Exhaust-Driven Crankcase Evacuation Systems

An extremely reliable process

by Marshall Murray, Sky Dynamics Corporation

Photos courtesy Sky Dynamics

Using exhaust flow to extract engine crankcase pressure has significant positive effects in piston aircraft applications. These benefits range from engine efficiency improvements to the general maintenance improvement of reducing oil leaks and the ever-important aesthetic improvement of keeping the breather oil from soiling the belly of the airplane. Over the last 30 years of exhaust system development at Sky Dynamics, we've advanced the interaction of the crankcase evacuation system into our collector-style exhaust systems to the point that it's now standard on all exhaust applications—whether it's a custom lightweight system for Sean Tucker's new plane or a production Cub Crafters light-sport aircraft system. Through in-house testing and our history of working with the top aerobatic and race pilots, we've been able to evolve the design details and the manufacturing process to make the system extremely reliable. Along the way, we've also found the system to possess other unique benefits.

The success behind our crankcase evacuation system is that removing the positive crankcase pressure which builds up due to normal combustion leaks causes the engine to operate more efficiently. This efficiency increase manifests itself as a lower fuel burn, an increase in ultimate power, and an increase in longevity. The increase in efficiency is derived from the many positive effects of the depression that is created inside the crankcase. The first positive effect is the reduction of pumping resistance felt by the piston. Considering the relatively large surface area on the underside of a typical aircraft piston due to the large bore diameter, this benefit alone proves substantial. The crankcase vacuum also increases the pressure differential that helps to maintain a piston ring seal. This not only increases combustion efficiency but also reduces the amount of engine

oil that finds its way into the combustion chamber. Oil in the combustion chamber can reduce the detonation threshold, which is extremely important to max-effort applications but is also becoming increasingly vital to all piston engine applications as we face the imminent demise of 100 low lead.

The crankcase evacuation system works due to a concept that we're all familiar with—the speed-pressure relationship of a fluid, defined by Bernoulli's principle. As Bernoulli's principle can be adapted into many specific fluid flow situations, including situations that approach high Mach numbers, the principle applies here in two ways. The first takes advantage of the Venturi effect through a low-pressure area designed into the exhaust system. This is similar to the basic function of a carburetor; the tapered throat area causes a reduction in pressure that draws fuel into the airstream. The second application of the principle is that the exhaust flow across the evacuation tube's open end further aids in reducing the pressure within the evacuation section. The most commonly known example of this dynamic pressure situation is the lift of an airplane wing, where a low-pressure area is formed due to higher-velocity airflow across the top of the wing. This airflow can be compared to the exhaust flow surrounding the evacuation tube.

While this type of crankcase evacuation system is beneficial to all piston engines, it lends itself particularly well to high-performance aircraft applications due to the allowable design requirements. As the typical noise constraints of performance aircraft are relatively loose, the exhaust system isn't limited in ways that standard category aircraft exhaust systems are. This means that the exhaust system can be built so that there's no compromise in performance.

You can also find different types of crankcase evacuation systems in other performance applications. Some owners of automotive breather systems attempt to employ crankcase evacuation with a misplaced suction tube inserted into the side of the exhaust stream. Then, because the fitment is rarely ideal, they're forced to put a check valve in the line so that exhaust backflow can't find its way into the crankcase. A problem appears when exhaust pressure forces the check valve to close. The crankcase has no breather and quickly builds pressure—exactly what we're trying to avoid. Another form of crankcase evacuation is found in high-end racing vehicles. These vehicles use a dry-sump oiling system which, in scavenging oil from the sump, creates a negative crankcase pressure to produce many of the same benefits that we get from exhaust-driven crankcase evacuation. Some may also be familiar with dry-

sump systems in aviation if they've had to deal with the older Lycoming AIO engines. Thankfully, further development led Lycoming to release the updated AEIO engines that addressed inverted flight situations in a more reliable manner.

