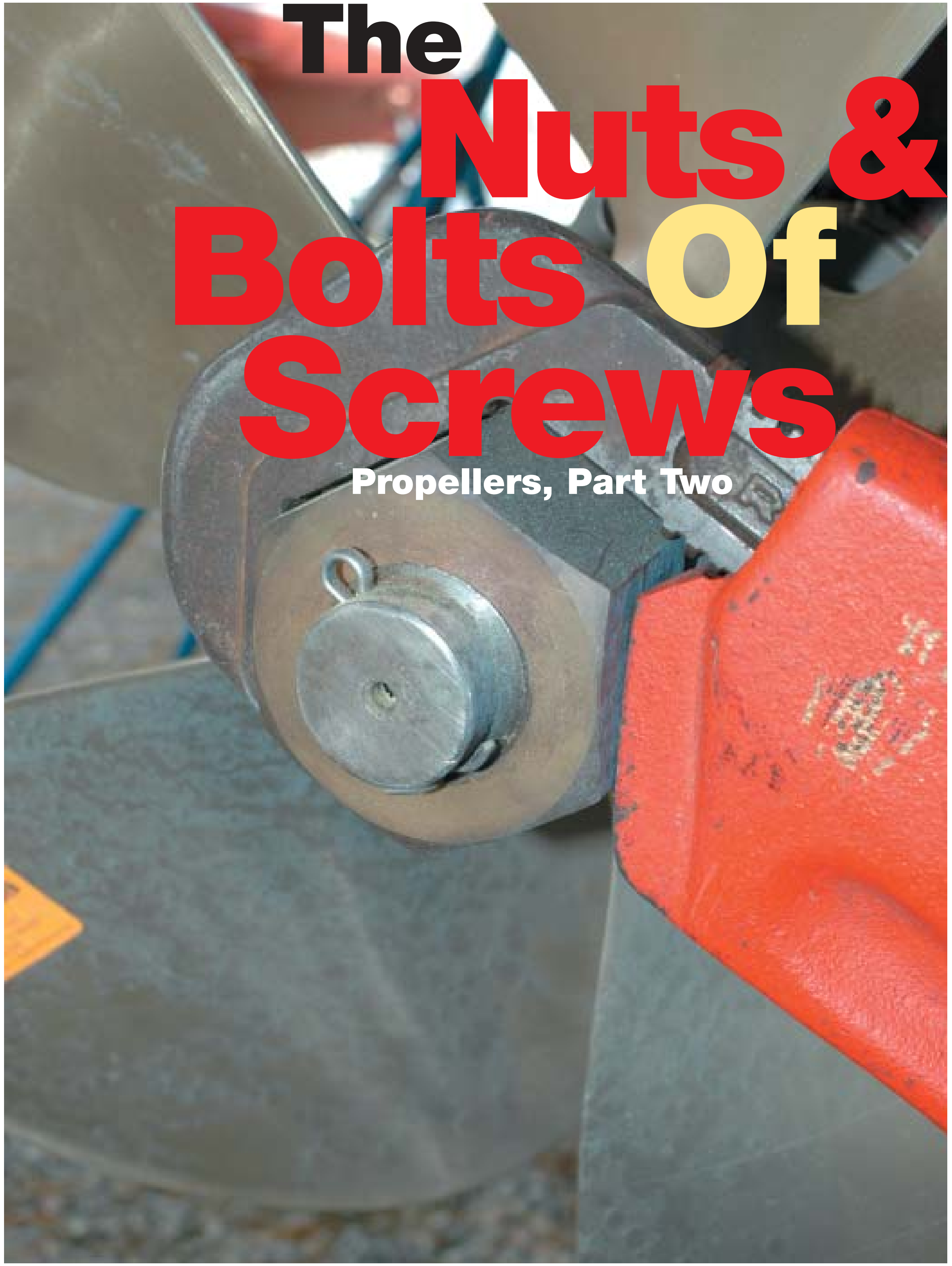
# The Nuts & Bolts Of Screws

## Propellers, Part Two



Story And Photography BY STEVE D'ANTONIO

*In Part One of this two-part series, we discussed propeller terminology and selection. In this second and final part of the series, we'll take a close look at some specific propeller problems and solutions, as well as computerized propeller scanning and repair.*

## PROBLEMS AND SOLUTIONS

In many cases, propeller work is undertaken only when there's a perceived problem: poor performance, vibration, grounding, etc. In other cases, already acceptable performance or fuel economy can be improved by "tweaking" or making small adjustments to the propeller.

