BEST PRACTICES

Internal Combustion's Backside

For new and refit vessels, here are the fundamentals of exhaust system design and analysis.

Text and photographs by Steve D'Antonio

Exhaust systems are critical to any vessel's design. They can affect everything from noise, vibration, watertight integrity, and engineroom temperature to performance, fuel economy, and crew safety. Failing to follow engine and generator manufacturer installation guidelines is, in my experience, by far the most common cause of system breakdown, poor vessel performance, and warranty disputes. Fortunately, there's very little new about exhaust system design and installation, so it's relatively easy to avoid the most common problems.

Design Basics

The typical inboard powerboat or sailing vessel auxiliary is equipped with a wet exhaust system. Nearly every wet exhaust system includes a dry segment between the engine's exhaust manifold or turbocharger and the point of water injection, called the mixing elbow. Because dry/wet exhaust systems are far more common, this article will focus on them, rather than on pure dry exhaust systems, which are all dry, and are used mostly in commercial applications.

In wet exhaust systems, an enveloping showerhead arrangement thoroughly mixes hot exhaust gases with cooling water, and they are ejected through a combination of metallic and/or fiberglass pipes, flexible hoses, and metallic or fiberglass mufflers. In most cases, they exit at or above the waterline; however, underwater exhaust is an option (albeit not without challenges).

Many marine engines are installed at or below the waterline. This makes them susceptible to flooding when seawater enters directly through a defective exhaust system, or indirectly via a siphon, through the raw-water intake, or a water-injected stuffing box. Simple precautions, including a design that complies with American Boat & Yacht Council (ABYC) and engine/generator manufacturer guidelines, proper installation, quality materials, antisiphon valves, and regular maintenance and inspections nearly always prevent these failures.

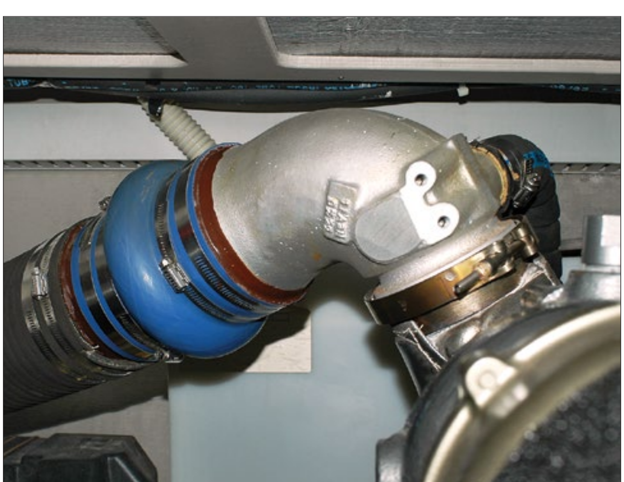
For the benefit of apprentices and journeymen, here's how it works. Gases created by the engine's combustion exit the exhaust manifold at up to 1,000°F (538°C). These hot gases must be cooled so they can be safely conveyed from the vessel to the atmosphere, via fiberglass, rubber, plastic, silicone, and other "soft"-material components. Cooling is accomplished by mixing the gases with the same seawater that cooled the engine, after that water has passed through the cooling jacket (or heat exchanger in a freshwater-cooled engine).

This mixing does several things: It cools the gases enough that they won't damage the soft components; it muffles exhaust noise by causing a rapid contraction of the gases; and it disposes of the water used to cool the engine. While a variety of exhaust designs are available, to accomplish this task safely and effectively, the two described below—the waterlift muffler and the jacketed elbow or riser—are the most common on marine recreational vessels. The choice of one over the other depends on the type of installation, the location of the waterline in reference to the engine, and the budget.

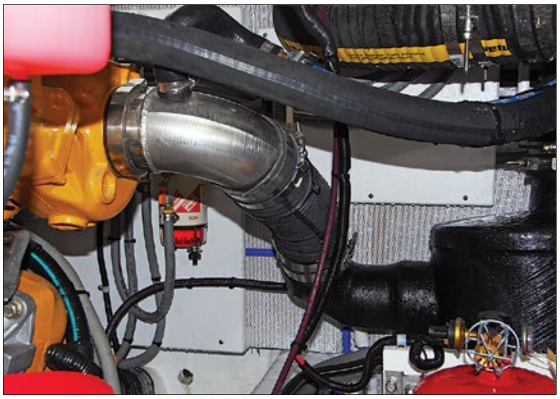
The Waterlift Muffler System

When an engine rests at or below a boat's waterline, you must implement reliable means of injecting water into the exhaust stream without running the risk of it traveling back into the engine.