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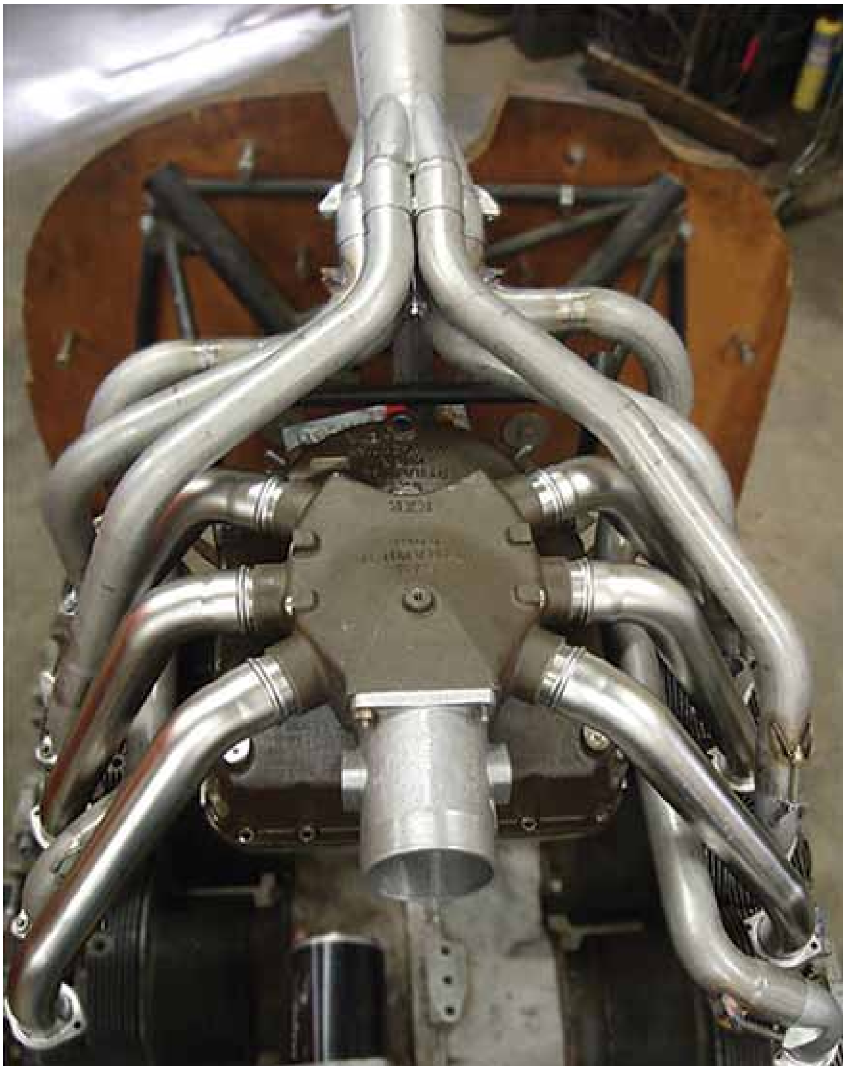
Over the years, Sky Dynamics has been privileged to work with the most innovative pilots, teams, and manufacturers in the industry. Most recently we've built close relationships with several of the Red Bull Air Race (RBAR) teams. Since we supplied parts to each of the teams, we were in an enviable and unique position as one of the very few companies who could walk from hangar to hangar in the Red Bull pits and discuss in detail each team's aircraft. One team was especially receptive to testing, and therefore very important to recent developments. The Spanish RBAR team of Alejandro (Alex) Maclean and technician Jesus Canadilla were continually willing to perform testing that contributed to our 6/1 lightweight collector development. During one of the initial tests of the race exhaust's crankcase extraction system, we were using our normal 24-inch liquid manometer for depression measurement. As the throttle was opened on a ground run-up, the evacuation system created such a negative pressure that the manometer fluid was almost sucked into the engine before power could be reduced. Soon after, we switched to a handheld electronic manometer for testing.

We had another memorable learning experience in the ongoing development of our evacuation system a few years ago when Bruce Bohannon was setting records with his *Exxon Flyin' Tiger* RV-4. We manufactured the turbocharger system that was necessary for his record time-to-climb run to 12,000 meters. Because we had such success with implementing the crankcase evacuation in our normally aspirated exhaust systems, we fitted a similar system into the turbine discharge tube of his exhaust. We selected a location that seemed comparable to the chosen point in our standard systems. Unfortunately, Bruce found that at certain manifold pressure/rpm settings, oil temperatures skyrocketed! As these things always go, the airplane had been finished up only days before the record flights with little time for comprehensive testing. Increasing the stress of resolving the issue quickly was that it all took place as an attraction at the Sun 'n Fun Fly-In at Lakeland, Florida. In hindsight, one of our first thoughts was the crankcase evacuation backflowing into the breather section of the rear accessory case and erroneously increasing the oil temperature reading. However, our design was so well thought-out, that couldn't be the problem! But in fact it was. The turbulence of the mediocre exhaust stream wasn't acting on the extraction point as it does inside our collectors which are optimized for smooth, consistent flow. This situation clearly demonstrated two things. First, the implementation of the crankcase breather requires thorough testing for each individual application. Second and more importantly, when troubleshooting a technical issue, preconceived notions will often delay finding the solution. After a day of troubleshooting, we corrected the problem; Bruce flew the flight on schedule and from there continued on to an ultimate ceiling record beyond 47,000 feet.

Being able to work with these pilots in real-world applications is the ultimate form of data gathering, though it would be impossible to obtain all of the necessary information from this method alone. For in-house testing we have an engine dynamometer cell that allows us to experiment in a controlled environment. Using our dyno cell, we're able to datalog all of the pertinent values that we're looking for as well as simulate atmospheric conditions such as increased manifold conditions due to ram air in flight. The dyno enables us to quickly, and more importantly safely, try new combinations. From that, we've been able to fine-tune the crankcase scavenging.

