Anatomy of a Hydraulic Failure
Hydraulic Fittings Need to be Very Carefully Tightened

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A hydraulic fitting failed and resulted in a gear up landing. What happened? The simple answer is that a ¼ inch aluminum hydraulic line terminated with a single flare into a 37 degree aircraft fluid fitting forced the flared tubing out of the flare nut in spite of being tight.

A more complete answer, one that might help prevent further such incidents, is more complex. The initial investigation suggested a possible cause.

The owner is particularly careful and thorough in his assembly procedures. For the hydraulic fittings, the tube was correctly assembled to the fitting, tightened and checked, then checked by another, and finally checked a third time, in effect a triple check.

The fitting in question had been fitted and refitted five times as it was required to be removed during maintenance procedures.

Why do we check?

There is excellent precedent for this type of repetitive process in the industrial world. Testing has shown that when doing simple repetitive tasks, trained human beings using appropriate tools in a hospitable work environment nonetheless make errors at roughly a 1% rate, that is, one error per 100 tasks. A 1% failure rate is not a very high quality standard. However, if the task is accomplished, and the person then checks their own work, the error rate in checking is also about 1% so that the overall error rate drops to 1% of 1%, or one in 10,000. If a second person then checks the work of the first, the 1% rule applies again and the overall error rate is down to roughly one per million. This level of quality is the goal of modern manufacturing processes worldwide.

Hypothesis

However, what if the fitting nut had been slightly over-tightened at any or all of the repetitions? Imagine the following. The fitting is tightened. The next guy put a wrench on it and gives it an extra tug “just to be sure.” The third fellow does the same. After this level of checking, there would be about a one in a million chance that the part would be accidentally left loose. But what happens if as part of the checking procedure it ended up **tightened too much**?

Approved Maintenance Data

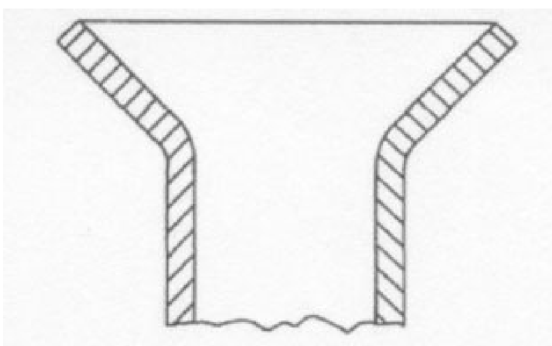
The document AC 43-13 outlines recommended practices for hydraulic lines and fittings on aircraft. The recommended torque for the nut is shown in the table below. Note the difference between aluminium tubing used in aircraft, and steel tubing used in many applications including aircraft and automotive brake lines which use a 45 degree instead of a 37 degree flare angle.

TABLE 9-2. Tube data.

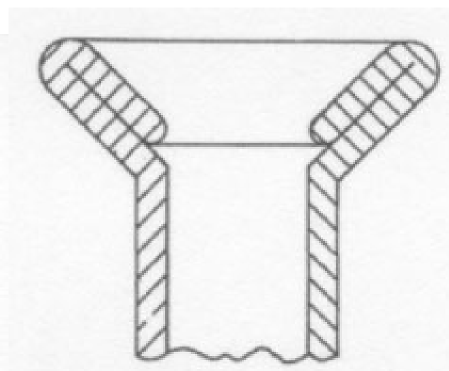
Dash Nos. Ref.	Tubing OD inches	Wrench torque for tightening AN-818 Nut (pound inch)						Minimum bend radii measured to tubing centerline. Dimension in inches.	
		Aluminum-alloy tubing		Steel tubing		Aluminum-alloy tubing (Flare MS33583) for use on oxygen lines only			
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Alum. Alloy	Steel
-2	1/8	20	30	75	85	–	–	3/8	–
-3	3/16	25	35	95	105	–	–	7/16	21/32
-4	1/4	50	65	135	150	–	–	9/16	7/8
-5	5/16	70	90	170	200	100	125	3/4	1-1/8
-6	3/8	110	130	270	300	200	250	15/16	1-5/16
-8	1/2	230	260	450	500	300	400	1-1/4	1-3/4
-10	5/8	330	360	650	700	–	–	1-1/2	2-3/16
-12	3/4	460	500	900	1000	–	–	1-3/4	2-5/8
-16	1	500	700	1200	1400	–	–	3	3-1/2
-20	1-1/4	800	900	1520	1680	–	–	3-3/4	4-3/8
-24	1-1/2	800	900	1900	2100	–	–	5	5-1/4
-28	1-3/4	–	–	–	–	–	–	–	–
-32	2	1800	2000	2660	2940	–	–	8	7

Wrench Torque for tightening Aluminium and Steel Tubing using 37 degree flare ends

AC 43-13 also specifies that aluminum hydraulic lines of 3/8 inch diameter and below are to be made with double flare ends with single flares being used on larger tubing sizes. See figures below.