In a waterlift system, exhaust gases are cooled by the aforementioned mixing elbow, or "injection elbow," installed immediately after the exhaust manifold or turbo outlet. The elbow is usually angled downward at a *minimum* of 15° (some manufacturers call for a minimum of as much as 25°) to prevent water from traveling back into the engine. Equally important, an insufficient exhaust down angle at the water-injection point often leads to overheating of the spine or top of the exhaust hose. The elbow is double-walled or jacketed, and filled with water, for a portion of its length, and has a port into which the water is injected. From there, water is sprayed into and *around* the exhaust gas stream by a series of small holes. Water should never be injected into the exhaust gas stream via a single point, as that tends to create hot spots in the wet portion of the exhaust, which in turn leads to extreme thermal stress, and may even erode the inner pipe. The engine manufacturer often specifies the size of the injection holes, usually about 5⁄16″ (8mm) diameter. They should be no smaller than the holes in the raw-water intake strainer, as this could become a choke point for waterborne debris.



Facing page—*The business end of a mixing elbow: Cooling water injected through the holes surrounds hot exhaust gases for uniform cooling without hot spots. Holes should be no smaller than those in the raw-water strainer or heat exchangers.*
Above left—*The down angle at the point of water injection prevents water from backing up into the engine and ensures that hot exhaust gases are enveloped by the mixing elbow's shower-like spray.* ***Above right***—*Fully jacketed risers operate significantly cooler than conventionally insulated risers, which is beneficial in close-quarters installations like the one shown here.*



Far left—*Insufficient drop between the water-injection point in the mixing elbow and the waterlift muffler can lead to "sluicing," during which pitching or rolling induces water to travel the wrong direction and into the turbo and/or engine's cylinders.* ***Left***—*Most engine manufacturers clearly warn against reducing exhaust size. Doing so increases horse-power-robbing back-pressure.*

The next step for the exhaust mixture is the waterlift muffler. In addition to quieting the exhaust, the muffler collects water from the remainder of the exhaust system and prevents it from returning to the engine upon shutdown. As water collects while the engine is running, exhaust-gas pressure propels the water and exhaust-gas mixture upward through the discharge outlet. The size of the waterlift muffler is critical; it must be able to hold all the water in the exhaust hose, both ahead of and behind it, that would run back into the muffler upon engine or generator shutdown. Muffler manufacturers usually provide formulas for calculating the volume of the system. If the calculations yield a borderline result, always go to the next larger size muffler. Also, hose sizes, *if changed*, must always become progressively larger as the exhaust travels to the outlet. Never reduce exhaust plumbing sizes in any engine or generator application. Doing so creates excessive horsepower-robbing back-pressure and could affect warranty coverage.

In a properly installed system the injection elbow is typically located 12″ (305mm) or higher above the load waterline (LWL). These measurements can be a bit tricky. They are taken between the bottom of the internal elbow pipe where it exits the turbo or exhaust manifold, or, in the case of a riser, at the bottom of the internal pipe above the LWL. I often advise installers to "look at the path water would take and assume the installation *never* gets the benefit of the doubt." Still, this can be difficult to visualize, and if these guidelines are violated, water will make its way into the engine.

ABYC standards are clear, stating in section P-1.5.11: "The exhaust system shall be designed and installed to prevent cooling water, rain water, or raw water from entering the engine through the exhaust system under all normal operating conditions. The exhaust system design shall consider the drop height of the manifold above the waterline and a provision for downward slope of the exhaust system."

Most manufacturers require that wet exhaust plumbing exit the vessel on a continuous downward slope of a *minimum* of 2° or 0.5″ (12.7mm) per foot.

Engine manufacturer installation manuals nearly always specify this information in great detail, often by **diagrams** (see facing page). Follow these instructions carefully, taking into account the boat's and the exhaust system's attitude while under way and/or when heeled. A 12″ drop at the dock may become an 8″ (203mm) drop, or worse, a rise, under way.

Flood Prevention and Hydrolocking

One of the primary roles of the exhaust system is to convey exhaust gases out of the vessel while preventing water ingress into the engine. Hydrolocking can occur when water enters an engine's cylinders (water, unlike air, is incompressible), and this can cause significant damage. To prevent this, two features are important: siphon breaks and an adequate riser.

