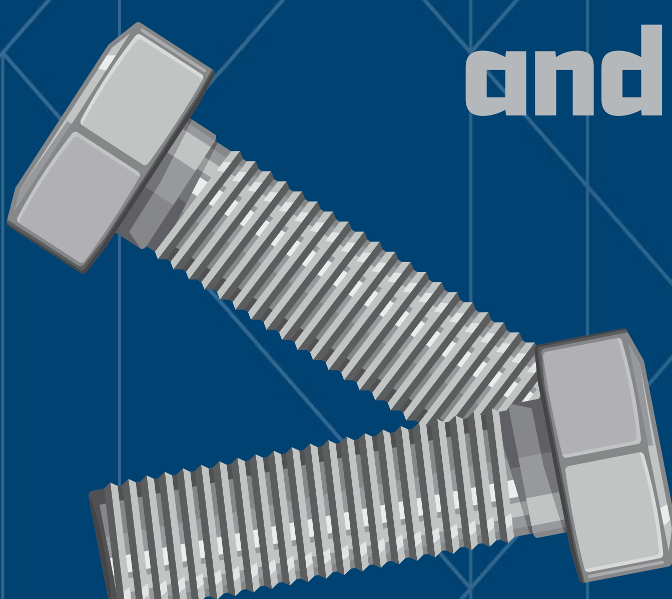
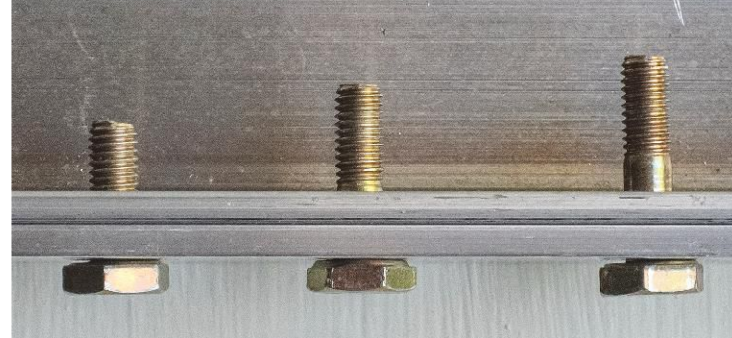
The Nuts and Bolts of Nuts and Bolts (and Washers)



Deploying AN bolts, AN960 washers, and lock nuts on structural joints

BY KERRY FORES



The *How* of Hardware Installation Without the *Why*

Here I skip wordy preambles and provide simple steps for choosing the correct length bolt and deploying washers.

1. **Make sure all the correct parts are in all the correct places.**
2. **Make sure the parts — both the edges and the holes — are deburred. Burrs are not only poor workmanship and stress risers, but also impact how well parts nestle together, which can impact the bolt length and washer usage, and lead to embedding loss.**
3. **Decide if you are placing a washer under the head of the bolt. One is almost never needed.**
4. **Select the shortest bolt whose grip extends fully, if only minimally, through the parts being fastened. Sometimes the grip of the shortest usable bolt can poke through a strong 1/8 inch.**
5. **Cover the bolt's protruding grip and relief with (a) washer(s).**
   - **a. When possible, use a single AN960L or AN960 washer.**
   - **b. If the fastener's grip length requires two washers, use an AN960L washer if possible.**
   - **c. If a third washer is needed (almost always an AN960L washer, resulting in two standard washers and one thin washer), first make sure you've used the correct length fastener. Though using more than 1/8-inch total thickness of washers goes against best practices, sometimes the real world leaves no choice.**
   - **d. A fourth washer will never be needed. Reach for a shorter bolt.**
6. **Install the nut, turning only the nut — not the bolt — until the proper torque is achieved.**

DURING MY 20-YEAR CAREER in the kit airplane industry, I often addressed why the specific bolt length and washer callouts in kit documentation didn't work for some builders. I was also questioned (or challenged) on the documentation's deployment of washers.

Some builders sought permission to use a different length bolt or add or delete a washer. Others would install the hardware identified in the plans and accept it as gospel, not noticing or questioning a bolt or nut installation that didn't meet best practices. Others added washers where they weren't needed.