At the boatyard I manage, sea trials are performed on nearly every boat we store–before each lay-up in the fall and when the vessel is commissioned in the spring. The majority[AQ#1] of the vessels fail to reach maximum rated power or engine rpm[AQ#2] during these trials because of[AQ#3] underrevving. (Technicians use an electronic stroboscopic tachometer to confirm the readings on the vessel's helm tachometer, which is often inaccurate.)

The sea trial and load test[AQ#4] involves running the vessel at wide open throttle (WOT) for a few minutes. Not only should the engine reach the manufacturer's full throttle rating, which is often where maximum horsepower is achieved, it should also do so without overheating. In the fall, many vessels fail this test because the prop or hull is fouled by barnacles and other marine growth–a sure sign that these boats are not being used often enough! But interestingly, 60 percent of the vessels fail this test in spring sea trials with clean bottoms and props! The degree of failure ranges from a 100 RPM below maximum[AQ#5] rating–while not ideal, usually considered acceptable–to several hundred or in some cases 1000-plus RPM below manufacturer's ratings.[AQ#6]

To be absolutely accurate, these tests should be performed with the vessel in cruising trim: with a 50 to 80 percent load of gear, fuel, water, and provisions–the way the skipper normally runs the vessel most of the time. In spring sea trials, vessels are often light and thus a slight overrevving–rpm ratings slightly over by a 100 or so RPM, but not yet reaching governed speed–is considered acceptable. (Governed speed is where the engine's governor stops the rpm rating from increasing to prevent internal engine damage. Check your engine owner's manual to determine correct ratings full throttle and governed rpm.)[AQ#7]

Armed with the results of the sea trial (assuming your vessel falls into the 60 percent failure category), you may think the next step involves a trip to the prop shop to reduce pitch–reducing pitch always equates to increased engine revolutions–and get the engine rpm back up where they should be. My response to this plan would be a definite "maybe." You see, by leaping to the conclusion that you have a prop problem, you may actually be missing a problem with your engine or running gear. In many cases, a vessel's engine fails to reach the manufacturer's full throttle rating[AQ#8] as a result of an internal engine problem,[AQ#9] excessive exhaust back pressure, misadjusted valves, fuel delivery problems, low compression, turbo malfunctions, or shaft

