ANATOMY OF AN EXHAUST VALVE FAILURE

By W.B. "John" Johnson, TTCF Member (and Tony Saxton)

Some years are like diamonds, others like stones. Last year was the latter for me. The reason? My observational skills, or lack thereof. I've owned and flown our C414 (1100 hours since RAM VI) for five years. It's well maintained and equipped, and pertinent to this discussion, that includes a JPI 760 engine analyzer. December is annual time so that in January, the airplane is ready to fly. After last year's annual everything worked great…for the first three flights. On flight four the left engine MP dropped to ambient, so I headed back to the shop. Long story short, my mechanic removed the oil filter and found metal – lots of it. Same for the prop governor. The starter adapter had failed, sending shrapnel throughout the oil galleries. Much money and time later we were back in the air again with a new limits overhauled left engine.

Failed exhaust valve results in engine shutdown and slow ride home for Thanksgiving.

Life proceeded apace until July, when I flew the extended family to northwest Iowa on the 4th. #1 son Trace is my ASMEL rated co-pilot. Coming home between Kansas City and Springfield, MO, at 15,000 MSL, severe clear, the right engine suddenly began vibrating. The #3 cylinder was cold – no EGT, no CHT. The other cylinders, oil temp, pressure and fuel flows looked fine. There was nothing alarming around the right engine cowling. It was still developing some power. The mag switch did nothing useful. There were dozens of airports within gliding distance and we were almost home, so we decided to continue on 1 ½ engines with hawk-like eyes on every gauge. The upshot was that a stuck exhaust valve had broken and exited the engine via the exhaust system, trashing the turbocharger on its way out. More big bucks were sucked into the black hole and we were airborne once again.

Recall I mentioned the JPI guage earlier. I had been having problems with my old laptop computer and couldn't download the JPI data. Downloading was a hassle anyway, so as long as the real time display didn't detect any anomalies I figured downloading three or four times a year was sufficient. My bad.

Fast forward 25 flight hours to November 24. This time it's me, my #2 son Ian (an airline captain) and family, coming home to Ozark from Minneapolis for the holiday. It was cool and severe clear at 15,000' with lots of airports within gliding range (again). We were almost home to Mama, and dang if it didn't happen again! This time the left engine vibration seemed a bit worse, and the JPI showed cylinders 2, 4, and 6 all cold and the manifold pressure was way down. Oil pressure and temperature were in the green, the other JPI temps were fine. The cowling looked OK to Ian. We didn't know wutnhell was busted that caused three cylinders to chill. There was nothing to do but feather it and hobble home – Happy Thanksgiving.

Upon investigation, we learned the #2 cylinder exhaust valve face fractured. We found the fragment in the intake crossover pipe so there was no turbo damage. Lucky me. Two more T notes in The Hole and I was back flying again.

Now I was getting paranoid. Three partial engine failures with one mandatory shutdown within ten months? I've been flying for 46 years and never had an engine failure of any kind – what was I doing wrong?

Broken valve #1 and the damage it caused before exiting the cylinder and the airplane through the exhaust system.

The starter adapter failure was an "It happens" thing. After the first exhaust valve failure, I sent some photos (see above) of the carnage to the Cessna Pilots Association. According to Mike Busch (and later confirmed by Tony) the first failure had the ear marks of a stuck valve – rare in big bore Continentals.

The second failure occurred on the heels of the first, so I assumed it was another stuck valve. The advice from CPA this time was to contact an engine shop in Tulsa, whose owner stated that "something was stressing the engine" and recommended a top overhaul. That advice was less than satisfying: Did I want to spend that kind of money and time on cylinders whose compressions, boroscope inspections, and oil analyses were fine, not knowing what I was looking for? Still unable to download the JPI data, I decided to buy one of JPI's

Direct–to-USB devices, and contact TCF.

Exhaust valve piece from failure #2. We found it in the intake crossover pipe.

The downloading doohickey finally arrived so I attacked the 414 with it and these questions: Why did a valve fail again? Why did three cylinders go cold? What might the oil analysis and JPI data tell me? Rather than trying to muddle through my educational process, let me turn it over to Tony Saxton here:

"This is a textbook example of a valve failure. Exhaust valves run very hot in normal operation and if exposed to the combustion flame temperatures all alone they would rapidly melt. To maintain its integrity, a valve must transfer that heat away from it. In a TCM engine this is done primarily through the valve-valve seat interface and then into the surrounding cylinder fins to the cooling air stream. The valve is closed approximately 3/4 of the time, during which its face is transferring heat.

