The Rest of the Story

by Bill Marvel and Bill Scott

As we mentioned in the attached cover letter, the May-June TBO Advisor story told what happened, but did not disclose the details of why it happened. The article told you that we had discovered several things: low oil flow in general to the rocker boxes, a shortage of oil to the rocker boxes of the odd-numbered cylinders (co-pilot side) as compared to the even, a preponderance of valve distress problems concerning the odd-numbered cylinders, and a correlation between low oil flow and these cases of valve distress. The information we received came from many pilots flying different engines in different airframes. Clearly, there were variations in pilot technique, engine maintenance, baffle seal condition, etc. in all of the subject aircraft. The only two factors in common with all of these instances were that the distress (in-flight disintegration or valve leakage during a compression test) was predominantly on the right side cylinders and these same cylinders received a lower oil volume going to the rocker boxes than did those on the left side. The obvious question is this -- why is the oil flow low in general and specifically, why is it lower on the co-pilot side of the engine? The May-June TBO Advisor issue would have you believe that only Lycoming's quality control of lifter bleed down rate is at fault. Not so. The answer to the low flow question is far more involved than that and goes right to the heart of the engine design. To get that answer, we had to research the history of hydraulic lifter design as well as acquire, disassemble, inspect and test many versions of them. These included not only lifters from Lycoming, but also Continental and automotive components. This testing and research provided us with very significant information that we have never seen revealed in any publication before. In the pages that follow, we will in turn pass that information on to you.

The very heart of our investigation of Lycoming valve guide distress is a component that few aircraft owners or mechanics understand. In fact, most owners and many mechanics have never seen one, given that the case must be split for this part to be removed. The component in question has many names, some of which are hydraulic lifter, valve lifter, cam follower or tappet. In the balance of this article we will remove the mystery and explain the difference between the Lycoming and Continental designs of this component. We will also point out a major shortcoming of the Lycoming design that we believe substantially accounts for valve train problems including stuck exhaust valves, prematurely worn valves and guides, and camshaft distress and failure.

What Does It Do?

A valve lifter, or tappet, is simply a component that converts the rotary motion of the lobes of the camshaft to linear motion to actuate the valves. In earlier engines, this function was performed by a solid tappet, prior to the development of the hydraulic version. The solid tappet design is still used in Lycoming O-235 engines and has undoubtedly been encountered by anyone who ever worked on a Volkswagen Beetle. One disadvantage of the solid tappet is that it requires a periodic adjustment. This adjustment is necessary to make sure that the valve lash, which is the spacing between valve train
components, is correct. This spacing is established to accommodate the expansion and contraction of various engine parts during the normal temperature changes the engine experiences while in operation.

In the late 1920s, automotive engine technology was improving rapidly, and much work was being done to eliminate the periodic adjustments required of the solid tappet. In addition to the time-consuming adjustment itself, the "one size fits all" aspect of setting the lash large enough to accommodate all engine operating temperatures made the valve train noisy. A clicking engine simply did not sell as well as a quiet one. For those two reasons, the first hydraulic lifters were developed. These used engine oil, under pressure, to automatically set the valve lash to near zero during each actuation of the valves. In one brilliant design move, both the noise and periodic adjustments were eliminated.

**Figure 1 - The hydraulic tappet shown in its initial automotive application with flat head engines.**
Figure 1 shows this initial design concept in its early implementation. It is **most important** to note that this hydraulic tappet, which is very similar to what Lycoming uses today, was originally intended for use in the old flat head engines. You can clearly see in the diagram that in this application, the plunger component of the hydraulic lifter presses directly on the valve stem to cause actuation. No pushrods or rocker arms, components used in the later overhead valve engines, are in existence in the flat head design. For clarification, you should be aware that the area in figure 1 from the top of the valve spring to the bottom of the cam shaft is bathed in splash oil from the crank case continuously. Therefore, in this application, the **sole** function of the tappet is to maintain as close to a zero valve train lash as possible. It has **no** role in providing any type of lubrication or oil transfer to other components.

Look more closely now at figure 1 and follow the oil flow path. Oil leaves the main gallery, which comes from the engine oil pump, and flows into the groove (annulus) around the tappet. It enters the tappet through an opening in the annulus and fills the lower portion of the tappet. When the small spring at the top of the plunger presses the plunger against the valve stem, thus eliminating lash, it moves the plunger upward and unseats the check ball below it. Oil now can flow from the lower portion of the tappet through the inlet tube, past the check ball and into the oil chamber. Since oil is an incompressible fluid, once it is drawn into the oil chamber it forms part of the component "stack" that raises the valve when the cam lobe begins to move in the direction of the arrow. As soon as pressure is felt by oil in the chamber, the check ball closes off, allowing valve actuation to occur as if by a solid tappet. It is at this point that something of great importance occurs, and you absolutely must understand it to later comprehend the problem we found in Lycoming's valve train system.

