Do You Have TIRED Metal?

How you handle your plane exerts a great effect on metal-fatigue process of aircraft components. Tiny scratch on propeller, for instance, could become stress raiser and speed deterioration

THE AUTHOR

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It's always the unexpected that causes trouble. Ordinarily, we can expect to obtain hundreds of thousands of hours of trouble-free service from our aircraft and engines if we take reasonably good care of them. But occasionally an unexpected failure suddenly strikes. An engine throws a rod, or blows a jug or swallows a valve. A wing or tail crumples under the pressure of a very mild gust or moderate maneuver, and private aviation gets another set of black headlines. These failures are typical cases resulting from metal fatigue. Fortunately, these unexpected fatigue failures are relatively infrequent (relative to other accident causes). But when they do happen, all too often the results are catastrophic. Like other accident causes, fatigue failures can be reduced or eliminated through a proper understanding of the problems.

The primary responsibility for providing us with aircraft and engines having fatigue-resistant structure and mechanical parts lies with the designers. However, as a result of the type of operation and maintenance we impose upon our aircraft, we as pilots also exert a very great effect on the process of metal fatigue in aircraft components.

Pick up a wire paper clip or coat hanger and bend it repeatedly back and forth. It will eventually break. Although this is an extremely exaggerated and accelerated example, it demonstrates what occurs as metal fatigue takes place. It's exaggerated in that we certainly, or at least hopefully, don't bend our airplanes each time we fly. It's accelerated in that we failed the wire in just a few seconds compared to the hundreds of hours of life expectancy of our aircraft and engine components. Nevertheless, this does represent the process of metal fatigue that is taking place progressively and irreversibly in virtually every part of our aircraft and engine every minute we are operating them.

If this is a rather disquieting piece of information, keep in mind that, while we do not have any control over the fact that the metal fatigue process is continually taking place, we do have considerable control over the *rate* at which it takes place. That is the purpose of this article, to show how we can minimize the rate of progression of fatigue damage in aircraft, and thereby realize the full service life that was originally built into the aircraft.

Let's go back to the coat hanger. As you bent it, you probably noticed that it became difficult to bend it in exactly the same place twice. It seemed to get stronger after it was bent. Let us see how this applies to our situation. One of the properties of metal is its ductility. This describes its ability to take permanent deformation without breaking. To look at an extreme example, lead is a very ductile metal. It can be bent, twisted or pounded into almost any shape without breaking. At the other extreme, cast iron is a very brittle metal. That is, it has very low ductility. It can withstand almost no permanent deformation without breaking. As you bent the coat hanger it became stronger, but it simultaneously lost its ability to deform without breaking. That is, its ductility was exhausted by the repeated loading and it became more brittle in the area where the deformation was greatest. This is the basis of the fatigue process in aircraft (or any other type) structures and mechanical parts.

"But we don't bend our parts," you may say.

This is true, from the viewpoint of any overall examination. However, we must recognize that any load, however small, produces a corresponding deflection in the part being loaded. It

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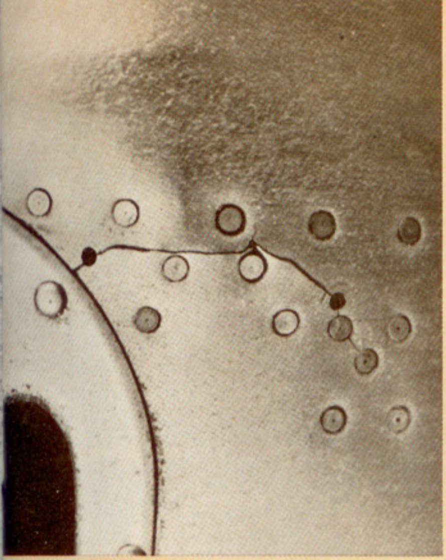
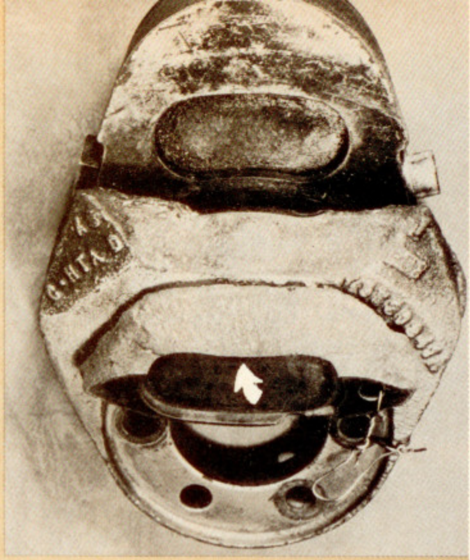


Stop-drilling is almost completely ineffectual in halting fatigue-crack growth. Fatigue crack in this cowling progressed through at least three stop-drilled holes, despite a neat repair job

