Waterfall Erosion

How to flunk a compression test without burning an exhaust valve.

By Dave Pasquale

The closer you look at things, the more interesting they can become. My partner Jess and I have spent a lot of time in the past several years looking at and analyzing borescope images. We have found what we think is a new cylinder failure mode related to the exhaust valve seat. We call it "waterfall erosion." The purpose of this article is to describe this new mode and speculate about its origins.

Waterfall erosion in its later stage causes persistent low compression with normal heat signatures, or in the case of a subset of waterfall erosion, star-shaped heat signatures. In either case the valve is not exhibiting the typical types of uneven heat signatures that result in burned valves.

Photo 1: Erosion on an ECI valve.

I should explain what I consider to be persistent low compression. When a cylinder has low compression and a normal heat signature, we ask the client to fly the airplane for one hour per Continental's instructions in the M-0 manual. We immediately recheck compression as soon as the airplane has landed. Note that all compression tests should be done hot. Cold compression generally yields lower results and less consistency. Doing this eliminates any lead balls that may be holding a valve open. If the compression was due to a lead ball, you should see an increased compression after the flight. We have seen some that go from 20/80 compression to 68/80 compression. If the compression remains low, this condition is what I call persistent low compression.

Waterfall erosion gets its name because it looks like a waterfall going across the valve seat from the combustion chamber to the exhaust port (**Photo 1**). It will be wider at the combustion chamber and taper as it extends across the seat with a trail feathering out into the port. We sometimes see two or three of these in close proximity to each other. Most examples of this we have seen have been on the valve seat to the left of the valve stem when looking through the top spark plug hole. One or two have been on the other

Photos 2 and 3: Star shaped heat signature from waterfall erosion

side and a handful of them had a series of equally spaced erosion spots that resulted in the star shaped heat signature (**Photos 2 and 3)**. The cases we have seen personally have all been what we would consider late stage. In all of them the compression was well below the master orifice. Early-stage waterfall erosion has the visible mark on the valve seat but has not progressed far enough to cause a significant loss of compression (**Photos 4 and 5**). We recently received a report from an aircraft owner that was able to lap early-stage waterfall erosion out of the seat. Like many things, early detection is key.

Each time we have seen waterfall erosion, we have tried to collect as much data about the operation and history of the affected cylinders as possible. I was not able to get calendar age and time-in-service for all the affected cylinders. The calendar age for the cylinders I had information for ranged from 23 years (2002) to six years (2019) in service. Except for one cylinder, the operational hours ranged from 527 hours to approximately 1,100 hours since new. One cylinder was reported at 2,050 hours since new. It was unclear if that cylinder had any work during that time. There may be a correlation to calendar time for Continental cylinders since all but one were manufactured prior to 2016. More on that later.

We are still at very low levels of cylinders affected by this issue and do not have enough data to come to any hard conclusions as to why this happens. So far most of the affected cylinders have been Continental cylinders, but we have seen a few Lycoming cylinders, two ECI cylinders, and one Superior cylinder that were affected by this condition. All but one of the airplanes I had data for were mostly run lean of peak (LOP). Given that all but one of the affected cylinders were normally run LOP, it seems like there could be a correlation between LOP operation and waterfall erosion. The ECI cylinders both had waterfall erosion on the valve instead of the seat. The different behavior between ECI's and Continental's cylinders along with the higher quantity of Continental cylinders over Lycoming and Superior cylinders suggest that it is possible that Continental's valve seats and ECI's valves are more susceptible to a chemical component of the combustion gases created with LOP operation.

I've asked several industry experts and manufacturers for comments on the subject. One suggested that this may be related to Continental's late entry into hardened valve seats. As far as I am aware, Continental switched to hardened valve seats in 2016. To date, only one Continental cylinder newer

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Photo 4: Advanced stage waterfall erosion. We tried lapping that out of the seat unsuccessfully.

than that has been found with waterfall erosion. Lycoming has used hardened seats since the late '90s. Superior was evasive on when or if they ever changed their valve seats.

Both Superior and Continental suggested that waterfall erosion was caused by poor valve guide to valve seat concentricity. This has been a strong marketing point from Superior. My impression of Continental's response is they are talking about valve seat to valve guide concentricity in response to Superior's marketing. Neither one gave a good explanation for how most valves have enough play in the guides to side-step when they contact the seat. I have not had the chance to discuss this with Lycoming since finding this condition in Lycoming cylinders is recent and in lower numbers.

Currently, my finding waterfall erosion is relatively rare. Still, new examples are being seen at an increasing rate. It is possible this will become a more common issue now that we know what to look for and as we get improved images. It would also be helpful to receive hot compression data and air leakage information with the images. Up until now we only requested one image for each exhaust valve seat. It may be beneficial to have two, one for each side if the entire seat is not able to fit into one image.

The last few years have seen a lot of progress in the world of borescope imaging. Up until a few years ago we couldn't get usable borescope images sent to us. Now we have a regular stream of images. There are still areas we can improve and one of them is getting the more difficult photos like those of the valve seat. Our hope is that as we collectively improve our imaging technique and receive more photos, we will be able to appropriately mitigate the waterfall erosion issue and further lower the rate of cylinder removals.

ABS Life Member ***David Pasquale*** owns Pasquale Aviation, a well-known Beech and engine shop in Pottstown, Pennsylvania. Dave has contributed videos on compression testing, borescoping, landing gear rigging and lapping valves in place that are free to members in the ABS Learning Center at *www.bonanza.org.*