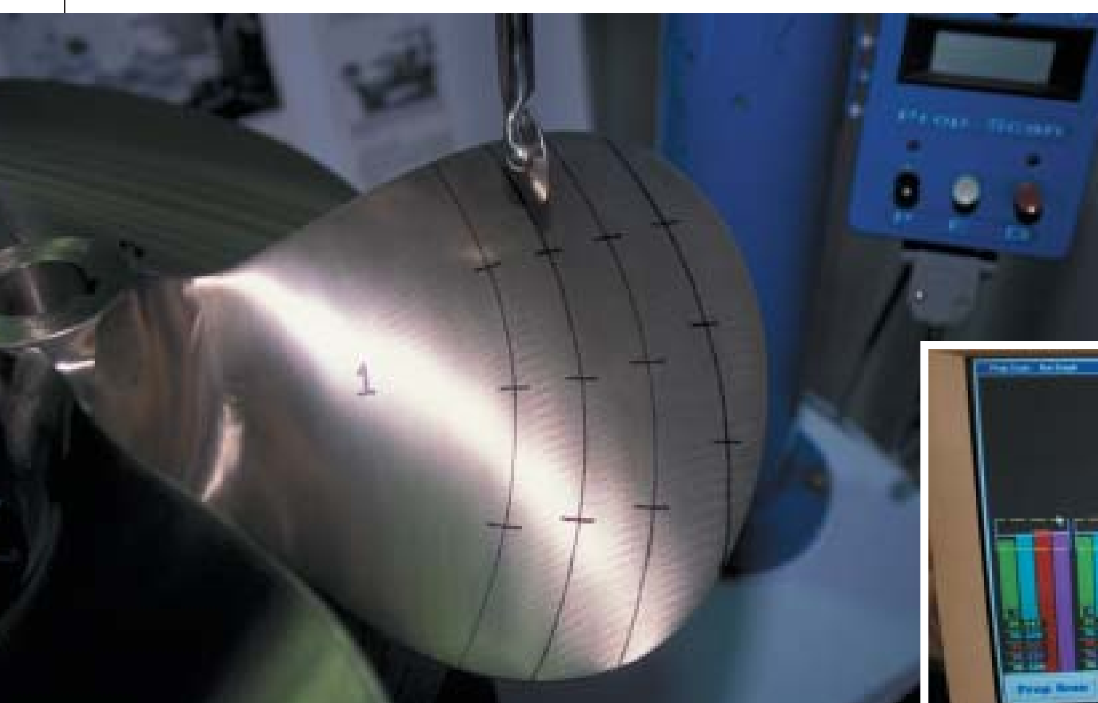
Left: The right tool for the job. A large adjustable wrench, shown here, which is designed for tightening hex nuts, is the correct tool for prop nuts. Although pipe wrenches (shown in some of the other photos, along with damaged nuts) are frequently used in this role, they permanently damage the nuts. Above: Propeller removal using a tool specifically designed for prop removal.[AQ#33] Notice that the nut is loosely screwed onto the shaft, to prevent the propeller from falling once it releases its grip on the shaft.

misalignment.[AQ#10] Taking pitch out of the prop will increase engine rpm,[AQ#11] but performance and economy will continue to suffer. So before adjusting a prop to account for an underrevving condition, first ensure that your engine and drive train are in top operating condition.

In my experience, the most common cause for this type of failure or diminished power is excessive exhaust system back pressure. The most insidious aspect of this failure scenario is that many boats operate in this mode new–straight from the factory. To determine if this could be your trawler's engine problem, have an experienced mechanic perform a relatively simple exhaust system back pressure test. If your vessel passes, and the rest of the engine and running gear are in good working order, then proceed to prop adjustment to obtain the maximum[AQ#12] rated rpm. If your vessel fails, however, then you must correct the exhaust system problem[AQ#13] before undertaking any propeller adjustment.

Another common problem[AQ#14] found in many damaged, overloaded, and overspeeding propellers is a phenomenon known as cavitation. If your propeller is suffering from cavitation, then the water adjacent to the blade back (the side that faces forward) is actually boiling. As difficult as this may be to believe, it's true. The boiling point of water is affected by barometric or water pressure. (This is why mountain climbers use pressure cookers. As the air pressure drops, water boils at too low a temperature to do any real cooking.)

If the pressure on the propeller blade is lowered enough–because the blade is overloaded, turning too fast, or damaged–then the boiling point of the water may be reached. When this occurs, vapor or partial vacuum bubbles[AQ#15] form on the blade surface. Although this lowers efficiency of the blade by causing uneven pressure, the bubbles don't cause any trouble until they collapse, typically when they reach an area on the blade where pressure increases or returns to normal. Then, each bubble collapses or implodes violently, taking with it a few molecules of metal. Add all these molecules up, and it leads to a noticeable loss of material from the blade, which may result in a propeller imbalance and surface unevenness.




Left: The PropScan measuring system in action. The lines, drawn using a marker for illustrative purposes, indicate the measurement radii—60 to 90 percent of the distance from the prop's center—each of which is broken down into four zones. The number represents the blade, one always being adjacent to the keyway. Right: A PropScan bar graph, each color bar represents a different blade, showing the measurements for a propeller that, after being tuned, meets ISO class 1 standards. The dotted rectangle shows the range of acceptable of measurement for this class.