**The Importance of Bleed Down**

The temperature variation of the engine that caused a need to set the "one size fits all" lash in the solid tappet design did not vanish with the inauguration of hydraulic tappets. Accordingly, there had to be a mechanism designed into the hydraulic tappet to allow some of the oil now trapped in the oil chamber to leave, so that the plunger spring could again set the lash to zero on the next stroke. The mechanism used to do this is called "bleed down." Bleed down is nothing more than a very small oil leak that is allowed to occur between the plunger and the plunger cylinder as shown in figure 1. (The plunger and plunger cylinder together are called the hydraulic unit). When this tiny amount of oil leaks out, it simply spills back into the crankcase to once again be part of the engine oil supply. To better see the components of the hydraulic tappet system shown in this drawing, refer to Figure 2. This is a photograph of the three parts of a tappet as removed from a 1936 Cadillac. It is nearly identical to what you see in figure 1.

**Figure 2 - A disassembled hydraulic tappet from a 1936 Cadillac**
Let's discuss bleed down a little further. Without question, the closest machining tolerances in your engine are those of the plunger outside diameter and plunger cylinder inside diameter. It is this tolerance that establishes the bleed down rate. Bleed down rate is nothing more than the speed at which oil can leak between the plunger and plunger cylinder under valve opening loads. If this speed is too fast, valve timing is harmed. In such a situation, the valves open too late, close too soon, and do not achieve the full amount of lift that the cam is intended to provide. The engine is thus unable to "breathe" efficiently, robbing it of power. Additionally, an excessively fast bleed down rate allows the lash, which is ideally held to zero (but never is in the real world) to increase beyond limits, causing components in the valve train to hammer into each other instead of operating smoothly. This wreaks havoc with the longevity of parts. On the other hand, if the bleed down rate is too slow, the valve is held open when it shouldn't be, causing compression (and therefore power) loss, as well as possible valve face erosion. Bleed down and bleed down rate are essential ingredients of all hydraulic lifters regardless of application or manufacturer.
Looking at both figures 1 and 2, you may wonder about the oil inlet tube that projects from the bottom of the plunger cylinder. There is a reason for this tube. As we mentioned above, oil is an incompressible fluid, as it must be to serve in its function as part of the hydraulic unit in the high-pressure environment of the oil chamber. Air, however, is compressible and must never be allowed to enter that chamber, or valve lash will be compromised (increased). The hydraulic tappet shown in figure 1 was designed to operate in a vertical position in the flat head engine. In order to prevent any tiny air bubbles that might be circulating in the oil stream from reaching the oil chamber, the tube was devised so as to draw only non-aerated oil from the bottom of the tappet while any air bubbles present floated to the top. It is unknown whether or not Lycoming knew of this fact when they designed their version of the same tappet to operate horizontally, not vertically, and with a much shorter inlet tube (compare figure 2 with figures 4 and 5).

The Overhead Valve Configuration

The tappet design shown in figures 1 and 2 performed well in flat head engines, and served the only function intended for it -- maintaining minimal valve train lash. As technology progressed, the flat head engine was eventually replaced by the overhead valve engine, which has features that made it superior in virtually all applications. Descendants of this overhead valve engine still power most of our cars and piston airplanes today. The most notable feature of the overhead valve concept, as it pertains to our investigation, is the fact that the hydraulic tappet operates the valves indirectly, through pushrods and rocker arms, and not directly as it did in the flat head design. As you can see in figure 3, the hydraulic tappet in this application presses on the pushrod, which presses on one side of the rocker arm, which in turn presses on the valve stem to complete valve actuation.

Figure 3 - The overhead valve engine design uses pushrods and rocker arms for valve actuation
Comparing figures 1 and 3, you should be aware of one obvious, major difference. In the flat head engine, abundant oil was available for **cooling** and **lubrication** of the valve and valve guide because they were in constant contact with oil from the crankcase. In stark contrast, in the overhead valve engine, there is *no* immediately available oil supply. It is thus clear that oil had to be brought to the rocker arms and valves, which are housed in the rocker box, by some specific mechanism which was designed for that purpose. It is here that future Lycoming valve problems began.

