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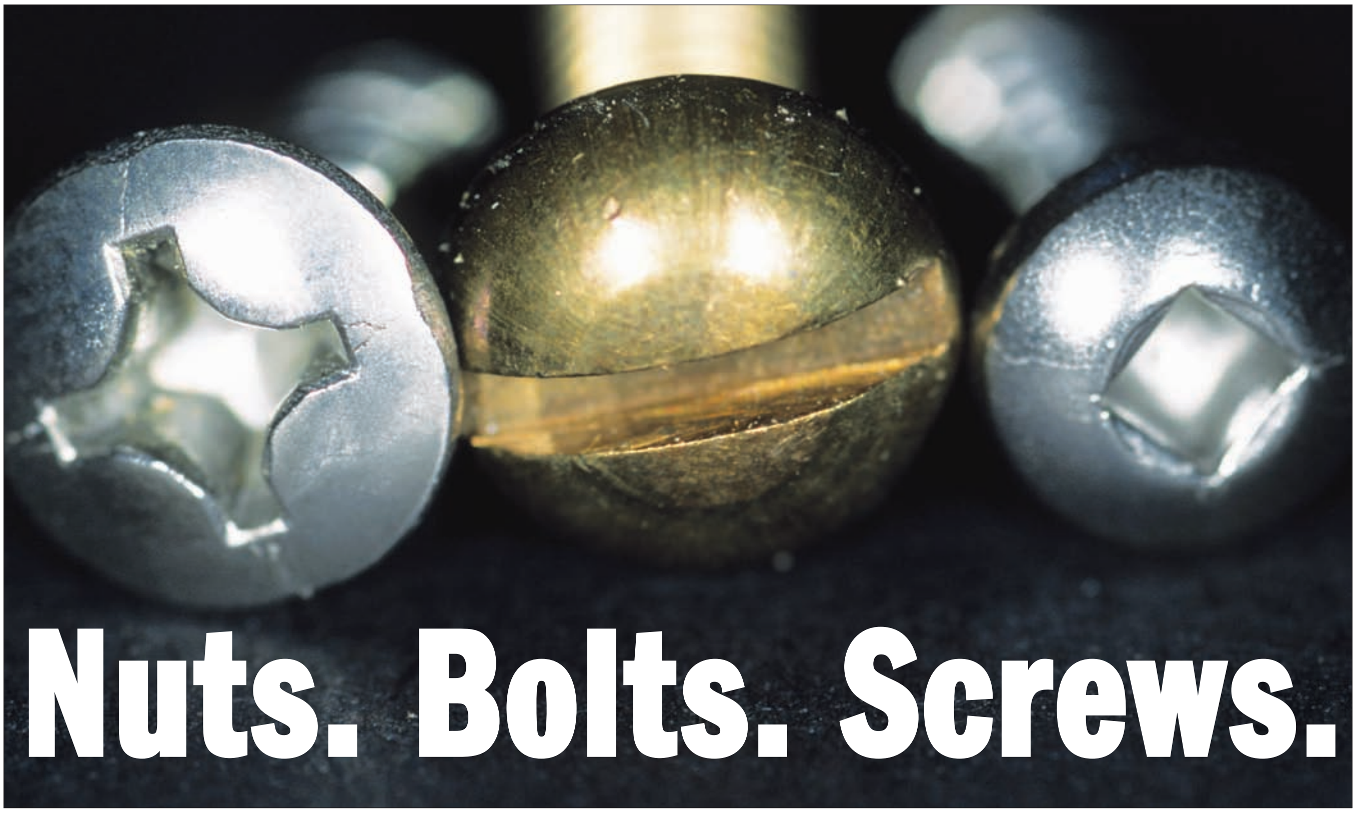


Nuts. Bolts. Screws.

Even if you've been building or repairing or installing (or doing the purchasing) for years, we're betting that certain critical details about, and properties of, the fundamental fasteners of the marine trades may well have gone overlooked.