Additionally, as each bubble meets its violent end, it creates some noise. Combine several thousand implosions per minute and you've got a noticeable vibration, rattle, hum, or other unpleasant sound.

The effects of cavitation–rough or cratered areas–are often noticeable on the blade back. Fortunately, propellers on slow turning, displacement vessels are not usually subject to cavitation unless the propeller is overloaded or damaged. (The irregularity in pressure caused by blade damage can create cavitation.)





Top: In the lapping process, the prop is rotated several times while the shaft remains stationary, allowing the valve grinding compound to do its job. Above right: The interface between the propeller and shaft taper is critical. Machinist's die, the red coating, is as an indicator during the propeller/shaft lapping process, ensuring maximum contact between the two components. A poor fit between the two tapers may cause prop wobble or loosening.

Propellers on faster vessels–semidisplacement fast[AQ#16] trawlers for instance–are frequently subject to cavitation because of high propeller loading that results from the vessels' high[AQ#17] weight and compromise hull shapes.

## REMOVAL AND INSTALLATION

I recall visiting a certain boatyard several years ago. (When I travel, I like to walk around boatyards, a practice my wife has yet to understand. "You don't get enough of these?" she always asks.) As I walked amongst the boats that were blocked, I heard an incessant clanging and banging. Intrigued by what this metalwork project could be, I finally homed in on the sound. To my shock and awe, I witnessed one of the greatest taboos in the marine repair world. A robust young man was swinging, for all he was worth, a large sledge hammer against the end of a 40-foot cruiser's shaft. Spun onto the end of the shaft was a large, brass "sacrificial" nut, used to save the threads–a little like applying protective wax to cars in a junk yard. I watched and cringed for a moment until he used my presence as an excuse to take a break–he was perspiring heavily. "What are you doing?" I asked. "Pulling the prop using a bang nut," he answered. Well, I thought, at least the tool is appropriately named. The idea was sound, each hammer blow drove the shaft and engine on its flex mounts forward a fraction of an inch. The mass of the prop would cause it to be left behind, eventually separating it from the shaft taper. The problem, however, is that each blow shortened the life of the thrust bearing in the transmission by 10, 50, or 100 hours. Thrust bearings are designed to absorb constant rather than shock loading of this sort. This is *not* the proper way to remove a propeller.

Proper propeller removal is usually accomplished in one of two ways: either with a mechanical or a hydraulic puller. Occasionally, the application of *careful, selective taps by an experienced professional, against the forward end of the propeller hub using a brass drift–never hitting the shaft or any other part of the propeller*–may be used to remove a prop. Some propellers simply do not lend themselves to pullers because of the shape of the blade or number of blades. In such cases, the careful application of light blows in the right location is acceptable. In rare cases, mild heat may be used to help expand a propeller's hub and loosen its grip on the shaft. An ordinary propane torch may be used, but never an acetylene or cutting torch.[AQ#18] The latter is simply too hot for this work as it may change the metallurgical properties of the propeller alloy. With any of these methods of prop removal, it's best to leave one of the prop nuts loosely screwed onto the shaft threads, but not touching the prop. That way, once the prop separates from the shaft, it won't fall

Left: A turbo, again, worn out or dirty turbo will rob an engine of horsepower, which may be incorrectly diagnosed as a prop pitch issue. Right: A close up of a propeller shaft taper and key. Grease was used during the installation of this prop and it was not lapped. The combination of the two allowed the propeller to rock back and forth on the taper, causing damage to both the shaft and propeller keyways.

onto the ground, or your foot.

