nuts & bolts

# building basics

# Fasten-ating

## Threaded fasteners

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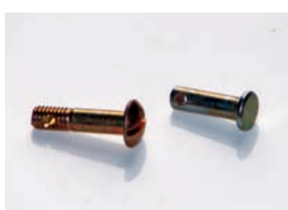
They are the simplest of machines, sometimes consisting of just one part. Still, without a relative few dollars' worth of threaded fasteners, most of our toys, tools, and transportation would not exist.

Screws and bolts hold things together against forces that try to separate them. Tension pulls on the bolt; shear forces try to bend it or cut it off. Threaded fasteners are engineered to precisely resist these forces. In this article, we'll concentrate on bolts, threaded fasteners that maintain a constant diameter through their uniformly threaded portions (unlike some screws that may grow in diameter from point to head), and accessory hardware that goes on and around bolts (like washers, nuts, and safety wire).



Bolts operate in tension or in shear, but rarely both. Generally, a bolt is stronger in shear, and it is stronger yet in a double-shear situation, where it is supported in two places with a center load. (The ultimate example of a fastener in shear is a pin.) Bolts that are used in shear applications should fit snugly in their holes; in tension, you'll often see a reduced-diameter shank—tension bolts don't like to rub!

Bolts are graded, with higher grades being stronger, but the tensile strength (measured in pounds per square inch, a measure of the tension the bolt will carry) should not be the only consideration in aircraft use. Brittleness (or its opposite, malleability) is important, as well. SAE (Society of Automotive Engineers) Grade 8 bolts, for instance, have 150,000 psi tensile strength (as opposed to aircraft hardware's typical 125,000 psi), but a Grade 8 bolt won't bend very far before it snaps. In overstress situations, as happen in aircraft, it may be more important to have a bolt partially fail (stretch or bend a little) than simply hold on a tiny bit longer—and then let go suddenly! In fact, some critical fasteners are most predictable when tensioned just barely into that partial failure, or yield, mode. (This is another good reason to always replace bolts that are specified to be replaced!)

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As a general rule, unless you have a specific situation that prohibits using aircraft-grade hardware (as you would in some engine fasteners, for instance), use AN hardware. Of the three components in a typical fastener assembly (bolt, nut, and washer), the bolt is the hardest and the washer is softest. (Sometimes very hard washers are used to avoid the bolt head's or nut's "embedment," or digging into the surface that is being clamped or the washer itself.) All three components are engineered together to give the most-consistent assembly possible for that application. Since this consistency can be counted on, engineers don't have to over-engineer fastener specifications, and they don't. That also means that our fasteners, while they have plenty of safety factor built in, need to be correctly installed and maintained to maintain that safety factor.

Torque ratings for various bolts and nuts assume several important conditions: Unless stated otherwise, these apply to new, clean, dry fasteners. The torque to achieve predictable tension in used fasteners is unpredictable—sometimes less, often more. Washers may work-harden, "squishing" less the second time they're used.

A larger factor is the cleanliness of the threads. A dirty thread may require a lot more torque to achieve the same tension in the bolt; an oily thread will require a lot less. Remember that when you use anti-seize compound, oil, or corrosion-preventive compound as you assemble nuts and bolts. In fact, many fastener manufacturers will give different torque ratings for assembly with lubricated versus dry threads, and the torque values can vary by 100 percent or more! Don't waste the bolt's safety factor by tensioning it more than it needs, and don't waste its strength by making it too loose.

Remember that torque applied to a threaded assembly gives only an approximation of the clamping force exerted by the bolt. Dave Miller, at RS Technologies, which (among other things) tests fasteners, says, "The effect of friction on the torque-clamp load relationship cannot be overstated. Torque is simply a measure of the energy that is used to tighten the fastener. It can sometimes function as an indicator of the amount of clamp load that will hold the assembly together. However, variations in the state of friction can produce significant changes in the amount of clamp load developed by applying the same torque, and clamp load is what is really holding the assembly together. Less friction can produce more clamp load, and too much clamp load can lead to fastener failure; more friction can produce less clamp load, which can lead to assembly failure due to loosening."

Bolt strength is usually given in yield strength and tensile strength. Experienced mechanics approach yield strength when they tighten the assembly and feel the fastener is "just right." Although a bolt will stretch a little up to the point where yield strength is reached, after that point, it stretches disproportionately fast. At its tensile limit, it separates. When the mechanic feels that the bolt's tension is "just right," that usually means that the mechanic has felt that the threshold at its yield strength has just been met. Any tighter, and the bolt will likely fail. That's why we use torque wrenches and put together clean assemblies, using new washers.