Text and photographs by Steve D'Antonio

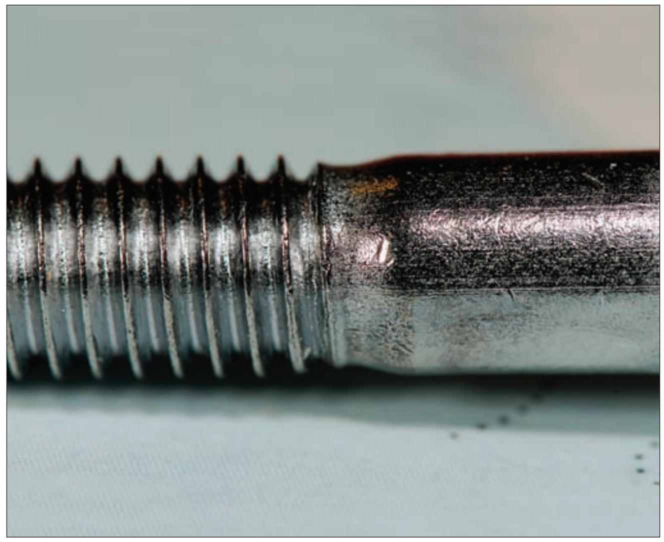
Nuts, bolts, screws, washers, and other mechanical fasteners hold nearly everything together, from engines and transmissions, to rigging and hull-to-deck joints. For the average boatbuilder, equipment installer, or repair yard, the importance of choosing the proper fastener for the job cannot be over-emphasized. Any number of fasteners will often appear to work for a given task; but, in most cases, only one will do the job reliably and safely. As a professional, the responsibility is yours to make the correct fastener selection and then to ensure it is properly installed.

With that in mind, let's review the key elements of fastener technology.

Above—*Not all fasteners are made equal. Those that lack provenance, specific identifiable head markings, and/or a clear paper trail from manufacturer to supplier may not perform as anticipated.* ***Right***—*Several fasteners in this installation failed in a similar manner, indicating a manufacturing defect.*

For machine screws, nuts, and bolts, it's all in the torque and resulting clamping force applied to the parts being secured. Whether that's an engine cylinder-head or a mast-mounted VHF antenna, applying the proper torque to the appropriate bolt or screw could very well mean the difference between fastener success and failure.

For self-tapping screws, it is head design, not torque capacity or brute strength, that often determines selection.



***Above left—**Machine screws are available in a variety of thread types; the most obvious distinction is that of fine (left) or coarse (right) threads.* ***Above right—**Rolling (rather than cutting) is the preferred method for making machine-screw or "parallel" threads. Rolled threads are often easy to identify by the transitional step between the threads and the shank.*

Nuts and Bolts

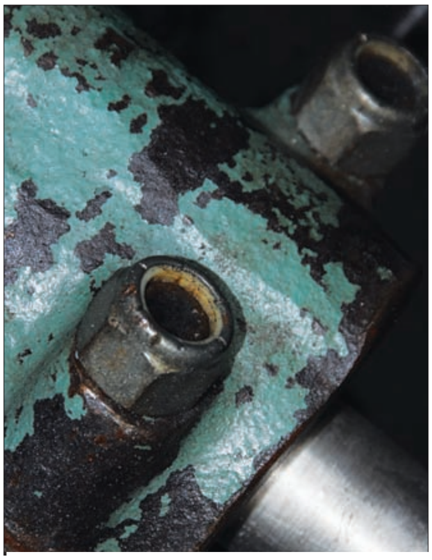
Understanding the components of a common nut-and-bolt combination will aid in its proper use. The *head*, which a wrench fits around or driver fits into, comes in many configurations. The most popular is the hex, or six-sided, variety. Head diameter, measured from flat to flat across the center, is the wrench size, but not the fastener size (more on fastener measurement below).

The head is often stamped with various markings that indicate its tensile strength and/or chemical properties. Beneath the head is the *shank*, which is, in some cases, an unthreaded section between the underside of the head and the threaded section. The transition between the head and the shank is usually radiused to promote strength, while the transition between the shank and the thread—referred to as the *runout*—is rounded for the same reason. It's important to note that not all fasteners possess these important radii features, which are typically found in *rolled,* as opposed to *cut*, threads.