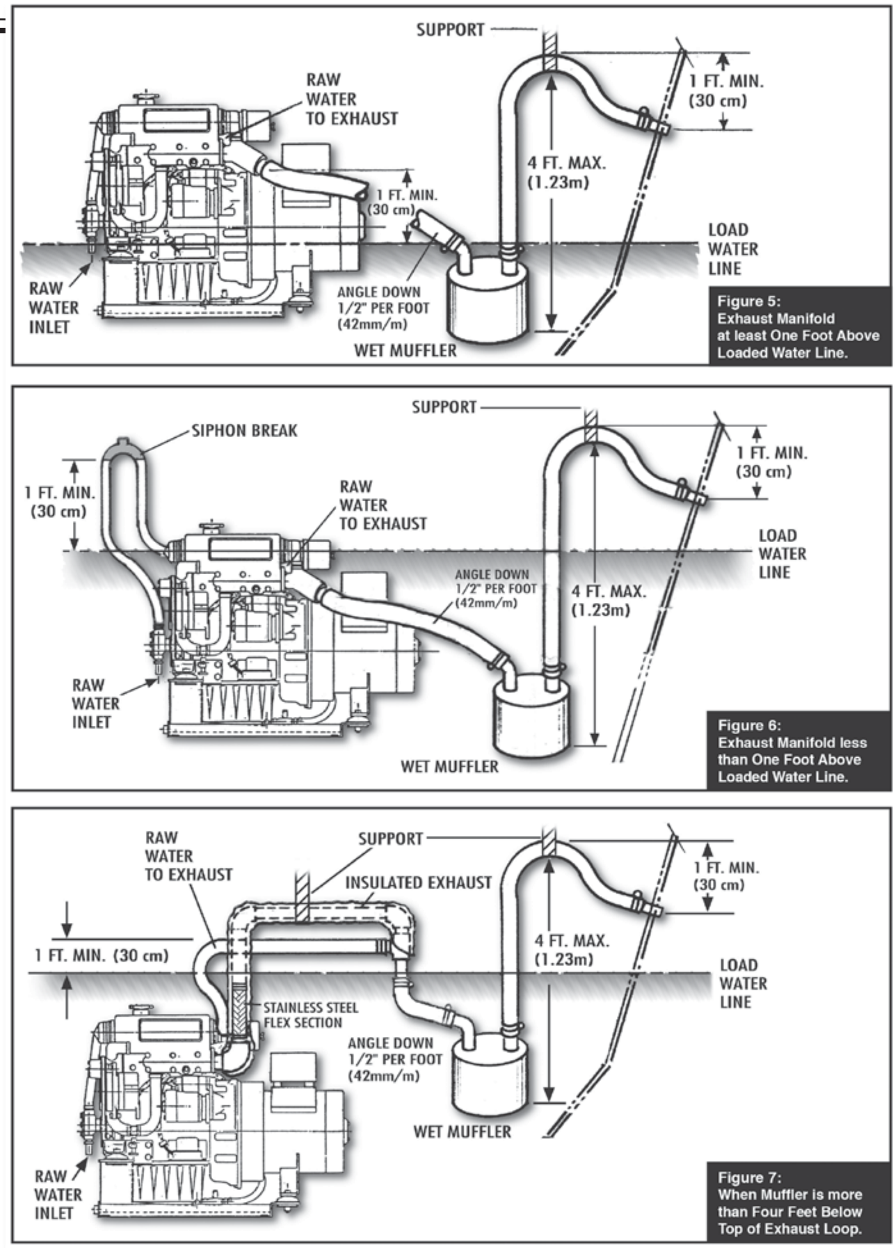
For vessels whose engines or generators are at or below the load waterline (LWL), a **siphon break** must

The U section is a clear violation of the engine manufacturer's guidelines. While the boatbuilder who assembled it claimed, truthfully as it turned out, that the engine dealer approved the installation, it was still condemned by the manufacturer.

The variety of riser designs include those directly above the exhaust manifold/turbo, those directly above the muffler, and those before the overboard discharge, typically adjacent to the transom. These are dependent on vessel design and engine/genset height above or below the LWL. The primary difference is that some are self-draining and some are not. In self-draining designs, mixing elbows are just after the highest portion of the system, so that no matter how much water is pumped into them, it runs overboard, even if the engine isn't running. In designs that aren't self-draining, water that accumulates in them can flow back to the engine and into its cylinders.

The Jacketed Elbow or Riser

More commonly found on power and larger sailing vessels, the jacketed riser or elbow is a slightly different approach. This system surrounds the hot exhaust gases with a double-walled pipe through which cooling seawater flows. Some risers simply consist of a vertical inverted U loop traveling



COURTESY NORTHERN LIGHTS

For good reason, engine and generator manufacturers provide clear, detailed guidance for exhaust system design and installation. They never give a warranty for water ingress via the exhaust system.

be installed in the exhaust system between the raw-water pump outlet and the injection elbow (see "Antisiphon Valves" on ProBoat.com). According to ABYC, it must be located "at the top of a loop which shall rise high enough to assure that the high point where the siphon break is installed will *always* be above the water level surrounding the boat." This means the antisiphon device should be well above the LWL regardless of the boat's attitude, often a minimum of 12″–18″ (305mm–457mm). On a sailing vessel it should be located as close as possible to the centerline to ensure that it doesn't end up below the waterline when the boat is heeled.

Most manufacturers of these devices have very specific installation requirements, particularly the vertical distance between the waterline and the siphon break. Some specify as much as 24″ (635mm) to ensure proper operation. Check the installation requirements even if you've used the same unit previously or if one aboard a vessel you are working on appears to be operating normally. It may be inoperative and you'd have no way of knowing it.

In many installations, all that prevents a siphon is the condition and resting position of the raw-water-pump impeller. A single rubber impeller blade will often prevent a siphon, but if that blade is damaged, water can flow into the exhaust system while the engine is at rest.