### Catch Basins, Mushrooms and Barrels

Over the years, Lycoming has used three methods to carry oil from the engine case to the rocker box. We generically call them the catch basin, mushroom tappet and barrel tappet methods. Here is a brief description of each.

#### Catch Basins

In the O-235 and other solid tappet engines, Lycoming designed the case halves with what we refer to as a "catch basin" in the upper portion of each to collect oil splashed during normal operation. These basins in turn funnel the captured oil to internal passages that drain it directly to the pushrod shroud tubes, through which the oil gravity flows to the rocker box. In the rocker box, this oil drains from the pushrod shroud tubes directly onto the exposed valve guide and valve stem, thereby providing both lubrication and cooling of these components. This method is simple and has generally served well in transferring sufficient oil to the rocker box to meet lubrication and cooling requirements in those smaller Lycoming engines which use it.
With the advent of hydraulic tappets, the availability of oil to the tappet itself made possible the use of this component to carry oil to the rocker box. Doing so would be a very elegant way to provide lubrication to the rocker box without having to wait for sufficient splash oil to first accumulate in the catch basins. When hydraulic tappets were first developed for automotive use, only the "mushroom" style was initially created. This designation is derived from the appearance of the tappet as shown in figures 1 and 2. One can envision the tappet as an upside down mushroom resting on the camshaft.

When Lycoming initially implemented hydraulic tappets to actuate their valves, the mushroom style of tappet was still all that was available. Keep in mind that this component was used at the time to operate vertically and only to adjust valve lash, bleeding down a tiny amount on each reciprocating stroke. Lycoming employed a modified version of this tappet in a horizontal position to actuate the valve through the pushrod and rocker arm mechanism of the overhead valve configuration. You can see a cross section of a close rendition of Lycoming's tappet in Figure 4 and a photograph of the real thing, disassembled, in figure 5. Note that in Lycoming's design the tappet is longer, and that the plunger cylinder now has a shorter oil pickup tube and sits further down in the tappet. Additionally, a pushrod socket that rests on top of the plunger has been added. This pushrod socket has oil passages in it that are clearly intended to carry oil from the tappet into the hollow pushrod that sits in the socket. It is the hollow pushrod that is the source of oil to the rocker box in most overhead valve engines.

Figure 4 - A cross section drawing of a close rendition of Lycoming’s mushroom style hydraulic tappet  
Figure 5 - A disassembled view of the Lycoming mushroom style hydraulic tappet
But this presents a problem. Recall that the mushroom tappet design was originally intended to actuate the valve directly in the flat head engine, and only to maintain lash, as shown in figure 1. It did not have any mechanism to pump oil through the pushrod, since it was not designed for that purpose. And yet it is oil flow through the pushrod that lubricates the rocker arm bearing and then, most importantly, flows out the rocker arm squirt hole onto the valve stem for both cooling and lubrication. As shown in figure 4a, the only oil that could flow into the pushrod in Lycoming's design was that which resulted from bleed down of the hydraulic unit, which is at most a tiny amount. It is a tiny amount because the foremost function of the hydraulic unit is to maintain as close to a zero lash as possible. That is what it was designed to do. Since flow through the hydraulic unit is dependent primarily upon bleed down rate, and since bleed down rate has to be carefully controlled to maintain minimal valve lash, one can immediately see a design paradox developing. Because the hydraulic unit in Lycoming's design is being asked to perform two opposite functions, sending oil up the pushrod and maintaining lash, it is literally true that the better it performs one of these conflicting functions, the worse it performs the other -- the faster it bleeds down the more oil it causes to flow up the pushrod, but at the expense of allowing an increased valve lash to develop. The slower it bleeds down, the closer to zero it maintains valve lash, but at the expense of providing little oil to the pushrod. The fact that the basic lubrication system design trades off one critical function against another is one of the major causes we identified as a source of the low oil flow problem in the mushroom style tappet engines.
The second, and only other, flow path in the design was for oil that came from the main gallery, passed around the outside of the tappet and leaked through the clearance between the tappet and case as the tappet reciprocated in operation. As can also be seen in figure 4a, oil in this path can flow in either of two directions - into the pushrod shroud tube and then to the rocker box, as in the earlier catch basin design, or back into the engine case. The problem here is that the clearance between the tappet and the case is specified by Lycoming to be a maximum of .004 inches (the thickness of a sheet of typing paper), so this flow path is also extremely limited in the amount of oil that can pass through it. Flow along this path is primarily dependent upon oil gallery pressure, unlike flow through the pushrod, which is primarily dependent upon bleed down rate. It is for this reason that flow to the right side cylinders (odd numbered) is less than to the left side. As shown in figure 9, Lycoming taps oil from the right side oil gallery to provide lubrication for both the crankshaft and camshaft bearings. This reduces pressure in the right side gallery as compared to the left. Little oil is tapped from the left side, allowing nearly full system pressure to supply oil to this flow path.

