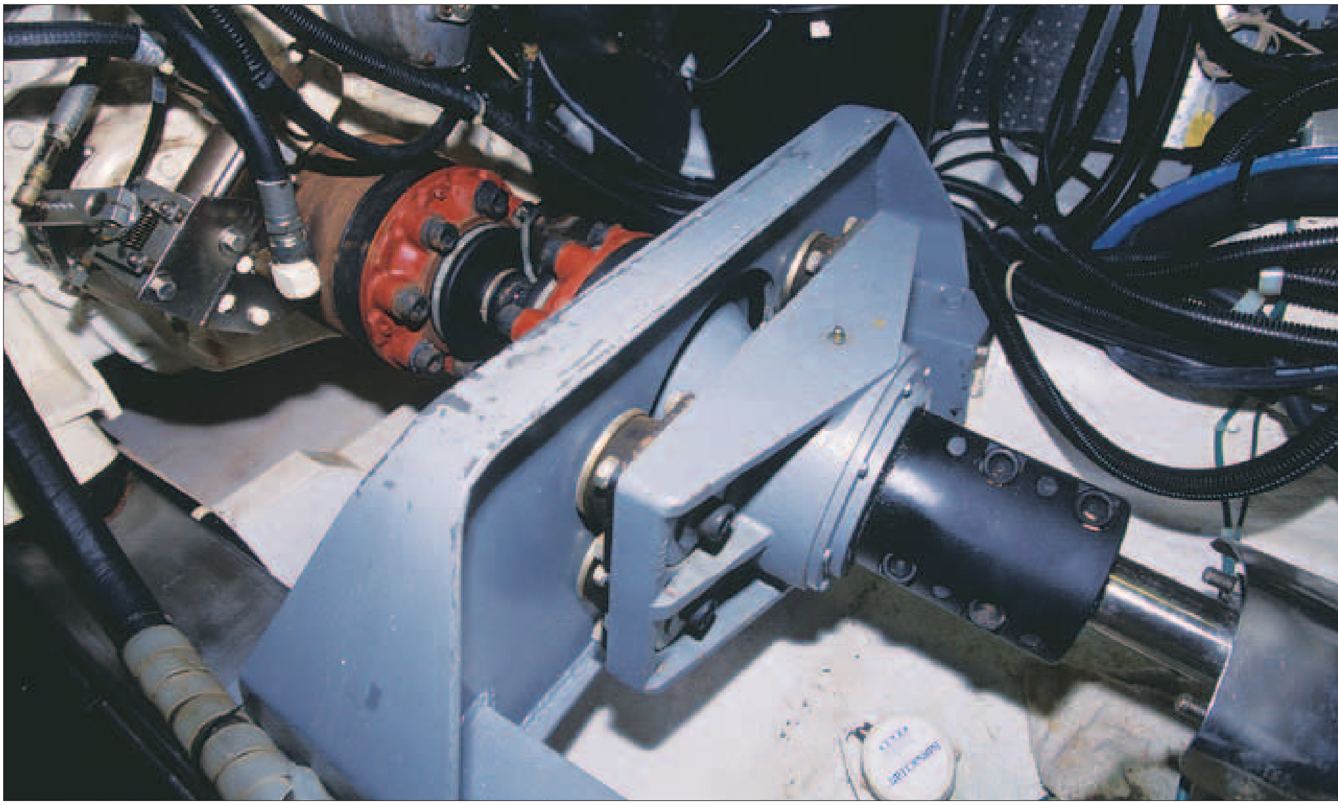


Refine the Ride

Do drivetrains fitted with thrust bearings (and associated joints) reduce noise and vibration? Indeed they do—provided the mechanical connections are properly specified, installed, and maintained.

Text and photographs by Steve D'Antonio

Above–*A good thrust-bearing system—like this one supported by a substantial metal "bridge" that spans the vessel's stringers—can effectively absorb all propeller thrust and vibration, reducing wear on the transmission.*

What can I do to make my boat quieter?