Siphon breaks require periodic maintenance or replacement. Most designs incorporate a small rubber "duckbill" valve, which can become encrusted with salt or other debris. This can cause the valve to either stick open, resulting in seawater dribbling or spraying out of it, or stick closed, which invites siphoning. Given enough time, a malfunctioning siphon break stuck in the closed position can cause a

ABYC Highlights

Along with specifying proper materials, the ABYC standard includes guidelines for installation. Here are a few highlights (some are paraphrased):

- All exhaust system fittings, joints, clamps, and supports must be accessible for inspection and repair (insulation should be easily removable).
- Each engine and/or generator must utilize its own dedicated exhaust system. Additional discharges, other than cooling water, shall not share the exhaust passage.
- Protective guards, jacketing, or covers shall be provided wherever persons or gear might come in contact with the exhaust system where the temperature exceeds 200°F.
- Hose used in wet exhaust systems shall comply with the performance requirements of SAE J2006, Marine Exhaust Hose, or UL 1129, Standard for Wet Exhaust Components for Marine Engines. All other exhaust system components shall meet the performance requirements of UL 1129.
- Every exhaust hose connection shall be secured with at least two nonoverlapping clamps at each end to produce a secure, liquid- and vapor-tight joint. Clamps shall be entirely of stainless steel metal. The bands shall be a minimum of ½″ (12mm) in width. Clamps depending solely on spring tension shall not be used.
- In boats characterized by extremes of roll and pitch, the exhaust shall lead as directly as practicable from the waterlift chamber to a high point in the piping, as near to the boat's centerline, and as high as practicable, to minimize the possibility of raw water flooding the exhaust during heavy weather when the engine is not running.

directly up from the exhaust manifold or turbo outlet, above the waterline, and then straight back down and overboard via hose and fiberglass tubing. Others rely on more complex designs, albeit with the same goal, keeping a jacket of cooling water around the hot exhaust as it makes its way to the mixing nozzle.

After the riser loop, the jacket water is injected and mixed into the exhaust stream using the same shower spray approach, and then into a muffler or overboard, in much the same way as the waterlift system. When the exhaust is above the LWL, such as in planing powerboats, the jacketed system requires little or no rise to achieve the necessary downward angle between the engine and hull outlet.

Jacketed systems, typically more costly and cumbersome than the lift type, are sometimes preferred in smaller engine compartments or in cases where the dry exhaust system would otherwise pass close by bulkheads or overheads, because those systems remain comparatively cool and require little or no insulation. Insulation may be needed at the connection point between the riser/elbow and the exhaust manifold or turbo outlet, as this section is often not jacketed and thus essentially dry exhaust. Downward injection angles, elevation above the waterline, and slope requirements remain the same in these systems as in the previously described arrangement.

There is one major drawback to the jacketed riser: Depending upon the design, if the inner jacket develops a leak, standing water within the jacket

boat to flood and eventually sink. At the very least, it will fill the engine's cylinders with seawater, leading to costly repairs or outright destruction of the engine. If a siphon break is not installed where one is required, or is not maintained, it is not a matter of if the engine will flood, but when.

A final note on siphon breaks: Many installers run a small hose from the valve's vent into the bilge, the logic being that if the valve ever sticks open, it won't spray seawater around the engine compartment. However, because the hose that's used is often clear PVC, when it gets warm it becomes kink- and crush-prone, and can also become clogged with salt. When that happens, airflow is cut off, and the siphon break is no longer effective. (I've seen this destroy a relatively new diesel propulsion engine.) If the hose is run into the bilge and it becomes submerged, the airflow is also impeded, which allows for siphoning. (I've seen this flood a new generator.)

The second necessary feature to prevent engine flooding is an adequate **riser** before the exhaust outlet. For sailing vessels,

Ideally, exhaust hull penetrations should exit above the resting waterline. Flaps help minimize the likelihood of water being pushed into the exhaust from a following sea or hard backing down.

a following sea can force water into the exhaust system of an idle engine (a flap on the exhaust discharge can help prevent this, but it is often lost). For power vessels without the proper riser, water can be forced into an engine while the vessel is at rest or when backing down (this is especially true for twin engines if one isn't operating). It's not uncommon for engines to flood years after they've been installed. Therefore, don't will seep into the exhaust system each time the engine is shut down. If the leak is low enough, water could reach the exhaust manifold. From there it will pass through any opened exhaust valves into the cylinders and wreak havoc on pistons, rings, and cylinder walls (for more on how to deal with this, see the **sidebar** on page 62). Jacketed elbows that point downward or lack a riser are less susceptible to such a calamity, as the double-wall section is all on the "downhill" side of the exhaust; however, a leak in the inner pipe could still lead to corrosion, water ingestion, and other problems.