Failure starts when the valve/valve seat doesn't seal well, creating a spot on the valve face that doesn't transfer the heat well. This causes the spot to overheat and begin to warp thus creating even more leakage in a worsening spiral of cause and effect. The warping and uneven face heating create "hoop stress" cracking; small radial cracks at the edge that can then grow to a large chunk failure.

Causes are primarily three things:

1) Initial machining fit: If the valve face is not ground to fit the seat properly the mismatched surface will soon exhibit leakage and at some point will start to overheat with the above mentioned results.

ELEMENTS IN PARTS PER MILLION		UNIT / LOCATION AVERAGES						UNIVERSAL AVERAGES
MI/HR on Oil	17		41	37	37	25	35	
MI/HR on Unit	1,053		1,017	1,031	995	942	891	
Sample Date	11/02/10		05/24/10	12/28/09	08/28/09	10/26/08	05/12/08	
Make Up Oil Added			1 qt	2 qts	2 qts	1 qt	1 qt	
ALUMINUM	8	13	12	**40**	10	10	10	10
CHROMIUM	**22**	22	**37**	**24**	**27**	16	**24**	11
IRON	**63**	94	**125**	**163**	**104**	67	**100**	51
COPPER	**8**	10	**19**	**13**	11	7	**10**	6
LEAD	3617	5525	7257	8315	6402	4307	5466	5740
TIN	0	2	**8**	2	5	3	0	1
MOLYBDENUM	3	5	6	0	6	4	7	5
NICKEL	**61**	58	**118**	12	**73**	**50**	**66**	19
MANGANESE	1	1	1	1	1	1	1	1
SILVER	0	0	0	0	0	0	0	0
TITANIUM	2	1	3	0	2	1	2	0
POTASSIUM	0	1	0	0	0	0	1	0
BORON	0	1	3	1	2	1	1	0
SILICON	12	9	**27**	7	**17**	4	6	9
SODIUM	0	1	1	1	0	0	0	1
CALCIUM	14	18	63	4	6	3	2	4
MAGNESIUM	1	2	3	2	2	2	3	1
PHOSPHORUS	1021	1044	1182	676	1019	1130	1050	268
ZINC	4	12	18	9	24	24	6	4
BARIUM	0	0	0	0	0	0	0	0

High nickel readings from oil analysis may be an indication of excessive valve guide wear. These readings are saying "watch me".

2) Wear: As the valve guide and valve stem wears the resultant slop allows the valve to walk around on the valve seat and this then leads to a similar situation as #1 above.

3) Crud: Heavy carbon or other deposits can preclude the tight fit between and valve face and the valve and result in failure as described in #1. These deposits can also accumulate on the exposed part of the valve stem and are then pulled into the stem/guide interface area and act like sandpaper to rapidly wear them. This causes #2 above. This scenario frequently happens when pilots mistakenly believe running very rich, low power settings is "good" for the engine

Warning Signs In This Engine:

1) Engine total time and oil analysis:

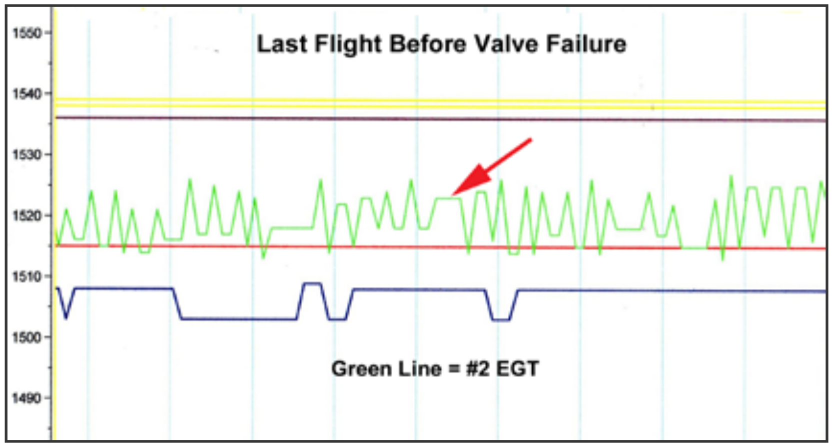
As the engine reaches mid-time the valve guides begin to wear. This wear is

(continued)

cumulative, meaning, "As it gets worse it gets worse faster". One indication of valve wear is in the oil analysis concerning nickel. (See chart on page 11) Your engine indicates ongoing amounts of 50 to 70 PPM, (on 12/28/09 it showed only 12 but I feel that was an anomaly). This may be normal given your nitride cylinders, although Blackstone Labs likes less than 50 PPM. But what they really look for is big changes in wear metals. (The 118 PPM on 5/24 may have been a harbinger of things to come.) In non-nitride engines I'd want 20 to 30 PPM. Increasing amounts coupled with advancing engine times would indicate valve stem/guide wear. Your level may be of no real concern and the engine could just continue with this level for many hours to come. So by itself it doesn't tell me if the wear is normal or above normal. All I know is with the time and possible wear indication it's just a little warning sign saying, "Watch Me".