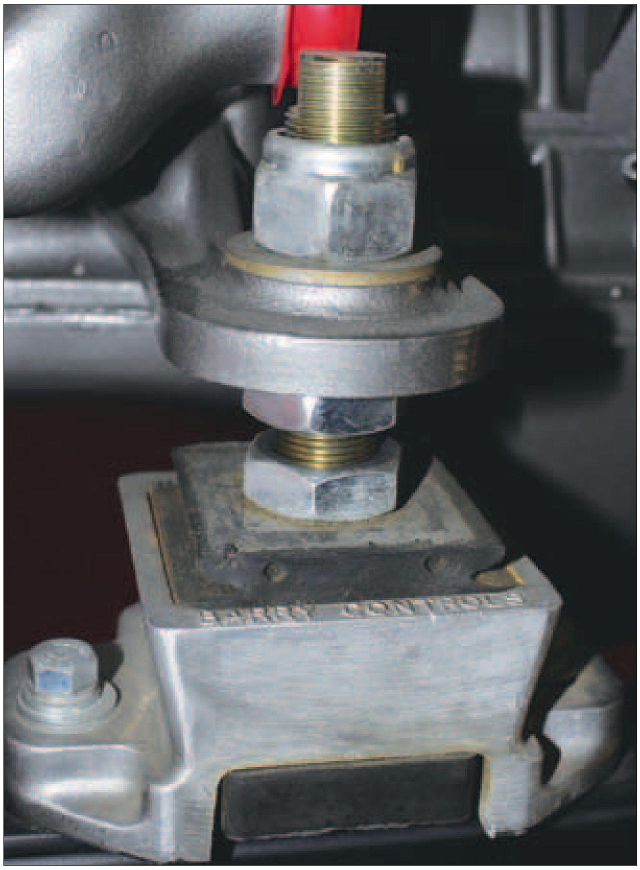
It's a question I've been asked many times in my years as a boatyard manager, technical writer, and marine industry consultant.

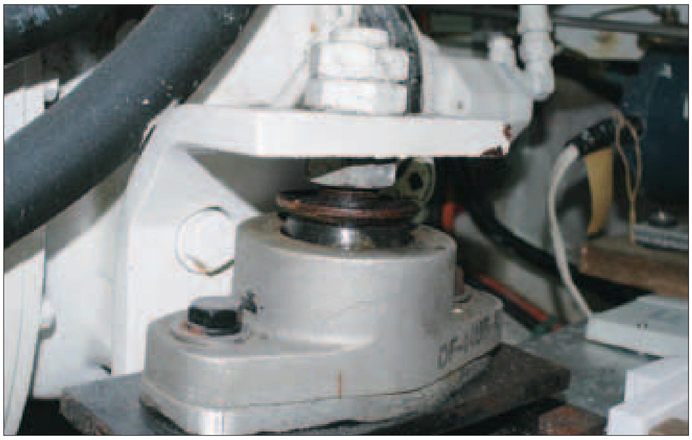
Insulation, perhaps the first thought, is not the answer. Granted, the more you surround noisy engines, generators, pumps, and compressors with sound-absorbing material, the less noise will reach your ear. But where noise and vibration are concerned, *isolation* is even better than sound containment, and that's where thrust-bearing drivetrains come into play.

Isolating rather than absorbing vibration minimizes noise from the outset. Perceptible sound is simply a compression of air, creating waves. So, many onboard sources from audio speakers to diesel engine blocks, have the capacity to make noise in the form of compression waves that reach your ear directly; or to cause other objects aboard the boat to resonate in sympathetic vibration, and thus generate their own sound waves. Isolating such sources of vibration gets challenging, especially in the confined space of an engineroom, where drive components must be hard-mounted to a vessel's structure.