Figure 9 - Lycoming oil system design taps oil from right side gallery for camshaft and crankshaft lubrication
As a result of Lycoming's design, the oil quantity that can be sent to the rocker boxes of their mushroom tappet engines can accurately be described in only two words: very little. In fact, we have run several oil flow tests where "in the green" oil pressure and temperature during the 7-minute test sent less than one cubic inch of oil to the rocker box of a number 1 or 3 cylinder. And this leads to our one-sentence summary of the core problem:

When Lycoming adapted the automotive mushroom style hydraulic tappet assembly to their engine, they failed to provide a dedicated, unrestricted oil flow path to the rocker boxes that could carry sufficient oil for adequate cooling as well as for lubrication.

As a result of this, oil flow to the rocker boxes stems from only the two sources mentioned above, which exist almost as afterthoughts. An ideal design would have provided for completely separate, dedicated
mechanisms for maintaining valve train lash and for providing adequate oil flow to the rocker boxes. The Lycoming design is a blend of these two functions and its shortcomings are the result. In summary, when Lycoming adapted the automotive hydraulic tappet for use in their aircraft engine, they appear to have done only three things:

1. shortened the intake tube of the hydraulic unit so that it would fit into the tappet body length already used in their solid tappet engines;

2. placed a pushrod socket on top of the piston of the hydraulic unit to support the pushrod and to accumulate and transfer to the pushrod whatever oil leaked out during bleed down, and;

3. rotated the entire tappet 90 degrees to operate horizontally instead of vertically.

What they did not do was to provide a dedicated, unrestricted oil flow path to the rocker box.

Lycoming, however, was not the only engine manufacturer making a move toward hydraulic tappets. The benefits of this mechanism were obvious to everyone in the engine manufacturing business, both automotive and aviation. Continental was also building aircraft engines, and also had available to them the mushroom style hydraulic tappet concept to integrate into their design. But there is a very significant difference between the tappet designed by Lycoming and that designed by Continental. You will see this difference quite clearly in the photo shown as figure 6. The Continental version has a second, upper annulus machined around its outside diameter, with a hole in it leading into the tappet above the plunger cylinder but below the pushrod socket. This annulus is connected to the lower one by two machined flats, one of which is visible in the photograph. (The other is 180 degrees around the tappet circumference). In operation, the Continental design routes oil into the tappet in two places: below the plunger cylinder for lash adjustment, and above the plunger cylinder to send oil directly into the pushrod socket for transfer to the rocker box via the hollow pushrod. This photograph shows that Continental engineers clearly understood the inability of the hydraulic unit to send needed oil to the rocker boxes, and thus designed a method of bypassing it to achieve this goal. They literally designed around the problem. Lycoming engineers, for reasons we do not know for certain, did not incorporate this, or any other bypass feature into their design. Do we have a thought as to why? Yes, as well as a reason for it. We think they may not have had a thorough understanding of how ineffective the hydraulic unit would be in providing oil to the rocker box. Why do we believe this? We believe it because Lycoming has specified several different pushrod socket configurations over the years. The pushrod socket sits directly atop the plunger, as shown in figures 4 and 5. The only significant difference in them is the number and geometry of oil passages they contain. The only purpose of these oil passages is to collect whatever oil comes from the hydraulic unit and to send it up the pushrod. The problem is that regardless of how many times Lycoming tried, they could not design an oil passage configuration that would improve oil flow because they had previously created a system where there is virtually no oil available to begin with.
Barrels

As overhead valve engines became more the norm than the exception, a new type of tappet was designed to meet the particular needs of this application. The new tappet was called the barrel tappet (as well as several other names) because of its cylindrical shape. The barrel tappet, largely unchanged since its inception, is still used in many new automobiles today. Most significant about this design, again as it pertains to our investigation, is the fact that it is capable of doing what the mushroom style hydraulic tappet cannot do -- performing two vitally important functions independently and simultaneously. These functions are the maintenance of lash and the directing of oil to the rocker box via the hollow pushrod. A cross section drawing of this type of tappet is depicted in figure 7. Although the drawing shown is of an automotive part, its overall layout and design are virtually identical to that used by both Lycoming and Continental in their respective engines that employ a barrel tappet. Today, all of the larger Continental engines use this design, as do the Lycoming O-320H, O-360E and the -541 series. The vast majority of Lycoming engines, however, still use the mushroom style hydraulic tappet with its built-in limitations.
Barrels