Single flare tube end



Double flare tube end

Yet single flare fittings are used almost exclusively on smaller general aviation and specified by kit manufacturers for amateur built experimental aircraft for all tubing sizes. This was the case with the leak described above. Why are single flares so widely used? We have three theories, none confirmed.

1) It is much harder to consistently make a double flare on the tube end. It is much easier to get consistently acceptable quality with single flare, and so this has been adopted as an "industry standard" by general aviation manufacturers. This has carried over to amateur built experimental aircraft.
2) Because the double flare folds the tube back on itself with a zero radius bend, there may a new ling term failure mode introduced, possible cracking of the flare around the perimeter.
3) Much of the data in AC 43.13 comes from WWII when aircraft were quickly and frequently serviced during the night shift. It was much more likely that fittings were assembled without torque wrenches and over tightened repetitively "just to be sure." If you start getting a lot of leaks from abused <u>single</u> flare fittings, it may have been that the double flare became the recommended procedure at wartime airports when maintenance was done in a hurry and over-tightening could have been common.

Whatever the reason, single flare fittings are used on smaller aluminium tubing throughout aviation today. We wanted to know why this particular single flare tube end failed so another failure can be avoided in the future.

The Tests

To test the hypothesis that over tightening was the culprit, we conducted a multi step experiment. First we made up a ¼ inch 37 degree single flare aluminum tube end using a flaring tool set obtained from Aircraft Spruce. The actual flaring tool is shown below.

Thirty-seven degree flaring tool

Before flaring, the tube must be prepared by cutting, deburring, and is then put into a clamp shown in close up below.

Tube clamp that holds tubing during flaring process

Tube end preparation prior to flaring **is critically important**.

- First, if you use a rotary type tubing cutter (like a plumber uses for cutting copper tube), the cutting processes introduce compressive strains in the tube which must be removed prior to flaring   This means filing back from the cut surface to remove all the stressed material, a distance of up to 3 mm or 1/8 inch. If this damaged zone is not removed, the flare will split when formed. For this reason, some builders use a fine tooth hack saw to cut the tubing, and then file the end square and smooth while removing the cut marks.

- The finished cut must be perpendicular to the tube centerline. Otherwise the flare is lopsided and will deform when the nut is tightened.
- The cut must be finished by de-burring the interior and exterior of the tube to remove sharp edges. Failure to remove sharp edges will result in a split periphery of the flare when the flare is formed.
- Note in the photo of the tube clamp the notation on the clamp "3/32." This is the amount that the un-flared tube must project above the clamp (in inches) before flaring so that the flared section ends up the proper length. Making the flare too wide or too narrow can create problems. Too wide and the flare may split or may not fit inside the AN 818 nut. Too narrow and the flare will not be wide enough resulting in excessive stress on the aluminium tube which will plastically flow (as we later demonstrated in our testing) and ultimately fail.

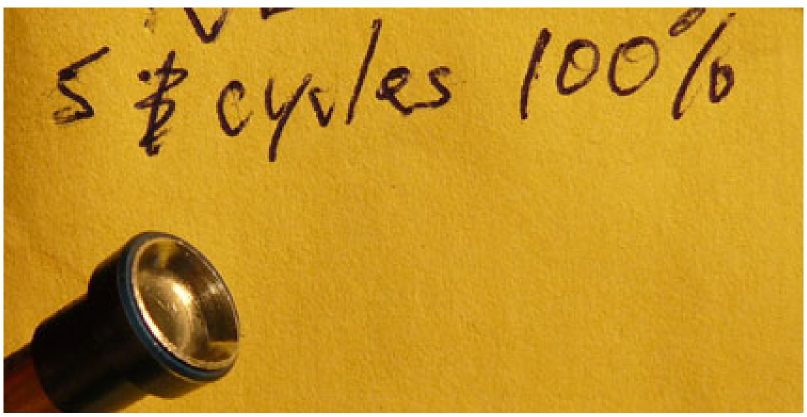
If you prepare the tube end square, deburred, and flare the appropriate length of tubing (3/32 in or about 2.5 mm for our tool), you should get an assembly that looks like this.

New tube flare, never used, with proper tube flare length

In our first tests, we made up a flared ¼ inch aluminium tube end, added an AN 818 nut and ferrule and then tightened onto a bulkhead fitting at 100% of recommended torque (50-65 in lbs. or about 5 ft lbs.). We used a new Kinchrome 3/8 drive torque wrench with a fresh calibration certificate driving the nut through a crow foot open end adapter as shown in the figure below.