Traditional Running Gear

The following traditional approach to running gear has worked exceptionally well for decades. We'll begin at the





Far left—*A vibration-damping propulsion-system mount from Barry Controls. Designed to absorb thrust loads as well as vibration, these mounts must be "set up" in accordance with the manufacturer's guidelines. Absent a thrust-bearing system, mounts of this type are the next best thing.* ***Top***—*Another vibration-damping mount, this one from Lo-Rez. Like the Barry Controls mount, it requires proper set up to be effective at absorbing vibration. It, too, is designed to carry thrust load without "locking up" vibration isolation.* ***Bottom***—*A motor mount from Bushings Inc. Mounts of this sort are simple, inexpensive, and moderately effective. They do "capture" the engine, keeping it bolted to the boat; however, their ability to effectively absorb vibration and thrust is limited.*

propeller: it's attached to the shaft, which is supported by at least one, and often several, water-lubricated, fluted rubber Cutless bearings. These bearings do a remarkable job, considering the circumstances under which they operate: supporting a shaft turning at a thousand or more rpm through salt- and silt-laden water.

If the shaft is properly aligned within the supports and the engine, Cutless bearings can be expected to last for hundreds of hours without maintenance or adjustment.

The thrust and vibration from the propeller transmit axially through the shaft to the coupling, through the transmission, and then to the engine. At that point, isolation of drivetrain vibrations becomes difficult. To move the boat, propeller thrust on the order of several thousand pounds must be transferred from the engine to the hull. A 100-hp (75-kW) engine, for instance, pushing a displacement vessel at 11 knots is generating nearly a ton of thrust.

Motor mounts come in numerous shapes, sizes, and designs with varying degrees of effectiveness, quality, and expense, but they all have one thing in common: they are the sole connection between the thrust of the propeller and the vessel it propels. Think of it this way: the propeller, shaft, transmission, and engine combination are collectively pushing the boat along with them through the motor mounts. Herein lies the problem: isolation of vibration and efficient transfer of forward and reverse thrust are all but mutually exclusive. As the thrust of the propeller pushes the engine forward, it compresses a portion of the rubber or silicone vibration-damping medium within the mounts. Once compressed, the rubber's ability to absorb vibration is diminished. The mount itself must be flexible enough to absorb vibration, strong enough to stand up to tons of thrust, and mechanically sound enough to hold the engine's mass in place even if the vessel were to roll onto its beam ends.

The motor mounts on one side of the engine are consistently compressed by the rotational force, or torque, opposed to that of the propeller, while the corresponding mounts on the engine's other side are lifted, or in tension. That switches when the transmission is thrown into reverse and the propeller turns in the opposite direction.

Aside from the torque, there's the propeller thrust pushing forward or aft. If you doubt how much thrust is absorbed and transmitted by the mounts, spend a few minutes in the engineroom of a moderately sized vessel as it maneuvers around a dock. You'll notice that the engine will often move as much as half an inch (12.7mm) forward or aft each time the shift is moved into gear. Under full load, the engine is straining at the mounts, wanting to tear free and leap ahead of the vessel. (I've seen the results when an engine has broken the bonds of the motor mounts. It's not pretty.) Look at the propeller shafts of vessels where they pass through Cutless bearings. You'll notice a polished ring-shaped section on the surface of the shaft just aft of the Cutless bearing. The width of this shiny section represents the distance the engine moves forward on its mounts when the vessel is under way.

Manufacturers have worked to create motor mounts that will absorb engine vibration while supporting the compression created by the propeller's torque and thrust. Considering the demands involved, the manufacturers have done well, but their advances are only as good as the builders who install the mounts. Loads imparted by the engine...through the mounts...to the vessel are transmitted through fasteners. Through-bolting with machine screws (see "Nuts. Bolts. Screws."—*Professional BoatBuilder* No. 118) is always preferable to screwing lag bolts into stringers. Lag bolts are notorious for failing in the presence of soft or rotten stringer or engine-bed core material, or because the threads of what is essentially a large tapping screw are not substantial enough to maintain contact under heavy cyclical loads. The 100-hp, 2,000-lb thrust loads mentioned above are impressive enough in their own right; but when a 900-hp (671-kW) engine is pushing a vessel at 15 knots, those thrust loads jump to 9,000 lbs (4,082 kg). The solid structural connection between engine and hull necessitated by these circumstances makes effective vibration isolation almost impossible in a conventional engine installation.