There are two significant physical characteristics of the barrel tappet design that should be pointed out. First, note that the oil entry point is toward the top of this component as opposed to near the bottom of the earlier mushroom tappet. This fact is key to its ability to perform dual functions. Upon entry into the tappet, pressurized oil flows in two directions. One direction is downward in this depiction, through the check valve at the bottom of the plunger, where it sets a near zero lash just as it did in the mushroom design. Simultaneously, however, pressurized oil also flows upwards through the pushrod socket and into the pushrod, which carries it directly to the rocker box.

A second feature of the barrel tappet that you should note is the greater width of its exterior annulus as compared to the mushroom design. This wider annulus, called a full registration annulus, is typical of automotive applications, and is seen in many Lycoming and Continental engines which use the barrel design. When the tappet annulus is in alignment with the oil gallery passage that supplies oil to it, the tappet is said to "register." During registration, oil is free to flow from the engine's gallery into the tappet. "Full registration" simply means that the annulus is sufficiently wide that oil can flow into the tappet at all times while the engine is in operation. Because the path to the rocker box (through the pushrod socket and pushrod) is always open in the barrel tappet design, full registration also means that there is a continuous flow of oil to the rocker box as the engine operates. The difference in oil flow between this tappet design and that which still exists today in the Lycoming mushroom style hydraulic tappet is the difference between a torrent and a trickle. This can readily be seen in figure 8, which shows a comparison between the oil volumes produced in one of our tests of the two types of tappets.
The Other Difference

Those of us who have been in general aviation for many years have seen numerous books and articles about various aspects of both Lycoming and Continental engines. Invariably, any comparison of the two types has always pointed out their fundamental differences:

1. Continental engines have solid stem valves, while Lycoming engines have, mostly, sodium filled valve stems, and
2. Lycoming camshafts are generally situated above the crankshaft and Continental cams are below the crankshaft.

Until our research into the entire area of Lycoming valve and valve guide distress uncovered these lifter variations, the above two features were the only known significant difference between Brand L and Brand C engines. That has changed.

A third, major difference between the two is now known. As a result of their very design, Lycoming engines with mushroom style hydraulic tappets receive far less oil to the rocker boxes than does any Continental engine. We believe that this fact alone will eventually explain the majority, if not all, of the unsolved valve train problems Lycoming's mushroom style hydraulic tappet engines have experienced for at least 30 years.

Yes, 30 Years

Almost everyone who owns a Lycoming engine is familiar with Service Bulletin (S.B.) 388B, the infamous "wobble check." When asked about S.B. 293B, however, literally everyone we questioned drew a complete blank. In our research of the history of valve guide distress in these engines, we uncovered the still-active S.B. 293B. Published in 1967, this S.B. is practically identical to S.B. 388B and even uses some of the same drawings and measurement tooling as does 388B. However, S.B. 293B applies to only the O-320 series engines, requires the same wobble check every 500 hours that S.B. 388B mandates every 400 hours, and most significant, is no longer applicable for engines that upgraded to sodium filled exhaust valves. Today, of course, almost all of the O-320s are equipped with sodium filled valves, so for all intents and purposes, S.B. 293B no longer applies. What we have to show for 3 decades of "progress" is that a guide wear check that 30 years ago was required every 500 hours on only one type of engine and not needed at all if sodium filled exhaust valves were used, is now required every 400 hours on every engine the company manufactures despite the use of sodium filled valves! This is the clearest indication of all that the problem of valve and guide distress has never been solved in these engines and has simply been passed on to the consumer via S.B. 293B and 388B. Think about that for a moment. S.B. 388B applies to all Lycoming engines regardless of engine model number, horsepower, number of cylinders, normally aspirated versus turbocharged, airframe to be used in, recommended TBO, etc. It clearly says there is a problem in the engine -- every engine. The reason it has taken so long for the cause of this oil flow problem to be discovered is that, apparently, neither Lycoming nor anyone else ever looked at the one area they had assumed to be sacrosanct -- the basic design of the oil system in the Lycoming air-cooled engine. Clearly, we are now calling that into question due to both the correlation we have found between low oil volume to the rocker box and corresponding valve guide wear, as well as the designed-in cause of the low oil volume. Having said that, we should clarify that we do not focus any blame on Lycoming for the original design that was implemented. After all, this occurred decades ago regarding then-new technology and without our benefit of 20/20 hindsight. We do, however, know that the company has acknowledged the exhaust valve and guide distress problem for at least 30 years and believe they could, and should, have found that problem and eliminated it.
The Problem of Sodium Filled Valves

