have gone unnoticed for much longer, especially if the lone CHT probe happened to be on the one cylinder that wasn't overheating. That could have easily led to engine damage well in excess of the cost of an engine monitor. Engine monitors are readily available now, unlike thirty years ago, and at a price that makes having one an obvious decision.

It's good to be back to "I love my airplane".

- Russ Erb