Thrust Bearings

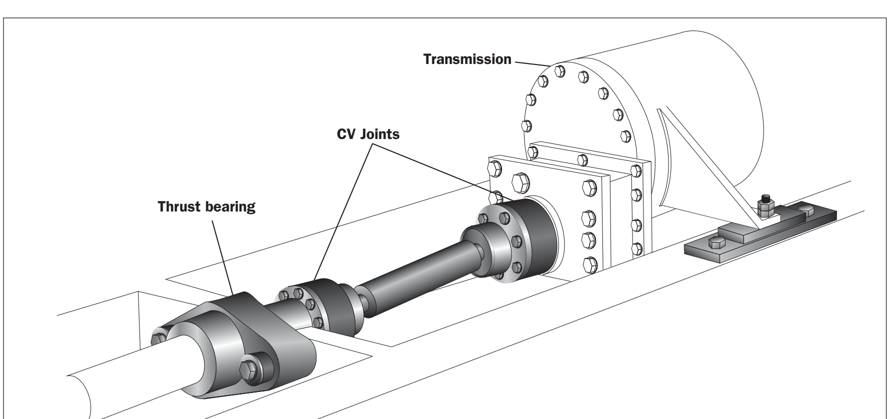
As reliable and well understood as traditional running gear may be, there is a more effective approach for better vibration isolation along with less wear on the engine and transmission. This involves two key components: a *hull-mounted thrust bearing*, and a *constant-velocity* or *universal joint*.

In every automobile several thrust bearings support the crankshaft, clutch, and wheels; a thrust bearing in every marine transmission carries the load imparted by the propeller. Its primary function is to support the fore-and-aft or axial thrust from the propeller, as well as the spinning loads imparted by the rotating shaft, at the same time allowing the shaft to spin with minimal friction.

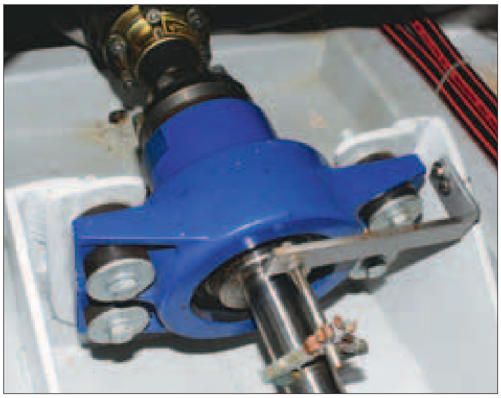
Thrust bearings come in two varieties: *ball* bearings and *tapered roller* bearings. Ball bearings are capable of carrying moderate loads, usually up to about 100 hp (75 kW) when employed as marine thrust bearings. Larger loads call for tapered roller bearings—the type in most automotive wheel bearings. The carrier is cone-shaped, while the bearings look like a series of miniature rolling pins.

As part of a thrust-bearing drivetrain isolated from the vessel's engine (i.e., not as part of the transmission), a thrust bearing offers several advantages:

- The motor mounts are no longer transmitting propeller thrust to the hull. Motor mounts in conjunction with thrust-bearing systems can be especially "soft" and markedly more effective at absorbing engine vibration. If a vessel with a traditional drivetrain setup is retrofitted with a thrust-bearing system, the motor mount specification should also be changed to significantly reduce vibration.
- In addition to reducing vibration, remote-mounted thrust bearings can extend the life of the transmission, which no longer needs to support axial loads from the propeller. Absent the secondary thrust bearing, these loads wear the transmission's own thrust bearing more rapidly, generate heat, shed metal particles, and stress the transmission's lubricating fluid in the process.
- Because an engine with a thrust bearing is separated from the propeller shaft by an intermediate shaft,



Above—*A thrust-bearing system partially decouples the propeller from the engine by transferring propulsive thrust to structural members in the bilge, without interfering with the rotational force from the engine driving the propeller.* ***Right***—*A cutaway of a traditional thrust bearing housed in a marine transmission. Note the tapered roller bearings and cone-shaped carrier that absorb thrust while allowing the driveshaft to spin with minimal friction.*



Because the thrust-bearing support or truss must withstand cyclical and reversing loads, carefully consider its design and construction. This one may appear light-duty but is probably adequate for the moderate horsepower involved. Avoid un-gusseted or "flat stock" structures; if, after installation, movement can be detected in the component under any operating conditions, then add more support.

a CV joint—as the constant-velocity version is generally known—broadens the choices for engine placement and orientation. The engine can be located farther forward or farther aft, since the centerline of the engine need not parallel the propeller shaft. (Down-angle transmissions can also facilitate this type of improved installation; however, their angles are fixed, whereas a thrust bearing supports a range of installation angles.)