Before you remove your own prop, or have it removed by a pro, take a few minutes to perform the following simple tests (after the boat has been hauled and blocked). Set up a ruler or just a thin, straight piece of wood trim[AQ#19] aft of the propeller. You can use blocking material or a sturdy ladder as the mount for your pointer. Adjust the wood so it is as close to the center of any one of the propeller blade's trailing edges as you can get it, without making contact–about the thickness of a dollar bill. (Remember, the trailing edge is the edge closer to you when you are aft of the prop.)[AQ#34] Then spin the propeller. None of the other blades should touch the stick and none should be further from the stick than the first blade–that is, about the thickness of a dollar bill. Next, move the stick so that it is just beyond the tip of one of the prop's blades and carry out the same rotation. You should get the same consistency or "run out." This procedure, while primitive when compared to using much more accurate measuring tools, will give you and the boatyard/propeller shop/shaft shop an idea of any problems that may exist with the prop and shaft. If you want a more accurate assessment of the shaft and prop, have the boatyard perform a dial indicator test on both of these components.

Once the propeller has been removed from the shaft, carefully inspect the taper–the cone-shaped portion of the shaft onto which the propeller fits–for pitting, scoring, corrosion, or other irregularities. The taper should be smooth and free of *all* defects. Finally, inspect the key–the long, rectangular object that fits into the shaft, locking it to the propeller via the shaft and prop keyways. (The keyway is the recess or slot into which the key fits.) The key should fit snugly into both keyways; however, it should slide in with little effort and tools should not be required for removal or installation. If it rattles or fits loosely in either the shaft or prop keyway, it must be replaced. A proper fit is essential for propeller security.

The correct procedure for installing a propeller calls for a considerable amount of attention to detail to ensure a proper fit. Begin by dry fitting the propeller. This involves pushing the propeller onto the shaft without the key installed. Push it on by hand, as far as it will go and rotate it several times while holding the shaft stationary. Then, mark the shaft at the forward part of the shaft hub,[AQ#20] to record how far the prop has slid onto the shaft taper.

To ensure maximum contact between propeller bore and shaft taper, lapping[AQ#21] is recommended. To gauge the need for, or effectiveness of, lapping, first apply machinist's bluing compound to the shaft taper (in a pinch, indelible marker can be used). Then, coat the shaft





taper with automotive valve grinding paste, again without the key installed. Push the prop onto the shaft. While applying light forward pressure, rotate the prop 90 degrees to the left and then 90 degrees to the right and then 180 degrees to the left and then to the right.[AQ#22] Repeat this left-right rotation several more times. Remove the prop, clean off the valve grinding compound (it's usually water soluble), and check the bluing. Ideally, 75 to 80 percent of the bluing will be gone, exposing the shiny, silver shaft taper, meaning that you achieved

Left: The results of the lapping procedure, the shiny areas indicate contact, where blue remains, however, insufficient contact has been made and thus more lapping is required. Right: Machinist's bluing being applied to a shaft taper in preparation for lapping. Lapping is essential in order to ensure proper shaft taper to propeller bore engagement.

75 to 80 percent contact between the shaft taper and propeller bore.[AQ#23] It may require a number of rotations to achieve the desired contact; however, it's worth the effort. Maximum contact with the shaft taper[AQ#24] means the prop will stay put. If the prop does not fully engage the shaft taper, it may rock and eventually loosen the retaining nuts.

After the lapping is complete, check the line you drew earlier on the shaft. You'll probably notice the propeller hub now covers the line because of the improved fit. Draw or scribe a new line where the forward end of the hub now rests on the shaft. Remove the prop and ensure that bore, shaft taper, and both prop and shaft keyways are clean and free of all valve grinding compound.

Next, *lightly* coat the shaft taper and key with low viscosity oil such as automatic transmission fluid. *Never* use grease on a propeller bore or shaft taper. A light lubricant is meant to ensure that the propeller fully engages the taper and key without binding. The lubricant is not meant to aid disassembly. In fact, many prop shops frown upon the idea of using any lubricant on a taper, no matter how light or little. Applying grease to a taper or bore may in fact prevent full engagement of the prop. Because it is highly viscous and a liquid of sorts, it's possible that the grease may hydrolock the propeller, preventing it from fully engaging the shaft taper. The bottom line is that you want the propeller to become well and truly stuck on the shaft taper. You, or someone else, can worry about removing it later.