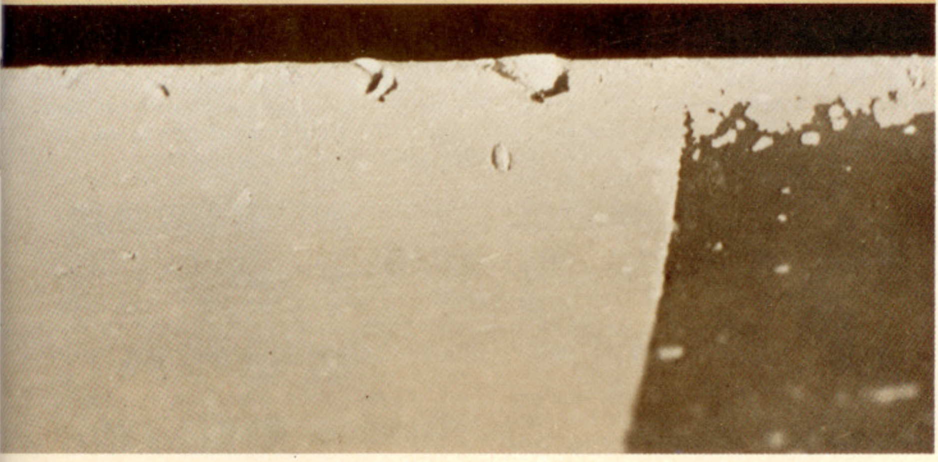


Both pieces of a fractured brake are shown here. Arrow show where the fatigue started along a sharp inside corner of the opening where the brake was machined out to take the brake "puck"

Fatigue failure of the threaded end fitting of this strut resulted in a fatal accident. Failure originated at the stress concentration caused by the threads *Photos by the author*

Typical failure of a connecting-rod cap. This failure originated at the stress concentration caused by an oil hole as shown by the arrow. The oil hole was partially peened closed by subsequent damage

Typical stone nick in propeller leading edge. Unless it is properly repaired, this type of innocent-looking damage may cause enough stress concentration to initiate a fatigue crack



acts just like a spring. This deflection may be small, but it is always there. Also, we must recognize that no matter how good a material is, or how well a part is manufactured, no material is completely uniform, nor is any load ever applied completely uniformly. Therefore, if we were able to delve deeply into these parts and examine them on a very submicroscopic scale we would find that somewhere, if we looked close enough, and on a small enough scale, there would be a point where a very, very small amount of permanent deformation takes place each time a load is applied. This would result in a small loss of ductility in this tiny area. Each additional application of load repeats the process by a minute amount until, after perhaps millions or even billions of loads have been applied, the ductility is sufficiently exhausted to result in a small fatigue crack. More load applications keep extending the crack until finally, if the crack goes undetected, the area of solid material remaining in the part is too small to carry the load, and, with a snap, a final, instantaneous failure occurs, even though the load being applied at the time may be very modest.

In order to see how we, as airplane operators, can influence this process, let us go back to our coat hanger again. It is not hard to see that we could break the wire by bending it severely a few times, or by bending it slightly a lot of times. This carries over into our fatigue process, and is really the basis of our preventative action. The severity of bending the coat hanger corresponds to the severity of loads applied to our aircraft. The number of bends required to break the wire is related to the number of load applications required to produce a fatigue failure in the aircraft parts. This is ordinarily expressed in terms of load cycles, where one cycle represents one application and release of the load. The number of cycles required to fail the part is the actual fatigue life of the part.

We can therefore come to one fairly evident conclusion. Applying large loads will shorten the fatigue life of aircraft parts; small loads will allow a longer life.

An example from the experience of the military may serve to emphasize this: There are two types of military operation that produce by far the greatest problems with airframe structural fatigue. One is in aircraft assigned to gunnery schools. These aircraft are continually making strafing passes, dive bombing runs, air-to-air combat maneuvers and performing other missions requiring high "G" maneuvering which puts large loads upon the airframe. In each hundred hours of operation these planes probably experience at least 10 times as many cycles of high structural loads as a similar type aircraft in ordinary squadron service. As a result they have many times the structural fatigue problems. At the other end of the scale stand the venerable transport aircraft that cruise along for hours with almost no high loads except for turbulence and gust conditions—but they have been doing this for tens of thousands of hours. These aircraft also experience a high incidence of structural problems, but it is just because of the astronomical numbers of stress cycles that have been imposed on them over their many years of service.

It seems almost too simple to say that large loads shorten fatigue life while light loads allow much longer life. To fully appreciate this effect we should see *how much* the fatigue life is affected by increasing the loads. While it is always somewhat risky to assign numerical values to a fatigue problem, a look at a typical set of fatigue test data gives some very revealing results. One series of tests showed that increasing the magnitude of loads by 50% would decrease the fatigue life (number of load cycles required to fail the part) by a factor of about 100 times. Greater increases in load shorten service life still more. For instance, doubling the applied load can decrease the fatigue life by a factor of as much as 150,000 times! Expressed slightly differently, this means that one application of a high load can advance this progressive and irreversible fatigue process by the same amount that would be produced by a lower load (one-half as large) applied 150,000 times.