2) The 1^{st} failed valve: I would assume equal operational wear with the other valves, so the above plus this valve failure would raise the warning to "Level Orange". Pay particular attention to the rest of the valves.

3) The JPI reading: Notice the fluctuation in the #2 EGT - it shows up slightly on the graph in the 6^{th} flight before failure (FBF) and is very evident in the 5^{th} FBF. On this flight the cyclic oscillation is showing the valve bad spot. As the valve opens it rotates slightly before setting back down. This happens at every opening and is a design feature that helps keep the valve face clean and evens out the wear in the valve face area. The valve rotates 360 degrees in a little less than one minute at cruise RPM. What we see is the valve rotating and as is comes to the place where the valve and the seat are both warped and not making a seal the exhaust spills out into the exhaust stack and bathes the EGT probe in exhaust, showing up as an up-scale spike. As the valve continues to rotate it starts to seal better as the disparity in the valve and seat no longer line up thus allowing the temperature on the EGT Probe to sag back to near normal. This very even (approximately 30 degree F) and consistent variation at a little faster than 1CPM is a classic textbook valve leakage/burning signature. At that time a quick borescope inspection would have shown a stressed "green valve" as shown in the picture on p. 22. At that time the cylinder could have been repaired with a minimum of fuss.

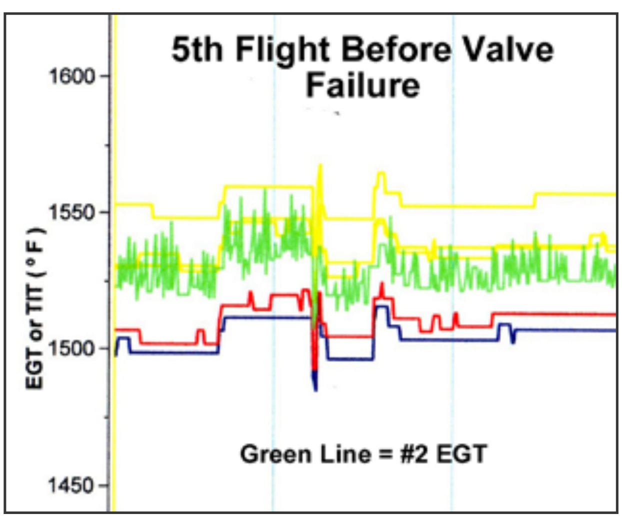


On the last flight before failure, the temperature peaks smooth out because the valve is leaking so severely.

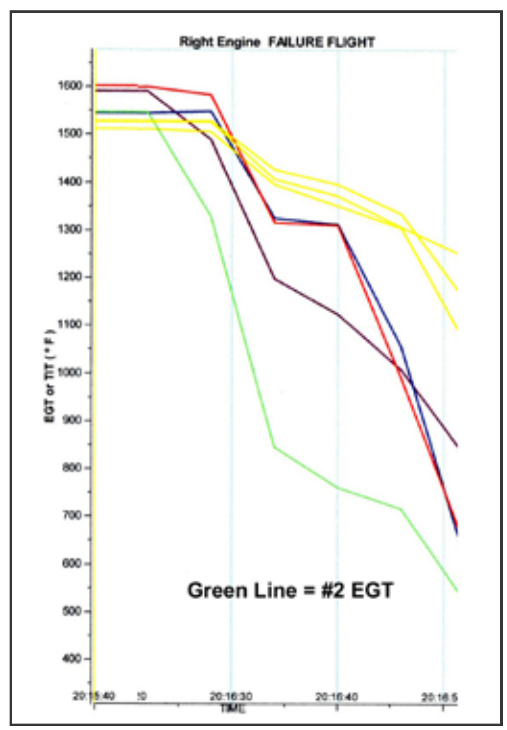
In the last FBF graph you can see that the temperature peaks begin to smooth out because the valve is leaking so badly that there is little difference in leakage from one rotational position to the next. It's starting to show up in the CHT as well. Sometimes this JPI spiking is misinterpreted as a probe failure but that never creates this regular cycling. Probe failure causes huge spikes that happen randomly, or as a big down scale reading or a very high upscale default reading (over 1800 degree F). It's the uniformity of the spikes that are a dead give away here.