Once you've placed the prop on the shaft, make sure that it aligns with the second line you scribed on the shaft, the one that's further forward. Then, spin the *larger* of the two propeller nuts onto the shaft's threads and draw it up tight using a *proper nut wrench*, not a pipe wrench. Most propeller nuts are made from relatively soft copper alloys such as brass or bronze. A pipe wrench, which is designed to clench and spin pipes rather than nuts, will simply mutilate most propeller hardware. Many do-it-yourselfers and boatyards use pipe wrenches because they are handy, available, and among the only wrenches that will fit a large nut. But that doesn't make them right for the job.

Why not just use a harder nut, like stainless steel, you might ask. True, these nuts would be less affected by a pipe wrench's aggressive teeth. However, if your shaft is made from stainless steel or an alloy of stainless steel, the nuts should be manufactured from a softer material to prevent galling–a process that overheats the threads as the fastener is tightened, causing them to eventually strip. Large wrenches that look very much like a pipe wrench, but whose jaws are smooth rather than serrated, are readily available from many tool suppliers.

Once you've spun the large nut on, place a soft

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wood block between the vessel's bottom and the edge–leading edge for right-hand rotation props, trailing edge for left-hand rotation props–of one of the propeller's blades so that the blade is on the upswing, traveling toward the hull. This will hold the prop stationary as you torque the nuts. Tighten the nut up as hard as you can, using only arm strength[AQ#25] and your weight. Then, remove the large nut. That's right, remove the large nut and install the smaller– thin or half-height–nut in its place.[AQ#26] Tighten the smaller nut as tight as you can and then reinstall the large nut.

While this may sound backwards–most folks think that the smaller or locking nut should go on last–in fact it's the other way around. Here's why. When the large nut is installed first and tightened down, it's bearing the entire load on its threads. When the second, smaller nut is then installed and tightened, it relieves–or unloads–the pressure from the large nut's threads, transferring it to its own, fewer threads, which makes little sense from an engineering standpoint. Reverse the order, however, placing the smaller nut on first, and its threads then get unloaded by the larger nut, which now carries the lion's share of the tension. The Society of Automotive Engineers (SAE), USCG, and many other engineering and maritime organizations specify this seemingly nutty but correct order for full and half-height nuts.[AQ#27]

Finally, install a cotter pin of the proper size and material and bend its halves fully apart and 180 degrees over. The proper size means it just fits, preferably snugly, in the hole drilled in the end of the shaft, rather than being a loose or sloppy fit. A loose cotter pin will tend to rattle around and chafe, and will eventually fail. The proper material for cotter pins is stainless steel, period. Never install a brass cotter pin in any shaft, particularly a stainless alloy shaft. The reason is that the zinc content in brass will cause the pin to rapidly corrode and disintegrate, particularly in this turbulent environment. This scenario is accelerated when a brass cotter pin is in contact with a more noble metal such as stainless steel or an even nobler proprietary shaft alloy

## REPAIR AND SERVICE

At some stage in the life of your vessel the time will come for propeller repair or simply a tune-up. If you have never had your prop removed and checked by a prop shop, then it's probably time, even if the prop shows no obvious signs of damage. Many new propellers are poorly balanced straight from the factory (or are damaged in transit). So even if your boat is relatively new, chances are good the prop could stand some level of attention. In my experience as the operator of a boat building and service yard, about 40 percent of new props require some work–and I tend to purchase only high quality props from reputable manufacturers. The number needing work jumps to 90 percent for poorer quality props and for props already in use.

Reputable propeller shops that use recordable and verifiable means of propeller analysis (more on what this means in a moment) will often assess a propeller's condition at no charge. Thus, you're only on the hook for the propeller removal and reinstallation, and that's usually reasonable.[AQ#35]

Prop 015: An example of the effects of propeller cavitation. Metal is removed, molecule by molecule, in this process. This propeller is either overpitched, under diameter, lacking in sufficient blade area, or a combination of all three. Prop 016: Propeller shaft cotter pins should always be stainless steel. This brass cotter pin has nearly corroded to the point of failure and it's unlikely it could have retained the nuts and prop in the event that they had loosened. Prop 013: An example of the proper method for installing propeller shaft nuts and a cotter pin. The order of the nuts is important, as is the material used for the cotter pin.