Three-eighths drive torque wrench with crow foot to drive AN 818 nut

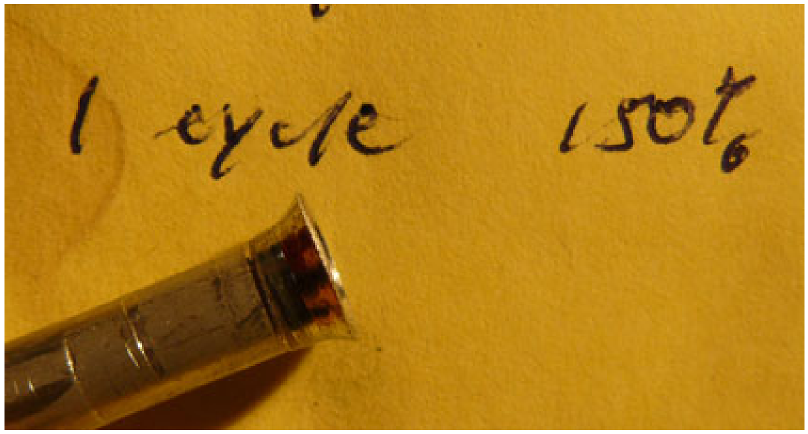
We adjusted the torque setting to reflect the change in leverage arising from the crow foot. We tightened the assembly to 100% torque once, removed, and then inspected. After five tightening and loosening cycle at 100%, the flared end appeared as shown below.



Proper flare tested with five cycles at 100% of recommended torque

After five cycles, the flared tube end appears slightly more polished, but the flare is not deformed or thinned in any way. Repeated cycling did not damage the flare.

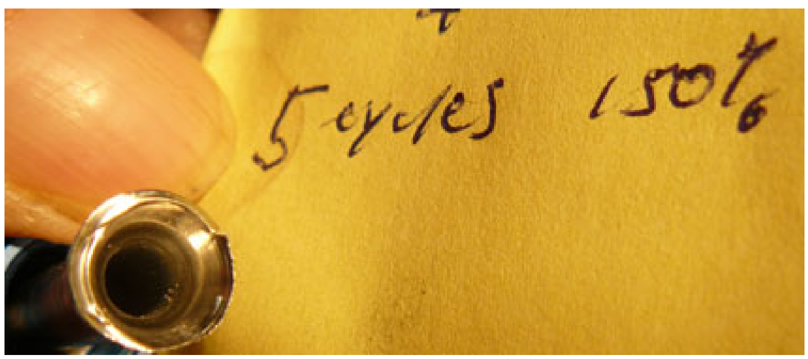
We took the same part and then tightened it to 150% of recommended torque, removed, and inspected. Once cycle of over-tightening produced the result shown below.



Tube flare after one cycle at 150% of recommended torque

While difficult to see in the photo, inspection with a magnifying glass showed that only one cycle at 150% torque was adequate to deform the flare, thinning the flare wall, and extruding metal toward the periphery which was now much thinner and starting to approach a knife edge. Clearly one cycle of torque overload had extruded the aluminium outward and permanently deformed the flare.

We reassembled the tube end shown above with nut and ferrule, and conducted four more cycles at 150% torque to see if the damage would progress with each abuse. It did. The result of five overload cycles is shown below.



Tube flare after five cycles at 150% of recommended torque

By the end of the fifth overload cycle, the tube flare wall was substantially thinned with much material extruded out the top of the flare where it formed a knife edge and interfered with the internal threads of the nut. To get the nut off we had to pull hard which bent that portion of the knife edge which is the upper half of the tube flare in the photo above. Clearly this flare is well on its way to failure.

We did one last experiment to see what happens if you tighten without a torque wrench and then check "just to make sure." One of us used a plain wrench to tighten the AN818 nut what we thought felt like "tight enough." After having pulled the torque wrench a few times, it is not surprising that a value of 4.5 foot pounds was obtained, close to the specification of five 5.0 foot pounds. Another individual tried it, and checking with the torque wrench showed 4.0 foot pounds, not bad for an un-calibrated hand.

Then we completed the test. Starting at 4.0 foot pounds, one person was asked to "check the tightness" by pulling the wrench until the nut just started to move, a tiny fraction of a turn. Then a second person did the same. Thus we have a fitting that was tightened, then "checked" and then "checked" again by another party. The finish torque measured was just over 7.0 foot pounds, or nearly 150% of recommended torque, more than enough to damage the flare. Repeat this cycle enough times, and the flare will become badly extruded with a very thin wall, and a failure is waiting to happen.

Conclusions and Recommendations

The smaller diameter aluminium tubing and 37 degree flare fittings we use on our aircraft for brakes and hydraulic lines is **very sensitive to extrusion by over tightening** of the AN818 nut. It only takes a onetime 50% overload to damage the tubing flare. A few cycles of overload at less than 50% excessive torque can compromise the strength sufficiently that a flare which may be appear to be in good condition can fail when hydraulic pressures are applied.

Always use a torque wrench when tightening your flare fittings, particularly the ¼ inch size. Buy a set of crow feet so that you can put your torque wrench on your AN818 nuts. Treat these parts gently, and DO NOT make it “just a little tighter just to make sure.” Do it too often and inadvertently you will make sure that you end up with a hydraulic line failure.