With this article, I address the hardware usage guidance in both *Advisory Circular 43.13-1B, Acceptable Methods, Techniques, and Practices — Aircraft Inspection and Repair* and the *Standard Aircraft Handbook*, which draws heavily from AC 43.13. Both are must-haves for every aircraft builder/owner, though both contain contradictions as well as statements that don't hold up to scrutiny.

I also highlight how manufacturing tolerances impact bolt length selection, and dispel some anecdotal hardware installation directives that circulate informally among builders. I hope to communicate that bolt length selection and washer usage is really quite easy. As my eighth-grade math teacher said, "If you know why, you know how."

AN Bolts in Structural Applications

Nearly every fastener in an airframe is loaded in shear, meaning the stress a fastener experiences is trying to tear through it. Engineers select a bolt's diameter based on the expected shear loads. The nonthreaded part of a bolt — the grip — is the portion meant to carry those loads.

The grip must extend fully, if only barely, through the components being fastened. While my goal is to give you the knowledge to choose the correct grip *length*, regardless of the kit's documentation (or lack of same), I caution you not to change a bolt's *diameter* without consulting the kit's manufacturer. Oversizing a hole to accommodate a larger diameter bolt can weaken an assembly.

An AN bolt's numeric designation (AN3-21, AN5-23, AN4-7, etc.) defines the grip's diameter and length. The number following "AN" is the grip's diameter, expressed in sixteenths of an inch. An AN3 bolt has a 3/16-inch diameter. An AN4 bolt has a 4/16-inch (1/4-inch) diameter, and so forth. The number following the dash (often referred to as the "dash number") is the bolt's grip length.

Oddly, the dash number's value isn't consistent across the various diameters. An AN3-31 bolt has a nominal grip length of 2-3/4 inches. An AN6-31 has a nominal grip length of 2-9/16 inches. AN4-31 and AN5-31 bolts have nominal grip lengths of 2-11/16 inches. But that doesn't matter to us. In fact, it can hinder us if we become focused on a bolt's dash number rather than its actual grip length. The correct grip length for any bolt can be chosen without knowing if you've grabbed a -7 or -10 for a particular hole. All you need is your eyes to confirm the grip extends fully through the parts being fastened.

Before I move on to washers and nuts, the physical act of installing a bolt needs a brief mention. Avoid twisting or "screwing" a bolt into its hole. Doing so can strip off the bolt's cadmium plating and radially score the bolt's grip, weakening its strength and exposing the underlying alloy to the risk of corrosion. If you encounter resistance inserting a bolt with your thumb, tap it in with a mallet or draw it in with the nut.

AN960 (Plain) Washers

There are two versions of the AN960 washer. The most common version (AN960) is 1/16-inch thick. A derivative, the AN960L, is 1/32-inch thick. When bolting Part A to Part B, an AN960 washer's primary function is to bridge the bolt's relief: the transition between the bolt's grip and its threads. The relief is not meant to bear shear loads. Therefore, it must not be inside the parts being fastened, nor must a nut come to a stop against it. If a nut runs out of threads and comes to a stop against the relief, it isn't properly tightened. A proper bolt installation will always have at least one washer under the nut.

Here's what AC 43.13-1B has to say about washer usage:

Section 3, Bolts, states: "… bolt grip length of a fastener is the thickness of the material the fastener is designed to hold when two or more parts are being assembled. Bolts of slightly greater grip