Though casual inspection may reveal little difference among fasteners, under closer scrutiny some bolts fail to measure up. This is particularly true for so-called "field-cut" fasteners. Those are bolts made somewhere other than in a fastener factory—often in the boatyard itself or in a nearby shop. Regardless of the skill of the die or lathe operator, and even assuming the machining tools are well adjusted and maintained, the process of cutting threads into round or bolt stock invariably does so across the grain structure of the metal, imparting an interrupted flow of stress through the bolt.

I realize what I've just said may be heresy to machinists and tool-and-die makers everywhere, but it's not to say threads can't be cut. Rather, it's simply that the metallurgy behind the process means rolled threads are stronger and more fatigue resistant when like alloys and dimensions are directly compared. Cutting threads leaves behind torn, irregular surfaces, which make for stress risers; hence, rolled fastener threads are preferable to those cut by a die or lathe. Rolled threads are nothing new (they've been around since the 1870s); then and now they

***Far left—**While they are not necessarily a guarantor of quality or performance, head markings are useful. Fasteners bearing the F593C designation should meet specified standards.* ***Left—**Correct fastener, wrong length. The bolts in this fin stabilizer installation were fine until the fin moved through the extremity of its arc and sheared them. Bolt specification includes several factors; diameter and length are among the most important.*



Above—*Fasteners with a locking mechanism, such as these nylon insert nuts in a shaft coupling, are commonly installed on moving and vibrating machinery. But the locking mechanism is effective only if engaged by the bolt's threads. When a nut and bolt is assembled, two threads should stand proud of the nut, with or without a locking mechanism.*

Above—*Fasteners in highly loaded applications fully exposed to the weather must be chosen carefully. Find the correct alloy—typically 18-8 or, where greater corrosion resistance is required, 316—as well as the proper dimension. To minimize movement and chafe, fasteners must engage all threads in the base structure, and be of the same diameter as the hole in the hardware they secure.*

are less expensive to manufacture. Nearly all commercially available machine-thread fasteners are rolled.

There are different rolling processes and related protocols. They include: heat treatment before and after rolling; employing reciprocating versus cylindrical dies; and two versus three dies. Suffice it to say, more costly fasteners often use more preferable manufacturing processes.

The nominal length of an ordinary hex bolt is measured from the underside of the head to the opposite end of the fastener. The grip length, on the other hand, is measured between the underside of the head and the closest parallel surface of a nut that has been threaded onto the bolt while allowing two threads to stand proud from the fastener's end.

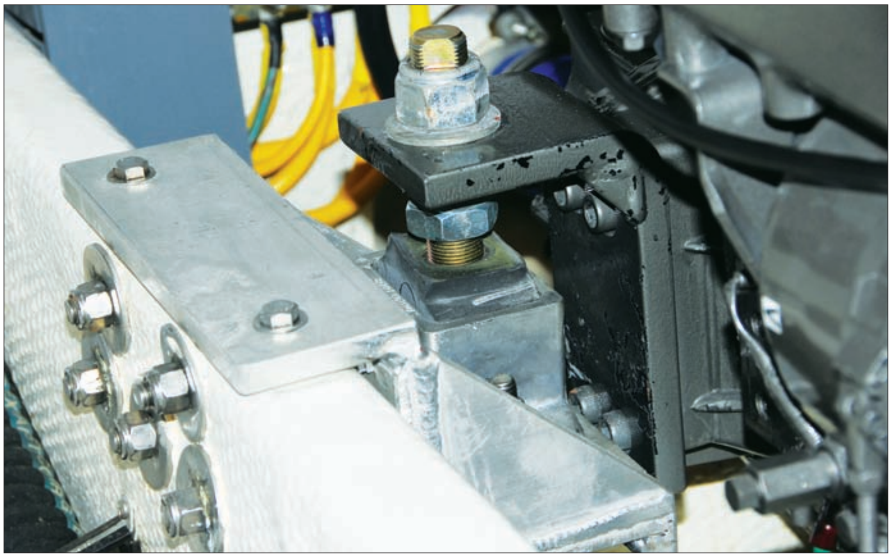
As a rule of thumb, a properly sized bolt when torqued should allow two threads to protrude from the nut's non-pressure-bearing end. This is especially important for nuts that employ embedded locking devices (such as plastic inserts) or intentional distortion of the final threads. The rule ensures that the nut has adequate thread engagement to the bolt to prevent thread collapse or stripping.