As revealed above, sodium filled valves in the O-320 engine did not eliminate valve distress problems. To the contrary, our question is whether or not they either cause or increase these problems. Sodium filled valves are an extremely expensive component that we believe are greatly to blame for valve/guide distress incidents. They do not make heat magically disappear, as some would have you believe. All these valves do, at great monetary expense, is transfer heat from the valve head to the valve stem, or more generally, from the combustion chamber to the cylinder head via the valve guide. They merely move heat from point "a" to point "b." It still has to be eliminated from the cylinder head by either air cooling or oil cooling or both. The problem is that valve guides are wearing out prematurely and are doing so in spite of operators keeping CHT levels in the proper range. Excess heat is the primary cause of premature guide wear (in a properly assembled cylinder), as most engine shops will tell you. The problem with sodium filled valves is that they serve to import even more heat into the guide by transferring it up from the valve head. Lycoming's long history of valve/guide failure incidents in the parallel valve cylinders has shown that there is simply no way that the guide can shed all of its higher heat load via the cooling fins alone, and Lycoming's design provides for very little oil to aid in that process. The irony here is that Continental uses solid stem valves that dissipate most of their heat into the valve seat. Relatively little comes up the stem and into the valve guide and yet Continental has an abundance of oil in this area to aid in heat transfer. If sodium filled valves are needed at all, one wonders why Continental doesn't use them, since their barrel style hydraulic lifters provide substantial oil for additional cooling of the guide and valve. Lycoming's mushroom style lifters do not. We think that without any change in oil flow to the rocker boxes, Lycoming valve and guide longevity might well benefit from simply going to solid stem valves. Unfortunately, these are not available.

The Importance of Aircraft Mission

All of us know of examples of Lycoming engines that have run to TBO and well beyond with no cylinders pulled for repair work. How do we explain this? Actually, Lycoming did. Service Instruction 1479, the Mooney TLS engine modification mentioned at length in the TBO Advisor article, revealed many things we never knew. In fact, we have written a 4-page article (published in Australian A.O.P.A. magazine) on just the implications of this document. Of primary importance is the fact that S.I. 1479 reveals for the first time (to our knowledge) that cylinders can be operated at perfectly normal CHT levels and yet sustain premature guide wear and related problems due to excessive guide heat. And yet we are aware of other cylinders that were operated normally and did not have this problem. What this says is that the cylinders have two different ranges of operation. In one, air cooling plus the existing amount of oil flowing to the rocker boxes is sufficient to meet all needs. In the other, heat input to the valves and guides is such that air cooling and the existing amount of oil are insufficient to meet all needs, even with normal CHTs. In this latter instance, S.I. 1479 provides for additional oil cooling of the exhaust guide to increase its longevity. The problem is that no one, including Lycoming, knows when an engine passes from one operating region to another. What we do know is that most of the people who reported valve problems to us used their aircraft primarily for long cross country trips with cruise power...
and mixture set for prolonged periods of time. Certainly this is the mission of the Mooney TLS. The resulting "heat soaking" of the valve and guide is evidently the critical factor in this failure mode. Pilots flying on this type of mission are at greater risk of valve and guide problems than are pilots flying on short trips, such as local sight seeing or basic student training, even with the same cylinder head temperatures.

An interesting aside related to this is the fact that Cessna is betting that merely derating the 180 H.P. IO-360 in the new Skyhawk to only 160 H.P. will increase engine "reliability" (i.e., decrease valve problems) as compared to the 160 H.P. O-320 that is being replaced. Given that the new Cessna engine has the same cylinder head and all head components as does the 160 H.P. O-320 (and the Mooney TLS), and given that the 160 H.P. powerplant also has valve and guide problems, it is our conclusion that this derating attempt will fail to achieve the desired objective because it still does not address the root cause of the problem. Again, if the mission involves long cross country flying with cruise power and mixture set for prolonged periods, this failure mode may occur in the parallel valve cylinders unless additional oil cooling is provided.

The O-320H

Earlier we referred to figure 8, which shows the very large differences in oil flow to the rocker boxes we measured in an O-360A 180 H.P. engine and the O-320H 160 H.P. engine. The O-360 has mushroom style hydraulic tappets and the O-320H has barrel style tappets. As you read earlier, the barrel style was designed for this application and provides a much greater supply of oil to the rocker box. You might ask how effectively this added oil carries away heat.