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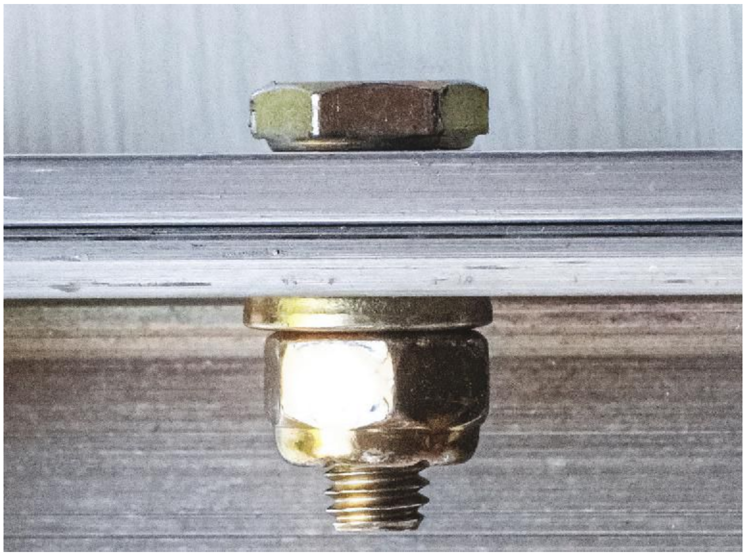
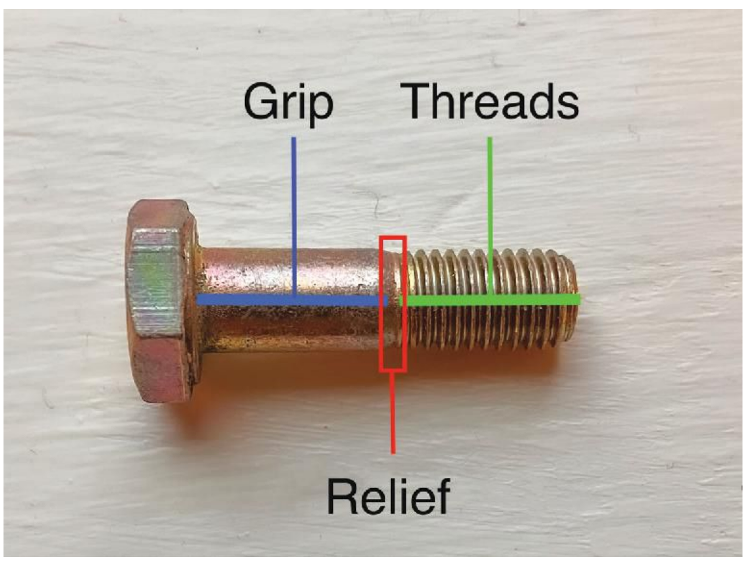


This photo illustrates two potential issues. The number of exposed threads may indicate the nut bottomed out on the bolt's grip, and though a minor detail, the "sharp" edge of the washer is against the airframe's surface rather than the eased edge.

length may be used, provided washers are placed under the nut or bolt head. The maximum combined height of washers that should be used is 1/8 inch. This limits the use of washers necessary to compensate for grip, up to the next standard grip size."

Despite AC 43.13-1B's optimism, the total thickness of the materials being fastened will almost never conform to the polite system of AN bolt grip-length progression. There are an infinite number of total material thicknesses possible and a finite number of bolt lengths.

While AC 43.13 implies a maximum of two AN960 washers may be used, it is widely accepted that up to three washers can be used, though a third is seldom needed and should be an AN960L thin washer whenever possible. Also, although it states "… washers are



The grip of a bolt must extend fully through the parts being fastened. The relief must be bridged by washers to prevent the nut from bottoming out.

Torque seal will visually reveal if a nut has turned on the threads, but it will not reveal if embedding loss has occurred.

Variations in thread length can negate the rule of thumb that no more than three threads should protrude from a nut.

This engine mount bolt has been used as a grounding point, leaving too few threads protruding beyond the nut. For many reasons, an alternate ground point should have been used.

PHOTOGRAPHY BY **KERRY FORES**

placed under the nut or bolt head," a proper bolt installation will *always* have a washer under the nut, to bridge the relief. Perhaps that is what AC 43.13-1B is referencing when it states: "Plain washers are widely used with hex nuts to provide a smooth bearing surface [and] act as a shim to obtain the proper grip length." Whether a washer is placed under the head of a bolt or not, the bolt's grip must pass through all of the parts being fastened, and at least one washer is needed under the nut to bridge the relief.