During testing, we're able to measure pressures in multiple locations. The two most beneficial areas for data analysis are inside the breather line near the extraction point as well as the interior of the crankcase. These measured values are plotted along with the dyno cell ambient pressure as a reference. Our dyno software incorporates linear-signal pressure sensors (similar to the ones used with the high-end engine analyzers) and has a sample rate that is configurable to beyond 100 times/second. With this data we can easily find the best location for the breather tube in reference to the exhaust collector shape and engine application. We can also quickly perform back-to-back testing with the crankcase evacuation line connected versus disconnected.

On a tight six-cylinder engine with a standard breather setup, we'll normally see a rise of approximately 0.5 inHg of pressure inside the crankcase by 2,700 rpm, though it's rising at an increasing rate as we push the engine through 3000 rpm. Whereas on a high-time six-cylinder engine at 2700 rpm, a pressure reading of 1 to 2 inHg is common. Considering the area inside the crankcase, that alone



can mean substantial force pushing the case apart. But in reality, that force is relatively miniscule compared to the many thousands of pounds exerted by cylinder combustion. It's not surprising then that case-split oil leaks and broken cylinder base studs are common problems. In contrast to a standard breather setup, with a proper evacuation system fitted we typically see a crankcase depression of at least 1 inHg by 1500 rpm, increasing to 3 inHg of negative pressure at 2700 rpm.

In addition to our engine dyno, we also have a thrust test stand with which we're able to accurately measure the force of an aircraft's thrust in a safe manner on the ground. (Think automotive chassis dyno but with a bit more wind.) We can also plot thrust versus rpm and even 3D maps that can reference lambda, exhaust gas temperature, crankcase pressures, etc. One of the recent test planes was Red Bull pilot Sergey Rakhmanin's MXS-R. We took the time to measure the thrust produced over a variety of modifications, but as is notable here, we were able to measure the thrust difference with and without the crankcase evacuation system hooked up. Because of the convenience of this testing method, we were able to repeatedly test with and without evacuation in a short period of time. Each time we unhooked the crankcase evacuation line from the exhaust system, the plane lost 8 to 9 pounds of thrust. In a series where the teams were looking for 1 pound of thrust from an engine or prop mod, 9 pounds was a great number to see and really made our time spent in development worthwhile. With all of the modifications made over the course of a busy three days between races, the aircraft had gained more than 100 pounds of thrust when technician Antanas Marciukaitis flew the plane out.

Although the crankcase evacuation system was created for the benefits mentioned earlier, we've found other advantages to the system. In practice, the air/oil mixture that manifests itself as oil dripping from a standard breather line outlet is now being burned in the exhaust stream. As such, some will notice a light puff of smoke from the exhaust after certain maneuvers. This is caused by oil building up in the inverted system's separator can, which is then drawn out through the exhaust. The same oil loss goes unnoticed in standard applications—[illegible]ets dumped overboard via the breather line. And because the oil turns to smoke inside the collector when the plane is under power, the crankcase vapors no longer leave their stain on the belly of the fuselage. When flying long vertical uplines in an application with a breather that extends back to the tail, the line can become clogged, which effectively closes off the engine's ability to breathe.

There are other, more exciting benefits as well. The vacuum signal is a direct result of flow through the engine. This can be translated a few different ways. Total engine power can be deduced from the vacuum reading as a relative number that can be referenced throughout a series of engine modifications. Keep in mind, though, that altering lambda by switching to a lower-energy fuel such as ethanol would greatly increase the mass flow through the exhaust and would need to be accounted for, just as an overly rich gasoline mixture would. Similarly, as the vacuum signal can be treated as a direct measurement of mass flow through the engine, it's ideal for use as a fuel delivery reference value. Because this method would pose no additional restriction to engine airflow like a Bendix RSA does by its incoming air measurement, we're looking into integration of this method for the power enrichment section of our new fuel servo.

Additionally, there are more pedestrian uses of the crankcase evacuation. The amount of depression created by the evacuation tube has proved to be an excellent indicator of engine health. Making note of vacuum readings at specific rpm points in the engine log on a regular basis can show if a piston ring seal is beginning to deteriorate. Also, the suction line can be used as an emergency backup source for vacuum-driven instruments in the event of a vacuum pump failure.

After considering all the advantages of using a low-pressure area inside the exhaust system to extract crankcase pressure, it's easy to see how the discussion could be extended into studying the slightly larger relationship between the airframe and exhaust collector outlet. While that is a substantially more complicated undertaking, it's something we take into account and of which we hope to continue to gain a thorough understanding. For now we continue to be challenged by airframe designs that make aero improvements the top priority and keep us on our toes by giving us a bit of thought to efficient exhaust system fitment. IAC