• With a thrust bearing, the propeller shaft's forward movement is all but eliminated because its thrust is borne by the hull through relatively thin bushings rather than large, flexible mounts. That reduces shaft movement and the likelihood of the shaft making contact with the shaftlog when the vessel is under way. Also, when a shaft moves forward under load, the adjustment of shaft-mounted line cutters and face-seal-style dripless stuffing boxes becomes more challenging. Secondary thrust bearings virtually eliminate such problems.

CV and U Joints

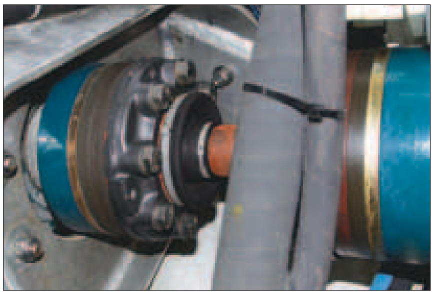
Constant-velocity or universal joints coupled with secondary thrust bearings are essential to the flexibility needed to break the unforgiving rigidity of a conventional drivetrain. The common CV joint can be found in virtually all current-production front-wheel-drive and many rear- and all-wheel-drive cars. But their ubiquity shouldn't be mistaken for simplicity. Developed in 1927 by Ford Motor Company engineer Alfred Rzeppa, the CV joint's primary function is to provide constant velocity while moving through a variety of angles. Imagine the shaft that powers the front wheels of a car providing constant, smooth power to those wheels even as the driver cranks the steering wheel to hard over. The CV joint reliably performs this tall (engineering) order.

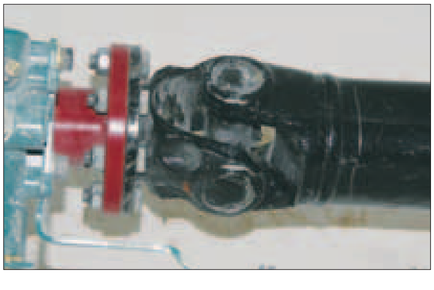
True plunging CV joints move axially as well as radially. The essential parts of the joint—a steel cage retaining hardened steel balls within a steel orb—are enclosed in a tough rubber boot, bathed in lubricant, and protected from water, dust, and other contamination. Constant-velocity joints come pre-lubed and are virtually maintenance free. Typically, automotive CV boots and their joints can be expected to last in excess of 100,000 miles and for 10 years, often much longer.

A less-sophisticated alternative to the CV joint is the universal, or U, joint. Known as U or Hardy-Spicer joints here in the United States, and Cardan joints in Europe, they are capable of changing the direction of rotational energy in much the same way CV joints do, but with one very important distinction: they cannot do so with constant velocity.

U joints are made up of two U-shaped yokes joined through a central cross-shaped pivot. When the driving and driven shafts are in line or parallel, they rotate at the same angular speed; when an angle is introduced, the *driven* shaft no longer rotates at constant angular speed compared to the *driving* shaft. Its motion becomes more irregular as its angle to the driving shaft increases, although the overall or average speed of the two shafts remains the same. Attaching a second U joint to the same shaft can counter the rotational irregularity, but it's important that the two be properly phased to cancel the undesired motion.