AC 43.13 recommends cadmium-plated washers (which is what AN960 washers are) be used under nuts and bolt heads on aluminum and magnesium surfaces to prevent corrosion. This directive doesn't hold up under scrutiny. Both AN nuts and bolts are cadmium plated; therefore, any corrosion protection provided by a cadmium-plated washer is superfluous.

Cadmium-plated flush screws and washer head screws are installed against aluminum surfaces without washers as a matter of routine, and the grip of any fastener is in direct contact with the aluminum or magnesium parts. If there will be corrosion, it can still occur on the grip.

My 1991 edition of the *Standard Aircraft Handbook* states, "The AN960 washer is used under hex nuts" and goes on to repeat, almost verbatim, the text from AC 43.13. However, two pages later it contradicts itself with the statement, "Be sure that washers are used under heads of *bolts and nuts* unless their omission is specified." [Emphasis mine.] It doesn't say why a washer should be placed under the head of bolt, leaving us to argue amongst ourselves. And, so, we do.

One oft-cited reason for placing a washer under the head of a bolt is to keep the bolt head (and wrench) from damaging the surface of the airframe when the bolt is tightened. But that damage can be avoided by holding the bolt still and turning only the nut. Both AC 43.13 and I agree turning the *nut*, not the bolt, is the proper method for securing bolts.

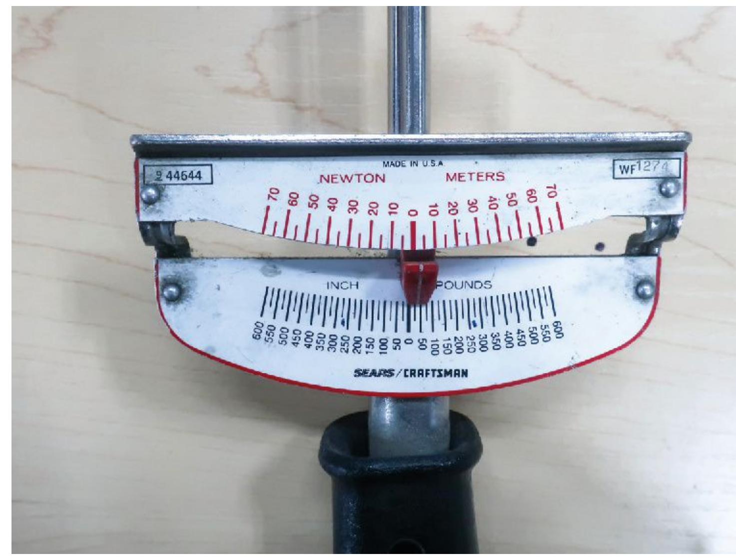
When someone insists a washer be placed under the head of a bolt, it may be driven by their exposure to that specific practice with a standard category aircraft. Standard category aircraft certified with a washer under a bolt's head must have a washer under that bolt's head, even though an otherwise airworthy installation can be achieved without one.

I mentioned earlier how individual manufacturers may have their own standard for deploying washers, and that may include always placing a washer under the head of a bolt. I spoke to the owner of an aircraft repair facility who told me the rules taught in A&P school went out the window the first time he worked on a standard category aircraft from an unnamed manufacturer, which had its own way of doing things.

Here are four reasons to *not* place a washer under a bolt's head on your experimental amateur-built aircraft:

- Placing a washer under a bolt head may require the use of a longer bolt to achieve the correct grip length.
- The added washer and longer bolt impact an airframe's empty weight and cost.
- Unneeded washers encourage embedding loss.
- A washer under the head of a bolt does not negate the need for one under the nut.