Screws

Generally speaking, a screw can either be a bolt—hex head or otherwise—without its mating nut, or a self-tapping fastener, such as a wood screw. The term *screw* in this regard is interchangeable.

The primary difference between a bolt and a tapping screw is the threads. Bolts and machine screws employ a parallel thread, which must be mated with a nut, or screwed into a threaded hole. Tapping screws, whose threads are tapered rather than parallel, make their own threaded hole as they are turned into comparatively soft material such as wood, sheet metal, fiberglass, or aluminum. (Properly sized pilot holes must be drilled in the harder materials.)

Left—*The most widely available stainless steel washer is comparatively thin and not suited for heavy machinery. The torque load of the fastener alone has distorted the washer on this motor mount. More substantial washers often must be ordered from fastener specialty warehouses rather than typical marine chandlers.* ***Right***—*Lag bolts, though common in engine-mount applications, are not ideal. A through-bolt is preferred for heavy machinery, particularly when it's cyclically loaded. Many lag bolts are plated carbon steel, which corrodes rapidly in substrates prone to moisture saturation.*



Through-bolting is ideal for maximum security and load bearing. But careful examination of these washers reveals distortion because they're too thin. In this type of application, choose backing plates for better load bearing and load spreading.

Because many tapping screws are designed for sheet metal, they are fully threaded and lack the smooth shank section often found on wood screws.

The variety of these features makes for a nearly endless selection of combinations. The number of different tapping, wood, and machine screw types found aboard a modest cruising vessel, from the hull and deck to engineroom and interior joinerwork, could easily number in the scores if not hundreds.

Before moving on, let's briefly discuss the lag screw or bolt. Terminology gets a bit fuzzy here; this fastener is part bolt thanks to its hex head, and part screw by virtue of its aggressive tapping threads. Lag bolts are typically designed for severe service in substrates softer than metal, such as wood and fiberglass. Their most common application aboard smaller vessels is to secure an engine mount to its bed or stringer. I've seen many of these fasteners fail in this application because of rust. Stringers and engine beds often become saturated over time, and the threads on the lag bolt simply disintegrate. Eventually, under a heavy engine load—such as hard backing, or driving up a wave under power—engine torque begins to lift the bolts out of the stringer on the uncompressed side.

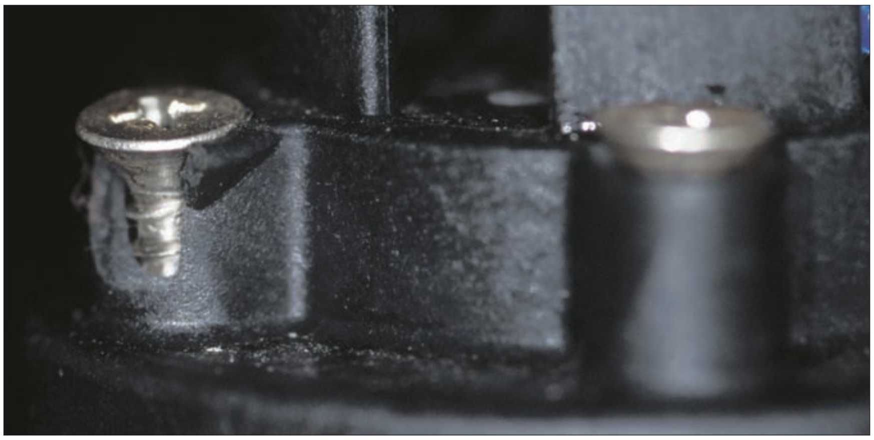
Older vessels with lagged motor mounts are almost certain to possess mild-steel lags. In this scenario, the head of the fastener may appear sound, while the threads have actually rusted away. The problem has been mitigated with the increased availability and popularity of stainless steel lag bolts. But even with a stainless fastener, if the stringer substrate, often wood, becomes sodden and decays, then the fastener may pull out.