The Dry Riser

A variation on the jacketed riser uses the dry riser with conventional water injection on the downward slope. The design remains the same as the jacketed riser; however, a single-wall "dry" pipe replaces the water-filled jacket. To prevent it from becoming too hot and radiating excessive heat into the engine compartment, the pipe is heavily insulated using one of the following: a proprietary, easily removable "blanket" material (the surface of the blanket should shed liquid so the insulation can't become saturated with oil, fuel, or coolant), a permanent hard-wall resin-based lagging material, or a wrapped fiberglass cloth

While a dry, insulated riser will generate more heat than a fully jacketed riser, it will not suffer from incipient internal leaks that can cause engine damage. Here, a removable "blanket" insulates the riser, minimizing heat transfer.

lagging. The advantage of the removable blanket is that it affords access for inspection or repair, but its life span is limited. Although the wrap is also removable, it's more time-consuming, and replacement is often a problem. While the hard-coat insulation cannot be removed, it is the most durable and long-lasting, and it won't absorb leaked flammable liquids. (Coolant can become flammable if it is spilled onto a dry exhaust wrapped with unprotected hygroscopic insulation and the water portion is then cooked off.)

This dry riser relies on permanent hard-coat insulation, which can't be removed but is more durable than blanket or fiberglass-wrap insulations.

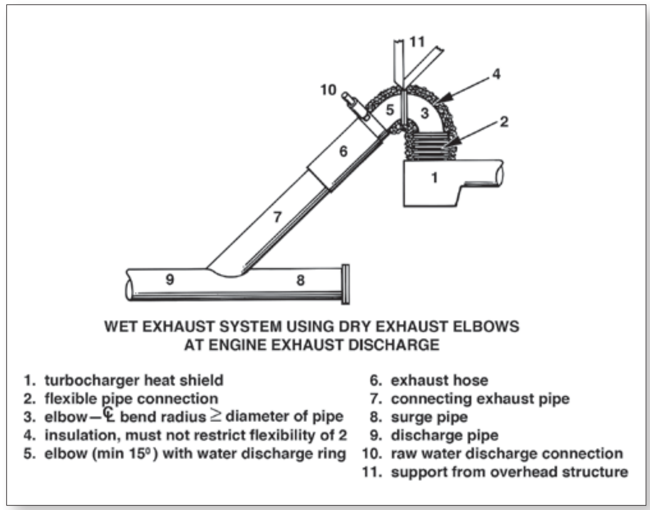
This hybrid approach is far less risky than a jacketed riser in that it virtually eliminates the possibility of a leak and water ingress; however, it's not without trade-offs. The dry riser operates at a higher temperature and must be thoroughly insulated. Even when insulated it could be as hot as 200°F (93°C),

assume an installation is correct simply because it has been in service and hasn't yet failed. If it doesn't meet manufacturer's guidelines, you should, at the very least, alert the owner and explain the potential circumstances.

Many bluewater sailing vessels are equipped with exhaust outlet seacocks or valves that can be closed in heavy weather or large following seas. However, if the user forgets to open the valve before attempting to start the engine, a hose, muffler, or other portion of the exhaust system may burst. My preferred approach is to add a placard warning adjacent to the key switch. Alternatively, a proprietary wet exhaust check valve may be installed. (Off-the-shelf bronze swing check valves often don't hold up in this application. I find the innards of many are broken or missing altogether.) The one drawback to such an installation is there's no way to know if it's working, because there is no way to check the operation, or even presence, of the flap.

An engine can also become hydrolocked if it is cranked repeatedly without starting. For example, when troubleshooting or bleeding a diesel fuel system, each revolution of the engine pumps raw water into the cooling jacket or heat exchanger and then into the exhaust system. Eventually, assuming the design is not self-draining, the exhaust system fills to capacity, and, with no combustion gases to force it out of the muffler or hoses, water may flood back into the exhaust manifold and engine cylinders. While waterlift systems are particularly susceptible, engines with jacketed risers can also back-flood, depending on the system configuration and elevations. To prevent this, the raw-water-intake seacock should be closed during periods of extended cranking. Once the engine starts, the seacock must be opened immediately.

If water enters an engine, it must be dealt with quickly to prevent permanent damage. The most effective means is to remove the injectors or spark plugs. For diesels, use suction from a Shop-Vac with a small hose adapted to the inlet—but not for gasoline engines, because of the risk of



COURTESY CATERPILLAR

The surge tube, shown in the engine manufacturer's exhaust system diagram, functions as a reservoir of sorts to prevent water from flowing up toward the turbo or exhaust manifold.

which increases the load on the engine compartment's ventilation system, and increases the risk of damage to gear within the engineroom—and even crew injury or fire if it's not installed properly. It may be impractical in very small engine compartments.

Whichever system is used, once water is injected into the exhaust-gas stream, it must be cooled enough so hose and fiberglass tubes are not damaged. While there is a 200°F allowable threshold for exposed portions of the entire system, typically the exterior of the wet portion of the exhaust should operate at a much lower temperature, in my experience at or below 150°F (65.5°C). At higher temperatures, components such as hose and fiberglass tubing may suffer damage as resin can be burned off, leaving the tubing porous. Properly designed and operating wet exhaust components typically operate at somewhere between 90°F and 160°F (32°C and 71°C).