How do you choose which propeller repair shop to patronize? My criteria for propeller repair and adjustment is verifiable accuracy that meets a recognized standard, as well as general good business practices. The first rule in finding the right vendor is one of geography–the nearest shop is not always the best shop. For several years, I used UPS to send all of my propellers to another state–or drove them myself–because I wasn't satisfied with the accuracy of work done by the local vendors.[AQ#28]

Until about 10 years ago, it was difficult if not impossible to bring all of the components of quality[AQ#29] of propeller service and repair together in the United States. In 1994, however, Larry Carlson of Wildcat Propellers, Chesapeake, VA (wildcatprops.com), brought the first PropScan system to this country. Developed in Australia by Terry Ryan in 1980, PropScan uses an accurate, computerized measurement system to assess the pitch and blade surface condition of a propeller. With this information, a propeller repair technician can determine how far out of tolerance a propeller is and what it will take to get it back into good working order. (There are other digital, electronic propeller measuring systems; PropScan is simply one with which I have the greatest experience and familiarity.)

Before the advent of PropScan and other systems like it, propeller repair shops used what was know as a *pitch block*[AQ#30] to repair a propeller. The pitch block was a die of sorts that matched exactly the pitch face of every[AQ#31] propeller blade for every type of propeller manufactured. A technician repairing a damaged propeller using this tool would beat on the blade with a hammer until it once again conformed to the pitch block. The system is crude, but it works and many propeller shops still use this technique successfully.[AQ#32]

Pitchometers are also used as a manual means of assessing pitch and inconsistency thereof, at a given number of radii on each blade (radii are usually expressed as a percentage distance from the center of the prop hub, usually beginning somewhere about 30 percent for the part of the blade closest to the hub to 95 percent, or nearly the blade tip). This is simply a measurement tool that gauges the distance of the propeller blade from a fixed point along each radius. The figures are then recorded onto a chart for later assessment. It's a tedious and time consuming process; however, it does yield useful results.

The digital, computerized propeller measurement system, on the other hand, measures pitch to within .001 inches and blade surface inconsistency to within .004 inches along every degree of pitch, meaning from the leading to trailing edge of the blade. This level of accuracy is far beyond the pitch block and considerably quicker, if not more accurate, than the pitchometer.

With the digital information recorded and stored in a computer program, a graphic representation of the propeller's health is then produced. The bar graphs and numerical figures displayed on a computer screen guide the technician through the adjustment of each blade on the propeller.

The assessment process begins by installing the propeller (the PropScan system used by Wildcat can accommodate propellers from 7 inches to 11 feet in diameter, and from two to seven blades) on the PropScan table. This is an extremely rigid, heavily built steel platform that supports the propeller, allowing it to rotate on precision bearings with single finger pressure. The radii are scribed into each blade at the desired intervals, beginning at between

Wildcat Propellers repair technician Troy Erb measures a propeller using the PropScan system.

30 percent and 50 percent from the center and then every 10 percent thereafter, sometimes including 95 percent or the outermost tip of the blade.

The PropScan technician then rotates the propeller by hand while allowing a sliding vertical shaft equipped with a small steel wheel to travel along the blade. The shaft sends a digital signal to a PropScan computer program that processes the information, converting it to measurements of pitch, pitch progression, and hydrodynamic consistency (the trueness of the blade surface).