Today, many production and custom builders have moved away from lag bolts—stainless or otherwise—for engine security. They opt instead for through-bolts and motor mount shelves, laminated-in-place studs, or pre-drilled and tapped stainless or aluminum plates that accept conventional hex-head stainless bolts.

If you encounter an engine secured with mild-steel lag bolts, they should be removed and inspected for signs of rust or saturated stringers. Both conditions need immediate correction.

Head styles for tapping and machine screws include the common *pan head*, which looks like an upside-down frying pan; *oval* and *flat heads*, which are self-explanatory; to the less common *fillister* and *cheese heads*, which are simply tall, and tall tapered, heads, respectively.

Pan heads work fine where surface clearance and appearance aren't an issue; or where they won't be bunged. Flat heads offer zero surface clearance and allow for bungs. Oval heads are a compromise that provide good clearance, a more attractive



***Left**—An example of the wrong head. The fastener's inverted cone head acted like a simple wedge, damaging the fuel tank component. Fastener heads must be chosen as carefully as threads and dimensions. **Right**—Setscrews are common in marine hardware applications, and are available in a variety of types and styles. The setscrew on the right is well suited for a propeller coupling, thanks to its seizing-wire orifice. The one on the left is better for the stacked application often found on face-seal stuffing boxes.*

finish, and deeper drive recess, which resists stripping. (In fastener industry argot, the appropriate term for such head failure is *cam-out*, with *stripping* traditionally reserved for thread failure.)

Fillister and cheese heads are usually found on small machine applications such as fuel-injection and lift pumps, where the fastener is driven into a machined cylinder or recess, or where greater drive torque is required for limited head-width clearance.

Hex heads have already been discussed above. They're common throughout most vessels, securing autopilot rams and brackets, steering quadrants, motor mounts, alternators, mast and rigging hardware, and all manner of equipment and systems.

Square heads are not quite as common, but at least one is often found aboard inboard-powered vessels: many propeller shafts are secured to their couplings by one or two hardened square-head set screws. These square-headed screws are specially designed for precisely this use and should never be substituted with ordinary hex head fasteners, even though the threads are interchangeable.

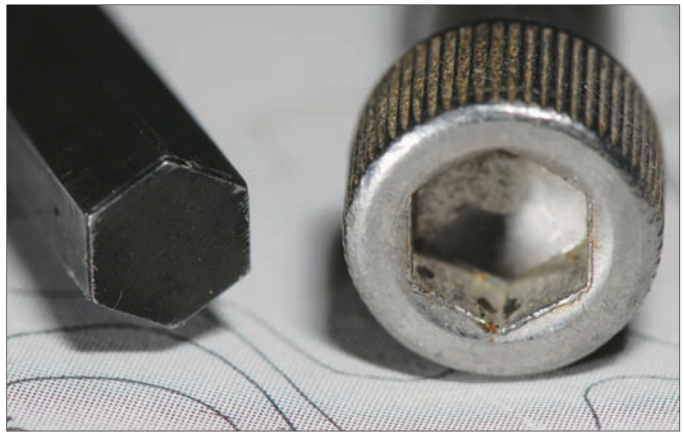
A few additional points regarding set-screws: Many set-screw heads are predrilled to accept seizing wire—a worthy addition where loss of the screw could be catastrophic. I say predrilled because this hole cannot easily be drilled in the field after manufacture when the screw has been hardened. If a set-screw lacks a seizing-wire hole, replace it with one that is so equipped.

Finally, set-screws are available in a variety of tip styles: plain, flat, and oval; dogged, cone, and cup. Set-screw tips that are employed on hard surfaces, such as propeller shafts, are usually cup tipped and the shaft dimpled to accept this shape; soft materials such as aluminum and brass often use cone points. Regardless of style, it's important that a set-screw tip match its corresponding recess.