One of the many things we learned is that the O-320H, despite its early problems, is now a very reliable engine and rarely encounters valve and guide problems. Its rocker boxes receive so much oil that this engine's oil return lines are actually larger in diameter than those on any mushroom tappet Lycoming engine. Furthermore, the oil cooler is 50% larger than that on the 180 H.P. Grumman Tiger, and is mounted on the same aft baffle location. Question -- why would an engine of 20 fewer horsepower need an oil cooler of 50% greater capacity in what is arguably already the best-cooled installation in general aviation? Answer -- because the substantial additional oil volume flowing to the rocker boxes carries away so much heat in this engine that the larger oil cooler size is needed to dissipate all of it. Remember that heat carried away from the guide and valve by oil does not have to migrate through the guide to the cooling fins to be transferred to the airstream. This relieves the guide of some of its thermal load with resulting increased longevity.

We also hasten to address the concern expressed by some, including Lycoming, that too much oil in the rocker boxes will cause valve sticking. This concern is pretty well dismissed by both figure 8 and S.I. 1479. Figure 8 shows that the O-320H has a much greater volume of oil flowing to the rocker boxes than does any mushroom style tappet engine and generally experiences few valve/guide problems. The O-320H is one of their newest engine designs and yet they knowingly increased oil flow to the rocker boxes dramatically as compared to engines with the older mushroom style hydraulic tappets. More
recently yet, the S.I. 1479 modification pumps additional oil into the rocker boxes after it has circulated around the exhaust guide. This oil then drains back to the case through the existing oil return lines. Although oil is most frequently associated with lubrication, the additional oil provided by the O-320H lifter and by the S.I. 1479 modification also serves to carry away valve and guide heat, which is causative of both excess guide wear and valve sticking. By keeping the temperature of these components in check with oil, Lycoming succeeded in greatly reducing incidents of valve and guide distress in these engines.

Valve Sticking versus Excess Guide Wear

One of the most vexing problems we had to consider is why some valve/guide failures result from excessive guide wear (the guide inside diameter increases) while others result from valve sticking, which is caused by a buildup of "cooked oil" (coking) on the valve stem. How could insufficient oil volume to the rocker boxes account for both of these seemingly opposite effects? The fact is that we cannot say for certain why one specific failure mode occurs versus another in any given engine. Both, however, are related to excessive amounts of heat in the valve/guide combination. Incidents of valve sticking appear to be greatly reduced now as compared to in the past. All but one of the incidents reported to us involved failures with either disintegrating valves in flight or with the valve's failure to seal during a compression check, caused by excessive guide wear. But we were able to find out how an increased flow of oil to the rocker boxes accounts for lower incidents of both excess wear and sticking.

The answer came in part from our testing and in part from a 50-year old Society of Automotive Engineers report. Our data was showing consistently that the odd numbered cylinders received considerably less oil to the rocker boxes than did those on the other side of the engine and that the odd side had much higher incidents of excessive valve guide wear. Lycoming has repeatedly stated that this distress is caused by excessive valve/guide temperature, although CHT levels in the affected aircraft were normal. We were simply finding that the additional oil to the rocker boxes evidently provides extra valve and guide cooling which is greater than what the cooling fins alone provide. And, not surprisingly, we found that cylinders with this additional oil (the even numbered ones) had generally longer valve and guide life than did those with a lesser amount of oil. But how did this relate to valve sticking problems?

The answer came from an extensive study done by the Society of Automotive Engineers nearly 50 years ago. As Robert V. Kerley of the Ethyl Corporation explained in a paper in *SAE Quarterly Transactions, Vol. 1, No. 2* (April 1947): "Practice has indicated that sodium-cooled valves will tend to increase valve-sticking troubles unless lubrication is increased, preferably by an oil jet to the stem, or unless the stem is run dry. *Light or moderate lubrication normally causes coke formation resulting in sticking.*" (Our emphasis).

The two of us had already concluded that additional oil to the rocker boxes was beneficial from the standpoint of valve and guide cooling to reduce guide wear. What Kerley's work showed is that exactly the same technique reduced incidents of valve sticking. We believe this is why the massive flow of oil in the O-320H engines (due to the barrel type of lifter -- see figure 8) has helped them acquire a
reputation of needing very little top end work. Sufficient oil is being provided such that the valve/guide combination is being held to a temperature below which oil coking will occur. Interestingly, the unique rocker arm design in this engine causes most of the oil pumped to the rocker box to flow directly onto the exposed valve stem where Kerley said it was most effective.