In fact, in an ideal world, nuts used in tension assemblies should also be replaced regularly. In shear, where the nuts are really just holding the bolts in place and there is little tension, it's fine to reuse nuts as long as they appear viable. Same with washers: The full-thickness AN960 washers can be used in either tension or shear; the thinner AN960-L washers are for shear applications. In critical assemblies,

**Bolts and machine screws (bolts with a screwdriver-driven head) have been holding things together for centuries.**

**Two types of locking nut plates. The left one uses out-of-round threads; the right one uses standard Nylok.**

**Front: Locking castellated nut (for high-temperature installations), castellated AN nuts, and standard AN365 (taller) and shear nuts. Back: For special applications: plain nut and brass exhaust-mounting nut.**

ASTM & SAE Grade Markings for Steel Bolts and Screws

| Grading * Marking | Specification | Material | Bolt & Screw Size, Inches | Min. Yield Strength | Min. Tensile Strength |
|---|---|---|---|---|---|
| | 18 - 8<br>18 Chromium<br>8 Nickel | "300" Series<br>Stainless Steel | All Diameters | 30,000** | 70,000** |
| B-8 | ASTM-A193 / A320<br>GR B8<br>CL-1 | Solution Treated<br>304 - 304L<br>Stainless Steel | All Diameters | 30,000 | 75,000 |
| B8M | ASTM-A193 / A320<br>GR B8M<br>CL-1 | Solution Treated<br>316 - 316L<br>Stainless Steel | All Diameters | 30,000 | 75,000 |
| B8A | ASTM A193 / A320<br>GR B8A<br>CL-1A | 304 - 304L<br>Stainless Steel<br>Solution Treated In Finished Condition | All Diameters | 30,000 | 75,000 |
| B8MA | ASTM A193 / A320<br>GR B8MA<br>CL-1A | 316 - 316L<br>Stainless Steel<br>Solution Treated In Finished Condition | All Diameters | 30,000 | 75,000 |
| B-6 | ASTM A193<br>GR B6 | 410 Stainless Steel<br>Quenched and Tempered | 1/4" thru 4" | 85,000 | 110,000 |
| B8C | ASTM A193<br>GR B8C<br>CL1 | 347 Stainless Steel<br>Solution Treated | All Diameters | 30,000 | 75,000 |
| B8T | ASTM A193<br>GR B8T<br>CL1 | 321 Stainless Steel<br>Solution Treated | All Diameters | 30,000 | 75,000 |
| B8R | ASTM A193<br>GR B8R | Nitronic 50<br>Solution Treated | All Diameters | 55,000 | 100,000 |
| B8S | ASTM A193<br>GR B8S | Nitronic 60<br>Solution Treated | All Diameters | 50,000 | 95,000 |
| F593U | ASTM F593<br>Cond. AH | 17 - 4 PH (Type 630)<br>Annealed and Age Hardened | 1/4" thru 1-1/2" | 105,000 | 135,000 |
| 307A | ASTM-A307<br>GR-A | Low or Medium<br>Carbon Steel | 1/4" thru 4" | --------- | 60,000 |
| 307B | ASTM-A307<br>GR-B | Low or Medium<br>Carbon Steel | 1/4" thru 4" | --------- | 60,000<br>100,000<br>Max. |
| | ASTM-A449<br>J429 GR5 | Medium Carbon Steel<br>Quenched and Tempered | 1/4" thru 1"<br>1" thru 1-1/2"<br>1-1/2" thru 3" | 85,000<br>74,000<br>55,000 | 120,000<br>105,000<br>90,000 |
| | J429 GR8 | Medium Carbon Alloy Steel<br>Quenched and Tempered | 1/4" thru 1-1/2" | 120,000 | 150,000 |
| BC | ASTM A354<br>GR BC | Alloy Steel<br>Quenched and Tempered | 1/4" thru 2-1/2"<br>over 2-1/2" - 4" | 109,000<br>99,000 | 125,000<br>115,000 |
| BD | ASTM A354<br>GR BD | Alloy Steel<br>Quenched and Tempered | 1/4" thru 2-1/2"<br>over 2-1/2" - 4" | 130,000<br>115,000 | 150,000<br>140,000 |
| B7 | ASTM A193<br>GR B7 | Chrom - Moly - Steel<br>Quenched and Tempered | 2-1/2" & under<br>over 2-1/2" thru 4"<br>over 4" thru 7" | 105,000<br>95,000<br>75,000 | 125,000<br>115,000<br>100,000 |
| B16 | ASTM A193<br>GR B16 | Chrom - Moly - Vanadium - Steel<br>Quenched and Tempered | 2-1/2" & under<br>over 2-1/2" thru 4"<br>over 4" thru 7" | 105,000<br>95,000<br>75,001 | 125,000<br>115,000<br>100,000 |
| A325 | ASTM A325<br>Type 1 | Medium Carbon Steel<br>Quenched and Tempered | 1/2" thru 1"<br>1-1/8" thru 1-1/2 | 85,000<br>74,000 | 120,000<br>105,000 |
| A325 | ASTM A325<br>Type 3 | Weather Resistant Steel<br>Quenched and Tempered | 1/2" thru 1"<br>1-1/8" thru 1-1/2 | 85,000<br>74,000 | 120,000<br>105,000 |
| A490 | ASTM A490 | Alloy Steel<br>Quenched and Tempered | 1/2" thru 1-1/2" | 120,000 | 150,000 |

* Manufacturer's ID also appears.
** Cold forming greatly increases these values. Actual properties will be considerably higher

we use new everything—nuts, bolts, and washers.