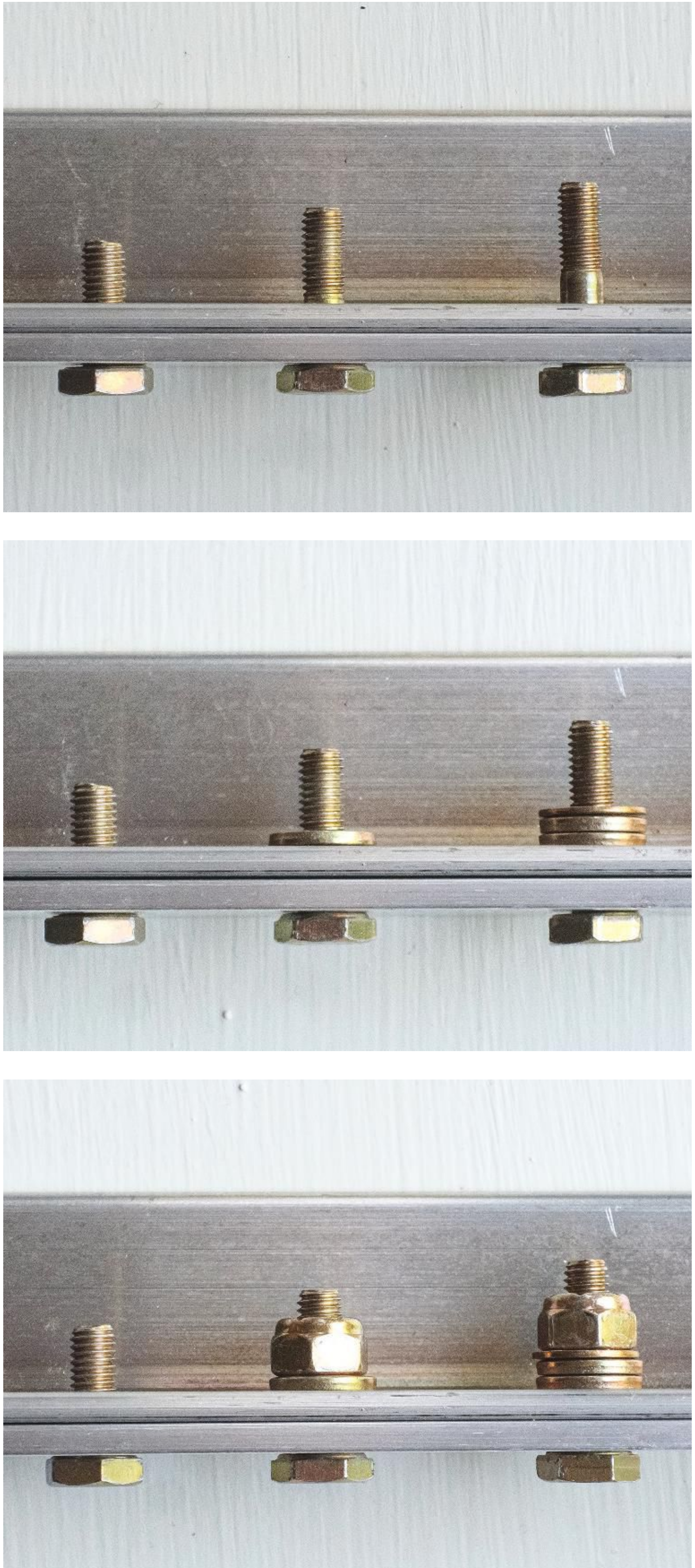
A proper bolt installation will always have at least one washer under the nut.



Torquing accuracy begins with an accurate torque wrench. This one reads 35 inch-pounds sitting on the workbench.


This bolt broke at the threads, which are not intended to carry shear loads.


Stop (lock) nuts come in a few varieties. The most common are the AN365 elastic stop nut and the AN363 all-metal stop nut. A low-profile elastic stop nut — the AN364 — is also available.



By observing how much grip extends through a hole, you can choose the correct bolt length. The bolt on the left is too short. Its grip is within the parts being fastened. The bolt in the middle is correct, its grip extends fully through the parts and one washer will prevent the nut from bottoming out on the grip. The bolt on the right is too long and would require too many washers.

Embedding Loss

Embedding loss, simply put, is surface erosion. Grab a handful of coins and you'll see evidence of surface erosion where the Lincoln Memorial has rubbed against Monticello in pockets, cash register drawers, and vending machines — possibly for decades. Similarly, the high spots of freshly minted washers erode over time, if ever so slightly, as do the mating surfaces of the fastened parts, creating space where there was no space.