On the failure flight the valve head section separated causing massive compression loss and for the most part the cylinder quit making heat, and power, thus running rough. You pulled the power off to relieve the roughness

(continued on p. 22)



The #2 EGT reading clearly stands out from the rest on the 5th flight before failure.



When the valve failed, cylinder temps plumeted due to massive compression loss.

VALVE FAILURE

(cont. from p. 12)

and as you did cylinders 4 and 6 dropped temps a lot more than the right bank of cylinders. This is a result of way the induction system is built. With the left bank receiving air from one single intake runner the failed valve in the #2 cylinder acted as a huge air leak and effectively reduced the MAP (air) in cylinders behind it. Less air = less power = lower temperature. This is all a normal failure mode and if the failed valve piece didn't enter the other cylinders they'll be fine.

How Would I Proceed? Continue with oil analyses specifically watching for any increase in nickel. Do a borescope inspection and compression check of all cylinders at each oil change. Finally I would down load and graph each flight and watch for any indication of these cyclic spikes in EGT. If they occur have the cylinder borescoped immediately [emphasis added]. If any indication of exhaust valve stress is noted remove and repair the cylinder before the valve fails." – Tony

Here's what a borescope inspection might have shown several flights prior to failure. Heat damage due to leaking exhaust gases is clearly visible.

I've learned a lot in the past year, and one of the most important lessons I learned is that engine operation has at least one thing in common with instrument flying: Use all the data available to you, and use it as soon as it becomes available. Fly safe. – John

"1031" AIRCRAFT EXCHANGES

by James T. Blakey, CFP & ATP, Southeast Tax Planning

Remove and Replace……The Entire Aircraft!

Jim has the opportunity to move up to the perfect airplane for his business missions: A 1981 421C. He's done all the research; comparing prices, reviewing the logbooks, mechanical inspections, studying the specs. His one major obstacle is the tax burden he'll incur when he sells his fully depreciated 1979 Cessna 310R. The tax payment will keep him from having the investable cash to acquire the new airplane. Is there a way that Jim can get his 421 without paying a fortune in taxes? Jim, it's time to learn about the merits of a 1031 exchange.

Especially when moving up, a 1031 exchange can result in significant savings by postponing the tax burden that might result from selling a depreciated asset.

What is a 1031 exchange?

Section 1031 of the United States Internal Revenue Code: *No gain or loss shall be recognized on the exchange of property held for productive use in a trade or business or for investment if such property is exchanged solely for property of like kind which is to be held either for productive use in a trade or business or for investment.* In layman's language; a 1031 exchange is a postponement of a tax burden that occurs if you sell a business asset and use the proceeds to purchase another very similar business asset. In the story above Jim appears to have the possibility to use a 1031 exchange. He plans on selling the Cessna 310 and replacing it with a 421.

What are the income tax consequences of a 1031 exchange?

Let's set the stage by first looking at the income tax consequences for Jim without the 1031. Typically, Jim's CPA would have fully depreciated the aircraft in the first few years of ownership - assuming he has used the airplane for business purposes. This would include improvements as well as upgrades. This depreciation would have resulted in significant tax savings during his ownership. Upon selling the aircraft, these tax savings will all come due. Assuming a 30% tax rate on the cumulative depreciation (and profit, if any), the tax bill could be significant. It's easy to see that by postponing the taxes using a 1031 exchange one would have considerably more buying power in the transaction. If in our story Jim eventually sold the 421 without replacing it via another 1031 exchange, he would have taxes due on the sale, which would include the taxes postponed during the exchange of the 310.

What makes airplanes different in a 1031?

Does your airplane meet's the definition of a property held for productive use in a trade or business or for investment? And will the use of the new aircraft meet this same definition? If so than an airplane is no different in a 1031 exchange than other business assets. The treatment of your airplane on your past tax returns is important. Was it treated as a business asset, an investment, or a hobby-related asset? Have a tax professional make absolutely sure that it has been treated as a business/investment asset prior to attempting a 1031 exchange.

What is a Like Kind Aircraft?

In general, most aircraft and helicopters, except those used as common carriers or to haul freight are treated as like kind and can be exchanged. A Baron for a Cessna, a twin for a single, or a prop for