The lesson is clear. High engine power, high r.p.m., heavy vibrating conditions, hard landings, rough taxiing, heavy gust and maneuver loads all place high loads on the engine and structure and reduce the fatigue life of the parts. These parts are designed and built to give satisfactory life under normal operating conditions, but their life can be drastically shortened by excessively high loads.

For example, some propellers have operating restrictions in certain r.p.m. ranges. At these engine speeds the propeller is subject to high loads from vibration. The propeller is restricted against continuous operation in this range in order to avoid accumulating a large number of cycles of these high loads and, therefore, to maintain a good service life. Other parts, such as helicopter blades, which are subject to severe fatigue loading from vibration or other causes, have certain maximum usable hours of operation. These parts *must* be junked at the end of their allowable operating life regardless of their outside appearance. The fatigue process has progressed too far within the structure of the metal to permit further safe operation.

Let us return to our coat hanger once more to check another effect. Suppose we were to file a notch in the wire and then bent it at the notch. We'd find our "fatigue life" was very much shortened, wouldn't we? The same thing applies to fatigue in aircraft structure. Any kind of a notch, corner, scratch, gouge, step, hole—or any other type of discontinuity—forces the load in the material to "crowd up"

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at the edge of the notch in an attempt to get around the disturbance. As a result, the load in a small area at the edge of the discontinuity can be many times the average load. In other words, we have a stress concentration, or stress raiser. The fatigue process will progress many times faster as a result of the stress raiser.

In one series of tests a plain strap of aluminum alloy was compared to another strap of the same size and composition, except the second strap was slightly notched on each side—a stress raiser. When loaded with a straight single pull, the notched specimen could take 80% as much load before failure as the unnotched piece. However, when they were subjected to identical cyclic (fatigue type) loads, the plain specimen took 10,000 times as many load cycles as the notched specimen.

Almost without exception, fatigue cracks originate at some kind of a stress raiser. Scratches and gouges, together with corrosion pits, are among the worst violators. Within reason, the severity of a stress concentration usually depends more on its sharpness than on its depth. Propellers have suffered fatigue failures originating at a scribe mark placed on the blade for a reference in measuring blade angle. They have also fatigued from file marks remaining after a stone nick had been "smoothed" out of the leading edge. Fatigue failures in engine parts have originated where part numbers have been stamped or even etched on the surface.

Of course, we have very little control over the parts inside our engine, but we can make sure that visible stress raisers in propellers, engine mounts, landing gear parts and critical structural fittings are promptly and carefully attended to, and we can see that the repair process doesn't intro-
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Crash Fatal To Joan Merriam And Friend

Flyers in many parts of the world were saddened recently by the death of globe-circling pilot Joan Merriam Smith (AOPA 103228) in a lightplane crash near Big Pines, Calif. With her in the Cessna 182 when it crashed into the side of a mountain and burned was another AOPA member, Trixie Ann Schubert (AOPA 260030), a Powder Puff Derby entrant, aviation writer and a prominent figure in the California Ninety-Nines. Mrs. Schubert also was fatally injured.

Readers of The PILOT will recall Joan's own story of her flight around the world about a year ago; how she determinedly continued to follow the route taken by the late Amelia Earhart in 1937 until her mission was completed, despite the hard luck that seemed to follow her on the flight. Her account of the flight appeared in the November 1964 issue of The PILOT. She was preparing another article for this magazine at the time of her death.

The late Joan Merriam Smith

Cause of the accident had not been determined at the time of this writing. It was being investigated by the CAB, FAA and private industry representatives. Weather was not a factor; conditions reportedly were CAVU at the time.

Friends of Joan Merriam, as she was known professionally, were impressed by her courage and her strong desire to promote general aviation. She spent a great deal of her time, following the completion of her world flight, lecturing and showing slides of the world as she saw it from her turbocharged Piper *Apache*. At the time of her death she was working on a program to promote flying among teenagers, she informed The PILOT in a letter written a few days before the fatal accident.

A mishap never dampened her love of flying, which dated back to her own teens. After her famous *Apache* crashed and burned last January, a PILOT editor called her to find out about her injuries. It was only a few days after the accident.

"Joan," she was asked, "when do you expect to fly again?"

"I've already been up," she said. "Two days after the accident."

"How did it go?"

"I was a little shaky at first, but after a few minutes everything was all right. Nothing is going to keep me on the ground."

After that first flight following the accident, she was eager to get back in the cockpit at every opportunity, close friends in California say. ●