The more layers there are, the greater the potential for embedding loss. Embedding loss is what causes a bolt to loosen (spin in its hole) even though the nut remains positioned on the bolt's threads exactly where it was when properly tightened. That's a strong argument for using as few washers as possible, for not placing one under the head of a bolt, and for deburring both sides of every hole of the parts that are being fastened.

Self-Locking Nuts

Self-locking nuts (aka, stop nuts) are used to secure bolts in permanent, nonrotating assemblies. Unlike common nuts, which can be spun onto a threaded fastener fully by hand, self-locking nuts tightly grip a bolt's threads and must be installed with a wrench. Elastic stop nuts use an elastic (nylon) insert to create the friction; all-metal stop nuts use slightly deformed threads.

All-metal stop nuts can be employed anywhere on an airframe but are required where temperatures exceed 250 degrees Fahrenheit. This requirement applies when it can be assumed the nut will experience those temperatures, but it doesn't mean elastic stop nuts can't be used under a cowl, though some balk at the sight of an elastic stop nut under a cowl. (VW Type I engine cases are bolted together with elastic stop nuts.)

Stop nuts — elastic stop nuts, in particular — lose some of their grip each time they are used. It is generally accepted that a lock nut can be reused once. If you are servicing an airplane, I recommend always reaching for a new nut. When assembling something temporarily, I use a used nut and bolt for the initial assembly and replace them with new on final assembly. There's no point compromising new hardware for a temporary need.

As pointed out earlier, at least one washer is required under a nut to keep the nut from bottoming out on a bolt's relief. Best practices also dictate that at least one full thread protrudes above a properly tightened nut. That ensures the nut is fully engaging the bolt. Some say no more than three threads should protrude from a nut, with more than three threads indicating the nut may have bottomed out on the grip. However, manufacturing tolerances can result in bolts with longer threaded lengths than "normal," so it is possible for some bolt installations to have more than three threads exposed and still be correct.

Torquing/Tightening Nuts

Torquing nuts can be debated without consensus. AC 43.13-1B recommends torquing every nut. I snug all but the most critical applications (propeller-mounting bolts, for instance) by feel, as was taught to me by trusted old-timers. When I spot-check my results with a torque wrench, I'm spot-on enough.

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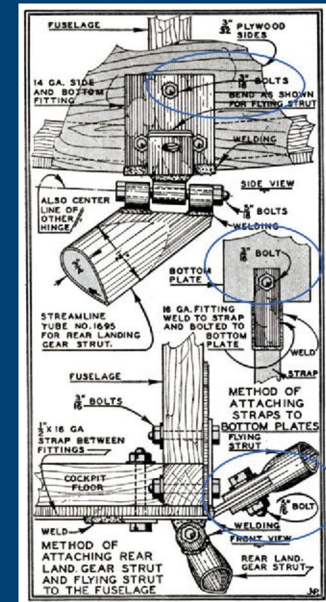
Used improperly, torque wrenches can provide a false sense of accuracy. There is more to using a torque wrench than waiting for the breakaway "click" or watching the pointer on a beam-type torque wrench. To begin, a torque wrench must be calibrated at least once a year and after it has been dropped or used as a hammer. There is no point in torquing to a specific value if you aren't actually achieving that value.

I've seen many builders rely on torque wrenches to their detriment, almost always overtorquing fasteners. Also, not every nut can be accessed by a torque wrench so having some feel for a properly tightened nut is important.

Another important factor in achieving the proper torque is accounting for a nut's friction drag, which is the torque needed to overcome the friction between the nut and the threads of the fastener. (There is also friction drag when a bolt rotates inside the parts it passes through, but we've already agreed that bolts should never

AN970 washers are larger in diameter than AN960 washers and must never be omitted when called for in construction documentation. They do critical work, like spreading loads across the surface of soft materials and capturing rod ends in the event of a failure.

Tolerances and Tolerance Stacking



Early aircraft plans often omitted bolt length callouts. Best practices did, and should, dictate the correct length bolt.