This scenario also fit the "simplicity test." This was a simple solution to both problems that had apparently not been tried by Lycoming because they never considered the possibility of a cause and effect relationship between oil flow and valve and guide distress that we appear to be seeing now. After all, their basic engine oil system design had been set into concrete decades before and what newly-hired engineer right out of college would ever question it? However, their publication of S.B. 293B and S.B. 388B, mentioned previously, are concrete proof that Lycoming was unable to solve this problem and simply passed it on to the engine owner via these two repetitive, mandatory service bulletins.

Over the years, Lycoming has published a great deal of service information on this subject blaming many things for the problem. Among them are too infrequent oil changes, highly-leaded fuel, valve guide material, camshaft design, excessively lean fuel mixtures, excessive CHT levels, solid stem valves, lifter design, insufficient valve to guide clearance, incorrect valve guide honing, exhaust valve material, contaminated oil, dirty air filter, infrequent flying, excess ground running, incorrect fuel grade, poor baffling, high ambient temperatures, slow flight, too rapid cooldown, reversed rocker arms, incorrect rocker shaft bushings and flangeless valve guides. All of these items share one thing in common -- correcting them did not eliminate valve and guide distress problems, as shown by the continued applicability of S.B. 293B and S.B. 388B. What Lycoming never pointed out as a possible cause of the problem is an engine design that provides insufficient oil to the rocker boxes for needed additional valve cooling in some operational situations. Once again, we point no blame their way for the initial design as it was developed. That was done long ago without our experiences in the years since. We do, however, believe the company had an obligation to investigate and to solve the problems they knew of 30 years ago that resulted in the publication of S.B. 293B, and which still remain today.

**Summary**

This was the "rest of the story" that Kas Thomas did not print in the May-June issue and which he also failed to print in the July-August issue, despite many assurances to us that he would. You now have read much of the story of what we have done to date. We'll leave it to your judgment as to whether or not it is significant. Evidently, Kas did not believe it was.

What you need to remember is simply that we have found an inverse correlation between oil flow to the rocker boxes and valve and guide distress. Valve/guide distress in turn places huge loads on the lobes of the camshaft during the valve opening sequence and we believe this is most likely the cause of Lycoming's camshaft problems, which also have never been formally solved. You also need to know that even if you do everything involving engine operation and maintenance perfectly, you may still encounter upper end problems if the mission of your aircraft involves extended flights with cruise power and cruise mixture set, regardless of CHT levels. This is the fault of the design, not of the pilot or of the
mechanic who maintains the aircraft. In short, if you have this problem, there is nothing you can now do to prevent its continuation other than to fly at greatly reduced power levels and/or enriched mixture settings.

For your information, our goal is simply to study this entire area in detail to gain a full understanding of all aspects of it. Once that is done we intend to develop a genuine solution to it that involves internal changes to the engine rather than the external oil lines used by Lycoming for the Mooney TLS (S.I. 1479). External lines and corresponding cylinder head modifications are just something else to go wrong and thus decrease the reliability of the powerplant.

In conjunction with our work so far (and all of this is in our spare time and at our own expense because we have full-time businesses to run), we are flight testing one possible solution to the problem. This test involves increasing the oil flow through the pushrods by using increased bleed down rate lifters. It is important to point out that oil flow through the pushrods goes to a different place in the cylinder head than does flow through the pushrod shroud tubes. It is flow through the latter that we believe may be most significant for valve and guide longevity. The reason is that we have very recently discovered that the so-called "oil squirt hole" in the rocker arm really does not squirt oil at all due to its large diameter and the relatively low oil volume that we can get to it, even with faster bleed down lifters. In fact, it is best called an oil "dribble hole." Additionally, the geometry of this hole is such that a squirted oil stream cannot reach the exposed valve stem and valve guide because it is blocked at all times by the upper valve spring seat. In contrast, oil flowing through the pushrod shroud tube drains directly onto the exposed valve stem and valve guide, which is exactly where it will do the greatest amount of good as a heat transfer agent. Only additional testing and time will determine what is the best course for us to follow.

And finally, there is one item we cannot help but point out. Please remember that you learned all of this through the efforts, expense and time devoted by Bill and Carol Scott and Bill Marvel. You did not get it from Kas Thomas, who was paid by your subscription to provide it and who was given all of our information and documentation for free. You also did not get it from Lycoming, which designs and builds the engines and should thus know more about them than anyone else. We thought you should know that.