Also, U joints are not as good as CV joints at isolation. The former transmit axial vibration, and in some cases will induce vibratory torque and secondary excitation. By themselves, U joints cannot accept axial motion through accommodating the lengthening and shortening of the driveshaft while it's rotating—a dynamic that is present to some degree in nearly every thrust-bearing installation. To enable U joints to be subject to axial motion, a splined, lubricated shaft connection must be included. Though rugged and reliable, splined connections become friction bound when under





Top—*Standard shaft-coupling installations can absorb only a few thousandths of an inch of misalignment between the engine and shaft, and there is no reliable method of measuring misalignment while they're under load.* ***Middle***—*CV joints are integral parts of many thrust-bearing systems because they allow for limited misalignment, even under full-load conditions. Their most common failure is the rubber boot (seen here intact where shaft meets joint), which leads to lubricant loss and rapid wear. Also, they must be installed at a slight angle.* ***Bottom***—*Universal joints in some thrust-bearing systems are not as sensitive to zero-angle installation as CV joints; but when installed at an angle, they must be phased to prevent rhythmic vibration.*

load, demanding roughly 10 times the force required by a plunging CV joint to move under the same conditions. This limits free movement of the engine and increases the undesirable transmission of vibration.

On the plus side, U joints are typically less expensive than CV joints, and, owing to their lack of a flexible rubber boot, are considered more reliable. Most are equipped with zerk fittings, allowing the operator to add grease when needed (which is seldom, unless the U joint's own rubber grease seals fail or wear out). Over-lubed or leaking U joints will sling grease in a clearly identifiable arc perpendicular to the shaft. If you ignore this call for service, the U joint is headed for an early, and potentially catastrophic, failure.

The majority of thrust bearings in the systems I'm familiar with on recreational and small commercial vessels rely on CV joints in preference to U joints—owing to their constant velocity, their low maintenance, and their ability to plunge without a splined shaft. With either flexible joint in a thrust-bearing installation, though, the engine and shaft can be mounted at different angles. While for longevity's sake, it's desirable for engines to be mounted as close to the horizontal plane as possible, in a conventional installation the engine must either be parallel with the propeller shaft or be coupled with a down-angle transmission. A CV or U joint permits flexibility in determining engine angle.

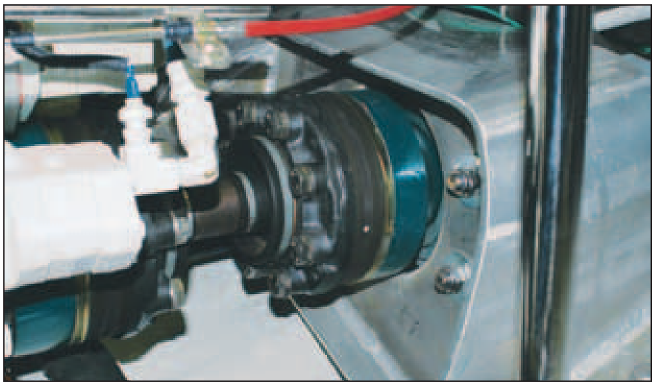
Installation

One of the most critical aspects of a thrust-bearing installation is how the bearing is connected to the vessel. Recall the previous discussion of the transmission of propeller thrust. Where a conventional drivetrain transmits thrust to the hull through the motor mounts, a thrust bearing and its connection to the hull must now effectively transfer this load to the vessel. There are two primary methods of providing the necessary structural support:

• The first method is a bulkhead capable of accommodating all the thrust from the propeller, located aft of the transmission/engine package. On FRP vessels, such bulkheads are preferably solid glass, tabbed into the boat's existing structure with accepted ratios for heavily loaded parts. I've supervised a number of aftermarket installations; solid, prefabricated fiberglass panels several inches thick were epoxied and substantially tabbed into place after the extensive secondary-bonding areas were ground and prepared for lamination. It bears repeating that such an installation represents a heavily loaded secondary bond, and all of the precautions and protocols for such structures must be closely followed. I would rely on at least a 12:1 ratio when tabbing in such a panel.