Drives

A fastener's drive type is the physical configuration or pattern on the head that allows torque to rotate the bolt or screw into a nut, threaded hole, or pilot hole. Nearly every builder, mechanic, and electrician is familiar with the most common drives: the *blade* or common screwdriver, and the *Phillips head*, both of which are found on self-tapping, wood, and machine screws. Today's professional may, however, be faced with more esoteric drives including the socket recess drive, also know as *Allen*; Reed and Prince, a.k.a. *Frearson*; *square recess*; and *Torx*, to name a few. There are few mechanical blunders less forgivable and more easily avoidable than a professional choosing the wrong tool to install or remove a fastener.

Six-point socket recess, socket head, internal wrenching, cap head, Allen—all different names for a single drive style—are common in large and small equipment applications such as watermakers, bow thrusters, and some electronic gear. They are essentially an inside-out hex-head bolt that utilizes either an imperial or metric male six-point drive. Allen drives perform best where a hex head is



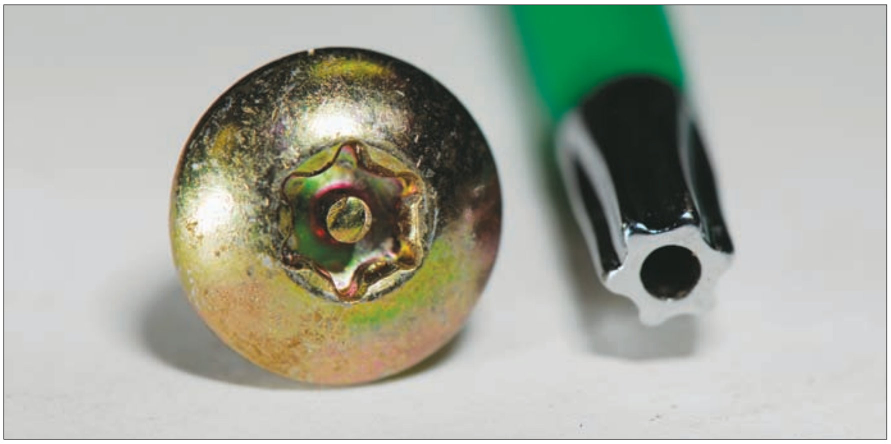
*Torx, or star **(left)**, and Allen, or recessed hex **(right)**, drives are gaining popularity in the marine industry. These cam-out-resistant fasteners work well where there's insufficient clearance for a conventional socket drive.*

impractical: for example, in limited-clearance applications such as motor-mount brackets, or recessed wells. Because they are especially strong and resistant to cam-out, such drive types are often found on high-torque and critical applications.

Frearson drives are commonly mistaken for Phillips heads. At a glance, they appear to be similar, but the Frearson forms a slightly larger X than the Phillips, and its recess is noticeably deeper. This drive is a favorite of ship's carpenters and joiners because of its resistance to cam-out when driven with a drill. However, it's also more susceptible to stripping and breakage if over-torqued.

Should you attempt to drive a Frearson head with an ordinary Phillips screwdriver, it may not be immediately apparent that they are incompatible; but because the Phillips drive is essentially smaller and shallower, it often cams out of a Frearson, even under light torque.

Recessed square drives, invented by Canadian screw salesman Peter Robertson in 1907, were once extremely popular in wooden boat



Top—*Looks like a Phillips, but it isn't. While Frearson-head fasteners are often mistaken for Phillips heads, the X is deeper and wider than on the Phillips, reducing the likelihood of cam-out. The drivers are not interchangeable.* ***Bottom—****Security Torx and matching drive are a variation of the Torx. These fasteners are often installed as tamper-proof devices on electronics and other non-user-serviceable equipment.*

building and are still among the most popular drives in Canada. They're especially resistant to cam-out, and thus favored by boatyard carpenters the world over. Square drives are even more resistant to cam-out than Frearsons, and are therefore easy to damage or break if over-torqued.