Every wet exhaust system should be equipped with an overheat alarm, which will sound well *before* damage occurs; most alarms trigger at approximately 165°F (74°C). If the system is routinely operating at a higher surface temperature—indicating a design or installation flaw such as inadequate water flow or mixing, or engine-

Far left—*Any portion of an exhaust system that can be touched must be insulated to reduce the temperature to 200°F (93°C) or less. A common scenario, this new engine's dry exhaust insulation is too thin, and incomplete.* ***Left—****Overheating nearly always damages wet exhaust parts, like the fiberglass tube shown here. The resin has been cooked off, leaving the tube porous and weak.*

explosion—or use a hand pump (such as a new, unused for fuel, outboard fuel hose) to draw as much water as possible out of the cylinders, and then slowly turn the engine over *by hand.* Do not crank the engine with the starter, as this rotation may be too quick to allow water to be pushed out of the cylinders, which may damage valves, connecting rods, or pistons. The water may be ejected with some force, so cover the injector or plug ports with a rag, and stand clear of their line of fire. This will pump the water out of each cylinder.

For gasoline-powered vessels, use extreme caution when clearing water from cylinders, as gasoline vapors can be ignited by "live" unattached spark plug wires or by even the smallest spark. The fuel supply should be turned off, and primary power supply to the ignition system/coil should be disabled whenever the engine is cranked, with spark plugs and/or wires removed or detached.

Once most of the water has been removed, crank the engine with the starter. When no more water exits the injector/spark plug holes, pour or squirt clean crankcase oil into each cylinder (no more than a tablespoon, as more may cause oil hydrolocking). Then turn the engine over a few times by hand, and replace the injectors/spark plugs. With the starter, turn the engine over a few times with the fuel supply turned off and the stop lever or solenoid engaged or ignition system disabled to prevent starting. This will force oil past the rings, lubricating them before the engine is started. If water has made its way into the crankcase, which is likely, the level will be higher than normal. Change the oil and filter at least *three times* or until all signs of water have been eliminated (crankcase oil mixed with water has a milky appearance). Operate the engine for 10 minutes under no load and in neutral between oil changes.

—Steve D'Antonio

Engineroom Ventilation

While high surface temperatures are usually the result of insufficient insulation, they may also indicate inadequate engineroom ventilation. A few years ago, I determined during the sea trial of a newly repowered vessel that the dry riser, which was insulated with a hard-coated material, was reaching temperatures in excess of 280°F (138°C). The refit yard and exhaust system manufacturer's engineers crunched some numbers and concluded that the engineroom air-turnover rate was insufficient, even though the difference between the combustion intake and ambient air temperature was below the engine manufacturer's threshold delta of 30°F (17°C). Consequently, once they installed a higher-capacity engineroom extraction fan, along with two smaller fans to more thoroughly distribute air, the dry-exhaust surface temperatures dropped below the 200°F threshold, and no further changes were required. (See "Venting the Engineroom" on ProBoat.com.)

—S.D'A.

room ventilation issues (see **sidebar**, above)—the alarm will be of little use, because it will sound under normal operating conditions.

The dry portion of an exhaust system, whether a dry, wet, or hybrid design, should be equipped with a port, typically a threaded ¼″ or ⅜″ NPT hole, to measure exhaust system back-pressure and temperature. (The plugs that fill these holes are notorious for seizing; be sure to periodically remove them.) Without this port, it is impossible to confirm whether an exhaust system meets an engine manufacturer's requirements for back-pressure, while exhaust gas temperature readings can determine proper loading. Many engines are unknowingly operated under excessive back-pressure conditions, which can diminish wide-open throttle rpm, wasting horsepower. This is often mistakenly "corrected" with a reduction in propeller pitch. Additionally, the correct back-pressure is required for warranty compliance on new engines, as well as for ensuring that engines operate within their mandated emissions limits.

It's common for wet exhaust system designs to include a "performance-enhancing" raw-water valve system that diverts some cooling water overboard rather than into the exhaust system. More water in the wet exhaust system than is necessary for cooling means more effort/horsepower must be expended to expel it. After the valve is adjusted to ensure that the exhaust system will not overheat *throughout the rpm range* (wet exhaust systems often overheat at a lower rpm range because less water is being pumped into the system), the valve handle must be labeled as well as locked or removed to prevent inadvertent adjustment.

On a valve that diverts some cooling water overboard, a placard should warn against the adjustment being unknowingly changed. The handle can also be removed.

Left—*Frequently, back-pressure measurements are dismissed as unimportant. Because excessive back-pressure is simply wasted horsepower, it's often incorrectly compensated for with propeller adjustments. However, exceeding manufacturer guidelines can affect emissions and void warranties.* ***Right—****To measure back-pressure, the exhaust system must be equipped with a test port in the dry section between the turbo/exhaust manifold and riser.*

Materials

Many injected elbows are made of cast iron, which is prone to rust and scaling. This leads to internal and external leaks, and debris that can block the injection water and cause the elbow, engine, and even the entire exhaust system to overheat. I've encountered cast-iron elbows that failed after just 300 hours, so frequent close inspections are necessary to check for cracks, burns, and weeping, as well as discoloration or plasticization of the hose immediately downstream of the injection elbow—the precursors of potentially catastrophic failures.