Speaking of nuts, they screw on, and they can screw off. Various methods are used to keep the nuts in place, to keep them from turning relative to the bolts. Even though assemblies should ideally be designed and assembled where the loss of the nut does not automatically mean the loss of the bolt (particularly in shear configurations), a lost nut signals poor assembly practice.

Nuts can have internal friction materials of polymer (such as an AN365 series) or can be made in a metal-gripping, distorted form, either out of round or as a slightly conical piece. Bolts can have a shake-proof coating or insert (e.g., a nylon "Spot-Lok" or "Long-Lok"). Finally, a thread-locking compound (Loctite) can do the job, provided the bolts and nuts are dry and clean.

A lot of us like to lubricate threads, using CorrosionX or an anti-seize compound or plain motor oil. That's fine, but we must reduce the torque used when tightening. Don Sustaire, a product manager at fastener distributor Winzer Corporation, says to always check your specific application, but motor oil, WD-40, or a copper-based anti-seize compound on the threads generally calls for a reduction in torque of 20 percent. A graphite/grease compound needs a 35 percent reduction to achieve the same tension. Obviously, Loctite won't work on lubricated assemblies. [Note, too, that these percentages are guides only. For more-precise assembly, a "torque-turn" (see sidebar) practice is a better idea.]

In some applications, such as with rod-end bearings, it's impractical to rely on a locking thread, so a jam nut is run against the thread of the first component. Since these are seldom in heavy tension assemblies, the method is usually acceptable; however, when there are tension loads, the jam nuts can come loose. Check these assemblies on every preflight. Use safety wire where practical.

## Torque-turn

The clamping force of a threaded fastener, once it's been brought up snug, is linear in a range that reflects the working range of the fastener assembly. When a more-precise clamping force is called for, practice moving to a "torque-turn" strategy. An initial light, measured torque is first applied to the fastener, to bring all the components into solid contact. Then a precise amount of additional rotation (say, 60 degrees or "one flat" of a hex-headed nut) is added, to come up with a predictable tension in the bolt.

This scheme is less affected by the age of the fasteners and their lubrication, but it does not account for differences in grades of fasteners (different grades stretch at different tensions, so one bolt may be at an ideal tension while a lesser grade may be far into yield) and the squish or work-hardening of the washers and the parts themselves. While generally a superior method of assembly, "torque-turn" is specific to each application.

Safety wire and cotter pins serve several useful purposes: they retain a bolt head (safety wire only) or nut in a shear application, and they serve as visual indicators of whether the mechanic has paid full attention to the assembly. However, they will not help maintain proper tension; they are most useful in shear applications. Just as you wouldn't reuse safety wire, don't ever reuse cotter pins.

When a fastener is in a critical application, it is good practice to remove the paint or powder coating from the mating surfaces, so that

## General Rules

- Always use the proper grade and type of fastener.
- Never bottom a bolt's thread in the female thread; have two or more complete turns exposed on both sides of the nut.
- Use new washers.
- Use new nuts in every critical tension assembly.
- Threads should be clean and dry during assembly unless otherwise specified. Corrosion protection may usually be applied after assembly. If lube is used, reduce the torque by the manufacturer's recommended amount.
- Use a calibrated torque wrench. Remember, "checking the torque" does not mean "tightening it some more!"
- Use safety wire, properly, wherever possible.
- Periodically remove bolts that are hidden (inside struts and through tubing). I've seen these rusted nearly through, while their heads look just fine!
- Cotter pins should be snug, not loose, in their properly aligned holes. Tighten to the recommended torque, then turn as required to line things up.
- When you're tightening a threaded fastener and something feels wrong, stop and figure out why—don't just continue twisting!

the bolts, washers, and nuts all are mating to metal, not a coating. Airworthiness Directive 2008-23-08 concerns a powder-coated engine mount that was held by a bolt, and the powder coating wore, releasing the bolt's tension and allowing the fastener to unthread itself! Treat the finished assembly with a corrosion retardant.

One more caution: Some unscrupulous offshore suppliers occasionally pollute the pool of fasteners, getting their shoddy products into reputable supply streams. A visual inspection may reveal burrs, poorly formed threads, rough machining, sharp radii under bolt heads, or off-center head markings. Many labs will "drop a point" (do a Rockwell hardness test) on a sample bolt for you. You may also stage a controlled test of your own, testing a known good fastener against your suspect: Run the bolt through a closely sized hole in a solid piece of steel and torque it until it breaks, noting the torque reading at the time. If you are in any doubt about the quality of any fastener, find out for certain, or don't use it. EAA

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### Resources:

- Sportplane Construction Techniques, Tony Bingelis; *http://Shop.EAA.org/html/publications_howto.html?cart_id=*
- The absolute best book for us on the specific subject of fasteners: Carroll Smith's *Nuts, Bolts, Fasteners, and Plumbing Handbook*, Motorbooks.com, 1990; ISBN-13: 978-0-87938-406-7
- Good table to demonstrate various head markings and strengths of various graded bolts: *http://IndustrialHardware.com/excel/gradeMarkings.htm*
- Fastener Testing:
RS Technologies Ltd.
24350 Indoplex Cir
Farmington Hills, MI 48335