In 1936, Henry Phillips introduced the Phillips drive to compete with the Robertson, or square, drive. One feature of the former was that the Phillips driver, unlike the square drive, cammed out only when sufficient torque was attained—a value that lent itself to less-skilled workers.

The Phillips drive was quickly adopted by Detroit automakers, which proclaimed its self-aligning attribute a considerable time-saver over slotted fasteners.

Torx drives are essentially a recessed six-pointed star pattern, the driver being the male and the fastener the female. (The inverse setup is available, but it's far less common.)

Equipment manufacturers often install this type of drive to deliberately discourage service by inexperienced or untrained personnel. Thus, electronics and computer equipment and, once again, fuel injection pumps, are frequently fitted with Torx drives. A minor variation is the *security-style* Torx; it has a small raised section in the center of the fastener's head recess, which fits into a mating recess in the driving tool.

Reading Bolt Heads

The markings on hex bolt heads provide critical information about a fastener's strength, chemical composition, and manufacturer. For carbon-steel hex head bolts, the most common grades are SAE 2, 5, and 8, identified by zero, three, and six hash marks on the head, respectively. Their tensile strength ratings are 74, 120, and 150 thousand pounds per square inch, respectively.

For metric mild-steel fasteners, the corresponding most commonly found grades are 8.8, 10.9, and 12.9, which are more logically indicated by these very figures stamped on the corresponding bolt's head. Their tensile strength ratings are 8,158 kg/cm^2, 10,600 kg/cm^2, and 12,447 kg/cm^2, respectively. This partial list of imperial and metric bolt ratings represents the most common fasteners found aboard the average recreational, and many a commercial/military, small vessel.

For stainless fasteners, bolt-head marking is more rare than common. Their tensile-strength *classes* (for stainless fasteners it's class rather than grade) are 50, 70, and 80, representing 70, 100, and 118 thousand pounds per square inch, respectively. Stainless bolt heads are rarely marked to indicate classes. When they are, though, the class is clearly indicated with the numbers 50, 70, or 80.

Lest the reader be left with the impression that metric fastener-head markings are entirely too logical, here's one wrinkle: When marked, 302- and 304-stainless metric fasteners are denoted as "A2"; 316-stainless fasteners are "A4".

One final head-marking worth mentioning is *F593C*. Now virtually universal in the marine stainless fastener industry, this designation denotes stainless hex bolts or cap screws that meet specific parameters set forth by the American Society for Testing and Materials, or ASTM. Compared to ordinary stainless fasteners, F593 (F594 is the equivalent classification for stainless nuts) fasteners meet tensile strength requirements roughly 20% higher than 18-8 alloy stainless, as well as minimum and maximum hardness requirements. Additionally, F593 guidelines call for specific alloy requirements, eliminating many common mixtures of 300 or 18-8 stainless. The *C* in F593C denotes a size range from ¼″ to ⅝″, while the

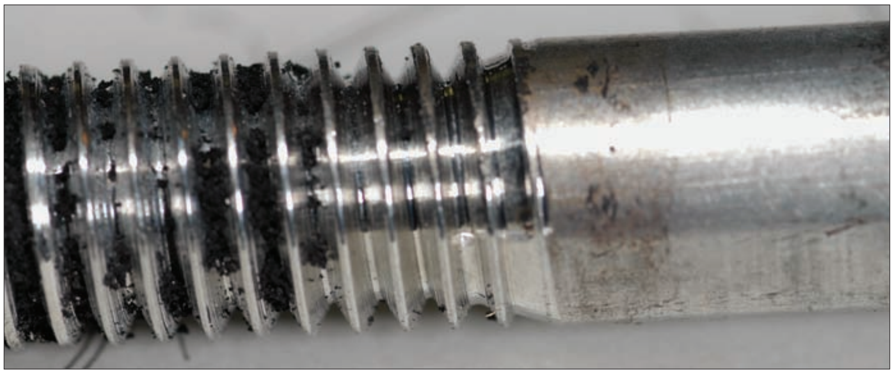
Different head markings are often found on stainless steel bolts. The F593C designation is among the most important. THE, common on the heads of many stainless bolts in North America and Asia, are the initials of the manufacturer.