In the days of yore, bolt length was often absent from airplane plans. That changed in the late 1970s, particularly after Frank Christensen introduced the Christen Eagle II with the promise the kit included everything needed to complete the airplane, including fasteners and detailed documentation to deploy those fasteners about the airframe.

I don't know how well that worked for individual Eagle II builders, but I fielded far too many inquiries from Sonex builders who both questioned discrepancies and sought permission to use a different bolt length. Worse, perhaps, are builders who don't know to act on a discrepancy.

While I was on a homebuilt-judging ride-along during EAA AirVenture Oshkosh, a short bolt was pointed out to an aircraft owner who responded that that was what the plans called for. That may be, but it doesn't make it correct.

When the plans and the real-world disagree on the proper bolt length, the most common cause is tolerance stacking. Tolerance stacking, loosely defined, is the impact the manufacturing tolerance of each part has on the total thickness of a stack of parts.

The raw materials used on homebuilts have manufacturing tolerances, as do the grip lengths of AN bolts. AN bolt grip lengths have a manufacturing tolerance of plus or minus 1/64 inch. That means two AN bolts of the same diameter and nominal length, manufactured to the extremes of their tolerance range, can have actual grip lengths that differ by 1/32 inch.

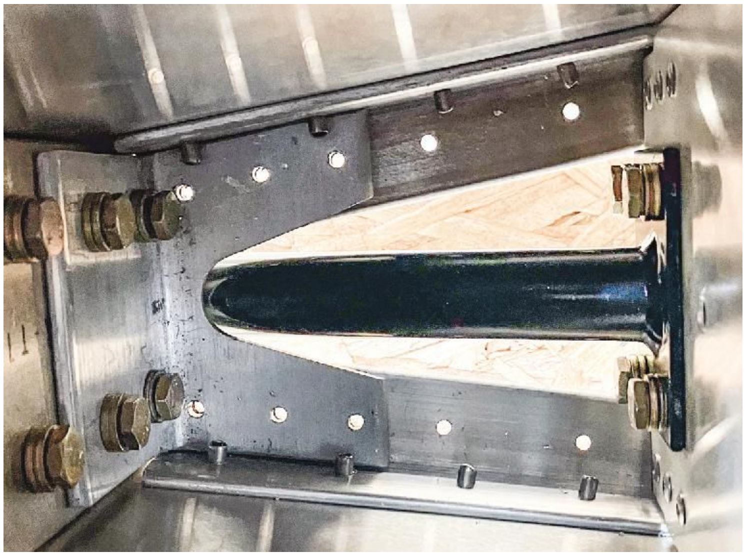
The score marks around these bolt heads were caused by rotating the bolt with a socket wrench. Such damage can be avoided by rotating the nut, not the bolt.

be turned.) To achieve the correct torque value, the friction drag must be measured and added to the bolt's torque value.

For example, if a bolt's torque value is 50 inch-pounds and the nut has 10 inch-pounds of friction drag, the torque value setting must be 60 inch-pounds. If friction drag isn't added to the torque value, a bolt will be undertorqued. Also, used stop nuts can have less friction drag than new ones. That's another reason to always reach for a new stop nut.

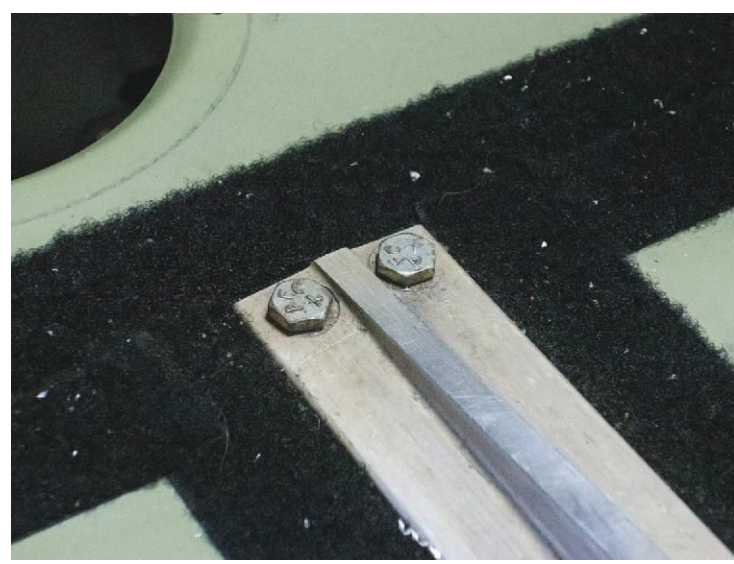
Other points to consider when using a torque wrench to tighten nuts are:

- Fine- and coarse-thread fasteners have different torque values.
- Don't confuse inch-pounds with foot-pounds.
- Torque tables reference a bolt's grip diameter, not the size of the socket used to tighten the nut.
- If you add an extension to the torque wrench (a crowfoot adapter, for instance, or a handle extension), the torque value setting goes out the window, and math must be used to account for the change in the tool's effective length.
- The torque wrench must be pulled or pushed smoothly until the final torque value is reached. Jerking the tool can over-torque the bolt.

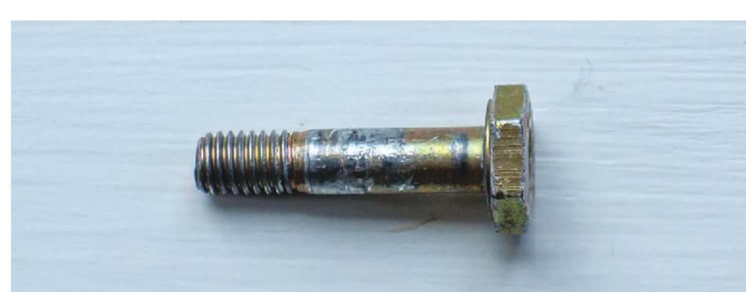


This is an abandoned Sonex project. Neither the hardware callouts in the plans nor best practices can explain why the builder placed two washers under each bolt head, leaving the nuts barely clinging to the threads.

Using a beam-type torque wrench isn't always possible. If the nut in this photo had been inside the structure, instead of on top, it would limit the torque wrench's range of motion and make reading the scale impossible.



I explored an aircraft repair facility and found that for the most part standard category aircraft, like these Cessna seat rails, lacked washers under bolt heads.



This bolt was "screwed" into its hole, damaging the grip and stripping away the cadmium plating, which protects the grip from corrosion.

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- The threads of the bolt and nut must be clean and dry. Lubricants, sealants, and locking agents will alter friction drag, resulting in an improper final torque value.
- If a nut goes from turning with moderate resistance to stopping outright, it may have bottomed out on the bolt's grip. The resistance felt when tightening a nut should increase gradually as you near the required torque, not come all at once.

A calibration certification label is meaningless if the wrench has been dropped or abused.

Let 'Why' Inform 'How'

The "how" of a proper bolt installation comes down to the details, none of which are hard to accomplish. But the task gets muddled when the "why" is unknown, forgotten, or confused with opinions.

There will be some who counter with "I'm an A&P and …" or "At Standard Category Aircraft we …." I acknowledge that guidance exists in some corners of aviation that dictates alternate methods — particularly the use of a washer under every bolt head. The reason for that guidance may be decades old and unknown even to those who must follow or enforce it. (An off-topic example: I asked an Air Force air traffic controller why pilots on air bases require ATC permission to start their engine. His answer? "Because that's how it's always been done.") As I've pointed out, I disagree with AC 43.13's mention that a washer should be placed under a bolt head "to protect against corrosion." But I do so only after thoughtful analysis.

I hope I've given you the knowledge (and permission) to choose the proper length bolts, deploy washers, and install stop nuts regardless of what a kit's assembly documentation calls for — or if there is no documentation at all. If you know why, you know how. *EAA*

Kerry Fores, EAA 131990, an Oshkosh native, scratchbuilt a Sonex that was awarded Plans Built Champion (AirVenture 2006). He's retired from a 21-year career supporting Sonex Aircraft builders and has written extensively on homebuilding. He's online at KerryFores.Substack.com.