• The second common solution is to install a stout bridge or dam-like structure—typically of steel or aluminum—bolted between the engine bed stringers aft of the transmission, to which the thrust bearing is then bolted. This support structure, like the bulkhead of the first option, must be strong enough to support forward

FRP thrust-bearing support trusses almost always require secondary bonding, so follow the highest industry protocols to ensure a reliable installation. ***Clockwise from far left***—*Careful bonding as a truss of G-10 fiberglass plate is fitted into an older hull; the same support with a 12:1 secondary bond zone and a cutout sized to accept the thrust bearing; and the final fitting of the thrust bearing in the refinished bilge.*



Choose the appropriate material for truss supports. Aluminum, ***left,*** *is ideal for its strength, low weight, and corrosion resistance. Mild steel,* ***right,*** *is a strong, inexpensive option. Both require corrosion-prevention measures. Aluminum needs no coating but cannot be continuously exposed to stagnant water, or to wet substrates (e.g., timber or insulation). Periodically inspect all supports for signs of corrosion, cracks, or other damage or defects.*

and reverse thrust as well as typical vessel dynamic and cyclical reverse/forward/reverse loading. It should be heavily gusseted. *Through-bolts*, not lag bolts, must attach the support structure to the boat. In steel and aluminum vessels, the thrust-bearing support is simply fabricated from the same metal as the hull, and then welded in place. Once again, generously gusseted, heavily built structures are a must.

Even in new-builds, if there's any question about the strength or construction technique, consult the thrust-bearing manufacturer and a naval architect. I cannot overemphasize the importance of the integrity of this structure, regardless of the build method or hull material; it is every bit as critical as the support between the motor mounts and the engine-bed stringers.

The supporting bulkhead or bridge must be perpendicular to the propeller shaft. The actual thrust bearing is attached to the bulkhead or bridge by through-bolts; however, it is isolated from the support with manufacturer-supplied bushings designed to absorb vibration transmitted to the thrust bearing through the propeller shaft. During installation these bushings must be properly compressed according to the bearing manufacturer's guidelines. In my consulting work I find that *improperly compressed bushings, along with a lack of perpendicularity, are the most common thrust-bearing-installation faults.* If bushings are over-compressed, they will *transmit* rather than isolate vibration; if *under*-compressed, the thrust-bearing assembly might suffer excessive movement under load or during transmission shifting.

Similarly, the motor mounts installed with thrust bearings often carry a compression specification. If the mounts are over- or unevenly compressed, they will not dampen vibration as intended. The only way to modify mount compression is to choose a mount with a different durometer, or hardness, rating. (Mounts are typically rated based on the engine/transmission weight they will support.) And the only way to ensure proper compression is to take measurements before and after loads are applied—that is, as the engine is lowered onto its beds. Mounts must be properly compressed and within a value of 0.04″, or 1 mm, of each other.

Any CV joint between the engine and thrust bearing should be installed with at least a slight angle. That's because the CV joint relies on a ball that moves through a groove as the joint compensates for angular misalignment; and installing them with a 0° angle means the ball remains fixed in the groove, which could lead to a flat or worn area. A 1° minimum angle should be induced for each joint typically located at either end of the secondary driveshaft. The angles at each of the joints should be as evenly distributed as possible. If the total angle between the engine and the thrust bearing is 12°, then each joint should be at approximately 6°, rather than one set at 10° and the other at 2°. You can measure these joint angles by placing two straightedges across and parallel with the centerlines of the joints. The straightedges should intersect at roughly the halfway mark between the two joints.

The maximum acceptable angle for most CV joint installations is between 5° and 8°. The greater the angles, the more important it is that they be as similar as possible. If excessive angles are unavoidable, then you must select a larger thrust bearing than one for a moderate-angle installation. Also, the maximum rpm the joints will be subjected to may need to be lowered.

Thrust-bearing assemblies rely on either a clamp or flange to attach to the shaft.

Note: Alignment between the propeller coupling and the thrust bearing is just as critical as the alignment between a shaft coupling and a transmission on a conventional running gear installation—no more than 0.001″ (0.025mm) of runout for every 1″ (25mm) of coupling diameter.

Tapered or straight keyed-flange couplings are desirable on conventional propeller shafts and with thrust bearings, because they are more precise and their alignments more repeatable than clamp-style couplings. If shaft diameter is undersized, there's a possibility the shaft could slip in a clamp-type coupling, creating excessive heat, and welding itself to the clamp body. A conventional keyed, tapered coupling virtually eliminates that risk.