D suffix is used for ¾″- to 1½″-diameter bolts.

Although fasteners sold as 18-8 or 304 stainless alloy meet, for the most part, self-regulated standards, the ASTM F593C designation gives engineers, builders, repairers, and consumers the assurance of an industry-governed specification that falls under the federal Fastener Quality Act of 1990. The act governs specifications for critical fasteners.

Fasteners in the recreational marine industry are *not* required to be subject to the Fastener Quality Act. But, the

__Top__—A 304-stainless class-70 metric fastener. Stainless fasteners are typically not as strong as their carbon steel counterparts, so never substitute a stainless fastener for a carbon steel one, particularly on engineered machinery components such as engines and drivetrains. __Bottom__—A die-cut thread. While many machinists and tool-and-die makers may argue the point, it's generally accepted that cut-thread fasteners are not as strong as cold-rolled ones.



F593 designation assures builders that a fastener is of consistent, high quality. Note that widespread counterfeiting of fasteners has been reduced by this Act, but there have been instances of fasteners marked as F593 whose properties did *not* meet ASTM specs.

One final caution: hash marks on the heads of *stainless* hex fasteners should not be mistaken for tensile strength grade indicators. Hash marks indicate tensile strength only on *carbon steel* fasteners. Many stainless bolts were marked at one time with two hash marks to indicate they were manufactured from 18-8 stainless alloy.

Machine Screw Size

Knowing how to properly read the size of a machine screw is a vital skill for any mechanic, boatbuilder, or yard supervisor. It's easy to master once you know the basics. The first number in an SAE fastener measurement is the thread diameter—diameter across the fastener from thread peak to peak—in inches, or fraction thereof. Thread count per inch of threaded length is next, followed by the nominal length of the bolt (the overall length excluding the head). Thus, a 5⁄16-24 x 1.5 HHCS is a hex head cap screw that measures 5⁄16″ in diameter, has 24 threads per inch, and is 1½″ long.

Metric fasteners adhere to similar measurement protocols, substituting metric measurements for imperial. The diameter is usually preceded by an *M*, such as M8, which signifies a bolt whose diameter (measured from thread peak to thread peak across the fastener's axis) is 8mm. Finally, the nominal length is indicated in millimeters. Therefore, an M8-1.25 x 25 RHMS would be a round head machine screw whose diameter is 8mm, with a thread pitch of 1.25mm, and a length of 25mm. (The term *pitch* in metric thread measurement replaces imperial's threads-per-inch approach. Pitch is the distance in mm from any one point on a thread to a corresponding point on the next thread when measured parallel to its axis. Therefore, a metric screw thread travels this distance in one revolution. For example, if one turn advances the fastener 1.5mm, then it is called "M1.5." It's the distance from one peak of the thread to the next one. This number is referred to as the pitch.)

Thread-pitch gauges are readily (and inexpensively) available for measuring imperial and metric pitches. This, along with an accurate ruler or caliper graduated in both inches and millimeters, will allow you to identify any machine screw or bolt. That, coupled with your ability to read hex head markings, will leave few fasteners indecipherable or unidentifiable.

There may still be a few mysteries, one being bolts devoid of head markings. Metric, imperial, stainless, or carbon steel bolts whose heads are smooth and unmarked are SAE grades 0, 1, and 2. The specific properties of such fasteners cannot be ascertained other than from their packaging, or from suitable documentation at point of purchase.

I follow the safe and sensible rule that fasteners whose lineage cannot be clearly established should not be used. If you choose to do so, you incur the risk and consequences of the fastener's failure.

Know your fasteners, and choose your threads and heads wisely. PBB

About the Author: *A newly named contributing editor of this magazine and former full-service yard manager, the author now works with boat builders and owners and others in the industry as "Steve D'Antonio Marine Consulting Inc." His book on marine systems will be published by McGraw Hill this year.*