Homemade risers and mixing elbows frequently prove unreliable, primarily

Above—*This welded exhaust pipe was located in the "splash zone." After remaining wet at all times, its mitered weld failed under only light pressure. Wet exhaust components should instead rely on nonmetallic materials such as fiberglass.* ***Right—****Many stock mixing elbows are made from cast iron. While cheap and strong, it's not known for longevity.*

at the interface between wet and dry sections, and because water is often injected by a single tube. As noted earlier, injected water should be sprayed around the exhaust-gas stream.

If off-the-shelf pipe is used for an exhaust system's dry components, it must be Schedule 80 and, ideally, welded at the joints. Often components are fabricated with black iron pipe, which is inadvisable, as its life span rarely exceeds a few years. Galvanized steel pipe, regardless of schedule, lacks ABYC compliance for any portion of a dry exhaust system. See the **table** on the next page, from ABYC P-1, for details of approved exhaust system materials for dry and wet applications. If a material is not included in the table, it is not approved.

One particular concern about a jacketed riser or mixing elbow is the potential for galvanic corrosion caused by contact with incompatible metals. With a few manufacturer-approved exceptions, galvanic corrosion can result if a copper alloy such as a bronze nipple or pipe-to-hose adapter is screwed into the injection port of an aluminum elbow or riser; and brass, because of its propensity to dezincify, should never be used in raw-water applications, including parts as seemingly innocuous as drain plugs.

Bronze and stainless steel, seemingly desirable materials for a jacketed riser or injected elbow, have drawbacks. Bronze, a copper alloy, is rather soft and can be damaged by sulfuric acid (formed when the sulfur in diesel fuel mixes with water). Copper alloys are particularly susceptible to a phenomenon known as erosion corrosion, a failure you may find in an injected elbow constructed of ordinary bronze or, worse, leaded red brass pipe.

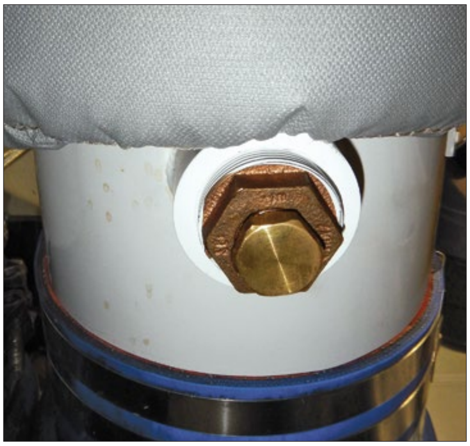
Some cast-bronze injected elbows have proven to be reliable; however, you should choose only those from reputable manufacturers that have been in the exhaust business for some time.

Although stainless steel is less susceptible to erosion corrosion, it may still suffer from crevice corrosion. That occurs when stainless steel remains in contact with stagnant, oxygen-depleted water, often found in exhaust systems left idle for extended periods, which can be exacerbated by exposure to sulfuric acid. It also occurs in stainless steel mufflers and other exhaust system components. Only the most corrosion-resistant alloy, such as 316L (the L denotes "low carbon,"

Exhaust System Materials

	Gasoline Engines		Diesel Engines	
Components	**Wet Exhaust**	**Dry Exhaust**	**Wet Exhaust**	**Dry Exhaust**
Exhaust pipe	aluminum	aluminized steel	aluminum	aluminized steel
	brass pipe	carbon steel	fiberglass	carbon steel
	copper-nickel	nickel-iron-chrome	galvanized steel	nickel-iron-chrome
	copper tubing	316L stainless steel	galvanized wrought iron	316L stainless steel
	enameled steel		nickel-copper	
	fiber-reinforced plastic		nickel-iron-chrome	
	galvanized wrought iron		316L stainless steel	
	nickel-copper		synthetic rubber hose	
	nickel-iron-chrome		copper-nickel	
	316L stainless steel			
	synthetic rubber hose			
Silencer or wet exhaust waterlift chamber	cast iron	aluminized steel	cast iron	aluminized steel
	copper	carbon steel	enameled steel	carbon steel
	enameled steel	nickel-iron-chrome	fiber-reinforced plastic	nickel-iron-chrome
	fiber-reinforced plastic	316L stainless steel	nickel-copper	316L stainless steel
	nickel-copper		nickel-iron-chrome	
	nickel-iron-chrome		reinforced plastic	
	reinforced plastic		316L stainless steel	
	316L stainless steel		synthetic rubber	
	synthetic rubber			
Engine flexible section	copper	carbon steel	copper-nickel	carbon steel
	copper-nickel	nickel-iron-chrome	nickel-copper	nickel-iron-chrome
	nickel-copper	316L stainless steel	nickel-iron-chrome	316L stainless steel
	nickel-iron-copper		316L stainless steel	
	nickel-iron-chrome			
	316L stainless steel			
	synthetic rubber			
Pipe connection	synthetic rubber	flanged, screwed, or welded	synthetic rubber	flanged, screwed, or welded
	flanged, screwed, or welded		flanged, screwed, or welded	