Once the condition of the prop has been assessed, the technician then moves the prop to another table equipped with a pneumatic ram. The ram applies several hundred pounds of pressure, rigidly securing the propeller to the table while the propeller is adjusted. The adjustment for smaller propellers–those under about 30 inches in diameter–is strictly an application of brute force, although it's applied with a large degree of finesse. The manual tools of the trade are a series of hammers whose heads range from soft rubber, lead, copper, and brass to hard stainless steel. For larger propellers, pneumatic pistons can be used to bend, torque, and tweak a propeller's blades. Still, this is a hands-on business practiced by those who are able to artfully swing a mallet and wield a disc grinder. Once the technician has finished with your prop, he or she has checked and adjusted its pitch, diameter, and hydrodynamic properties as well as its physical balance. Once heavy work is done, the prop is sanded and dressed smooth using a range of abrasives from 36 grit (about equal to coarse sand) to Scotchbrite pad (something like a dish scouring pad). At this point, your propeller is as right as it's ever going to be.

The standards adhered to by those using PropScan equipment are defined by the International Standards Organization (ISO). Created in 1981, the ISO propeller standard is, by Larry Carlson's own admission, not quite perfect for the types of propellers he works on–recreational, commercial, and small military vessels–however, it is a rigid guideline set forth by an independent standards body.

When Carlson first got into the business, he inquired of a prop manufacturer's representative as whether the manufacturer built its props to any particular standard. "Yes," the representative responded, to which Carlson asked, "Which one?" "Our own," came the reply. Carlson thought he was making progress. Knowing he needed some guideline that he could follow when repairing propellers manufactured by this company, he asked, "Can I have a copy of the standard to use when doing repairs?" To which the representative replied, "No, I'm afraid not, that's proprietary information." That cinched it for Carlson; he began to search for a solution. PropScan and ISO were it.

Adherence to the ISO standards is entirely voluntary for service and repair of recreational vessel propellers. Not every prop shop follows the ISO standards; however, all facilities using the PropScan system are obligated to toe the ISO line. The overall ISO standards are designated as 484/1 (props larger than 8 feet) and 484/2 (props smaller than 8 feet). (Officially, the standard only applies to props 31 inches and larger; however, PropScan applies the standard to the all the props they service, as small as 7 inches.) The various classes of conformity within this standard range from O, which is used for submarines (extremely precise) to classes S, 1, 2, and 3–in descending order of accuracy. S would be reserved for high performance recreational and military craft, although any prop could be tuned to this standard, for a price. The recommended standard for fast and displacement trawlers is class 1, with class 2 reserved for work boats and vessels that operate regularly in shallow water, where propeller damage is likely to occur. Class 3 is quite low and not recommended for any recreational vessel. The difference between each class represents an order of magnitude of 50 percent. That is, class S has a 50 percent narrower tolerance than class 1, and class 1 has a 50 percent narrower tolerance than Class 2, and so on.

Currently, there are 31 PropScan shops around the country. An added benefit of the PropScan system is absolute ability to duplicate a lost or damaged propeller once it's been scanned into the PropScan computer. If, for instance, you have your prop measured and serviced by Carlson's PropScan facility in Virginia and a year later you run aground in Florida, you have a couple of options. One, you could call the shop in Virginia and ask them to manufacture a duplicate of the propeller you had and ship it to you. (PropScan shops keep a computer record of all the props they measure.) Or, you could go to the PropScan website and find a PropScan shop in Florida. Take your damaged prop to that shop, along with a copy of the PropScan report you received when you had your prop serviced last year and ask them to carry out the repair, returning the prop to its original specifications. If you've lost your report, not a problem. A PropScan serial number is stamped into your prop that the Florida shop can use to access the original records from the Virginia shop. (The number is recorded by the original shop, so if the prop were lost all together, your records are still accessible.)

I've used the PropScan system through Wildcat Propellers for nearly 5 years and I'm pleased with the results. When my yard is troubleshooting a vibration problem, I must have absolute confidence that, once the prop's been checked and serviced, the propeller can now be ruled out as the culprit. With a PropScaned propeller, I'm confident that's the case.

Proper propeller selection, installation, and service will ensure that the horsepower produced by your engine is used as efficiently and economically as possible. Pay attention to the prop, take care of it, and it will serve you and your vessel well.

In the next issue of *PMM,* look for a comprehensive discussion of the propeller's cousin, the propeller shaft and its related components.

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