Maintenance

Thanks to their robust industrial components, properly installed thrust-bearing systems are exceptionally long-lived and require little maintenance. The life of rubber components such as bushings, CV boots, and to a lesser extent, U-joint seals, should be a minimum of 10 years, depending upon the environment. (There is evidence to suggest ozone generators accelerate the demise of rubber.) Note that the greater the angle at which CV joints operate, the shorter the life of the boot. In fact, the boot is typically the limiting factor; CVs can handle extreme angles, while the boots cannot.

Thrust bearings for larger engines are often equipped with zerk fittings, but, depending on the type of load the unit is subjected to, many don't require additional grease until the 2,000-hour mark. Over-greasing a bearing can increase heat generation and be as detrimental as a lack of lubrication. The lubricant required for most greasable thrust bearings is LGEP#2. The best way to determine the need for lubrication is by monitoring the temperature of the bearing with an infrared pyrometer. Depending on the manufacturer and the ambient temperature, thrust bearings and CV joints often operate at somewhere between 110°F and 140°F (43°C and 60°C), with a maximum allowable temperature of approximately 165°F (74°C) at full load. Pyrometers work well, provided a target is placed on the bearing to ensure the readings are taken in the same place each time. Boats equipped with

Top—*The signage posted above the zerk fitting is mistaken: thrust bearings do require greasing, but most don't require it very often. To avoid over-greasing, follow the equipment manufacturer's guidelines.* ***Above***—*Here, instead of grease lubrication, an oil reservoir gravity-feeds oil to the thrust-bearing assembly.*

integrated monitoring systems can rely on a temperature sensor fixed to the bearing assembly. Thrust bearings and CV joints will often run cooler after an initial break-in period of between 300 and 500 hours. It's not unusual to see a drop of between 5°F and 10°F (3°C and 6°C) during this time.

U joints, many of which are equipped with zerk fittings, also benefit from periodic lubrication. Like thrust bearings, they should not be over-greased. Even if this is less likely to cause harm to the needle bearings located within a U joint, the excess grease will be slung around the compartment.

The Evolution Company (Rockland, Maine) and Seatorque Control Systems (Stuart, Florida) are two marine thrust-bearing manufacturers I'm aware of that get around the need for bearing greasing by utilizing an oil-lubricated combination shaft-log/thrust-bearing assembly. The support structure is an oil-filled tube that surrounds the propeller shaft. It supports the bearings and reduces inefficiency created by the Magnus effect, whereby turbulence caused by the rotating shaft lowers propeller effectiveness.

Seasonally, the entire thrust-bearing assembly should be visually inspected for loose nuts and bolts, and for signs of galling or fretting around all metal-to-metal contacts such as the heads of fasteners. I prefer to install all fasteners in thrust-bearing systems with a thread-locking compound/system such as Loctite 271, or Nord-Lock washers. A common trouble spot is the CV joint cover; if its fasteners loosen, grease will leak out of the CV joint. This is difficult to miss because, as mentioned above, a grease sling line will bisect the engine compartment. If your CV should disgorge its load of grease, and you catch it in time, it can be reloaded. Note that CVs usually require molybdenum disulfide, or MoS2, grease.

✦

Thrust-bearing drivetrains offer a number of advantages over conventional running gear. While their expense is not insignificant, if you're searching for the smoothest, quietest, most reliable and mechanically sound drivetrain for the boats you build or service, don't overlook a thrust-bearing system.

In rough terms, for a 40′ (12m) single-screw powerboat, a good thrust bearing and installation hardware would cost between \$8,000 and \$10,000. Labor for the installation would be between 40 hours and 50 hours in new construction, and probably twice that for a retrofit.

Boat owners who've suffered from excessive engine noise and vibration, or had to replace drivetrain components worn out from absorbing prop torque and thrust, understand the seemingly high price.

It's the cost of quieting their boat. PBB

About the Author: *For many years a full-service yard manager and now a contributing editor of this magazine, Steve works with boat builders and owners and others in the industry as "Steve D'Antonio Marine Consulting Inc." McGraw-Hill is about to publish his book on marine systems.*