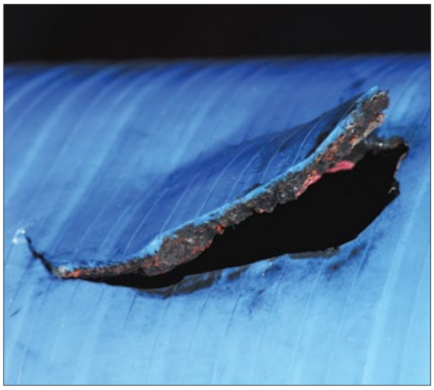
COURTESY ABYC



Far left—*Brass plumbing components have no place in wet exhaust systems, as brass tends to dezincify (the zinc corrodes, leaving a porous copper shell).* ***Left***—*For wet exhaust systems, the less metal the better, with as few welds as possible. There's no reason this part could not have been made from fiberglass.*

making it suitable for welding), should be utilized in wet exhaust systems, and it should be inspected frequently for signs of corrosion or leakage. Ideally, metallic exhaust system components, especially stainless steel ones, should be self-draining. Note that alloy 304 stainless steel is *not* approved for use in any part of an exhaust system, diesel or gasoline, wet or dry. (See "The Power and Peril of Stainless," PBB No. 146.)

A more suitable material is Inconel (also called Incoloy, or 25-6). This nickel-chrome-iron super-alloy is strong and highly resistant to corrosion even at its welds. (It can be found in power plants, gas-turbine engines, and nuclear submarine propulsion systems.) In my experience, it's superior to all other metallic exhaust system materials, including iron, bronze, copper-nickel, and 316L stainless steel. I have yet to encounter a corrosion-related failure with it. Like most exotic and semi-exotic alloys, it's more costly, and it requires specialized



Overheated exhaust hose is typically caused by water starvation or design flaws. This hose failure was the result of a mixing elbow with an angle too close to horizontal.

welding skills; thus, not all exhaust system fabricators are acquainted with its use.

The ideal system has as little metal as possible. Welds should be kept to a minimum. While it's not (yet) possible to manufacture a nonmetallic injected elbow or riser, many proprietary waterlift mufflers, gas/water separators, and tube/pipe/plumbing components are constructed of fire-resistant fiberglass. Not all off-the-shelf fiberglass or plastic components meet ABYC P-1.7.1.5/UL 1129 standards, which is required because they may be exposed to short-duration dry exhaust if the flow of cooling water in the engine or exhaust system is interrupted. The latter scenario, when brought about by the failure of an exhaust-cooling-water hose, is particularly insidious. The engine will not overheat or sound an alarm, even though portions of the wet exhaust system that are normally exposed to comparatively low temperatures of 150°F–200°F are now enduring searing heat as high as 1,000°F (538°C). Additionally, fiberglass pipes in wet exhaust applications should be equipped with embedded metallic anticrush rings to prevent damage from hose clamps.

System Support

Because exhaust systems tend to be heavy, they must be properly supported. Most engine manufacturers are clear on the maximum weight that can be supported by an exhaust manifold or turbocharger output flange. Some engine manufacturers limit turbo flange loading to the weight of the turbo, while others specify that the turbo flange should support no weight. Improperly supported exhaust systems can lead to exhaust leaks or, worse, flange failures. Those can be especially catastrophic because there may be no immediate indication of an exhaust failure while the engineroom fills with exhaust gases and hot, atomized seawater.

Far left—*Dry-exhaust-component misalignment, or inadequate support, can lead to catastrophic and costly failures of the system.* ***Left***—*Tube stock with flattened ends, which are prone to stress failure and not easily adjustable, is a poor choice to support metallic risers.*

Additional supports will be necessary for all but the shortest engine-manufacturer-supplied exhaust risers. Choose those that utilize screw thread adjustments and articulating heads. Avoid supports that rely on tube stock with flattened ends; they are prone to cracking and are virtually impossible to size with the precision required to ensure proper flange loading. Ideally, because most engines are soft-mounted (and move independently of the vessel), such supports are attached to the engine or transmission; this ensures that the entire rigid metallic exhaust riser/mixing elbow/engine assembly moves in unison when the engine vibrates or shifts gears. The transition from the engine-supported metallic exhaust to the wet exhaust, attached to the hull, should be with a very flexible section, often silicone "hump" hose.

Larger, longer exhaust systems that are suspended from the overhead and do not move in unison with the engine must include a flexible, metallic, typically corrugated "wrinkle belly" pipe section, which absorbs the difference in movement between a soft-mounted engine and the vessel's structure.

Large, heavy systems should include shock mounting to prevent vibration from being transmitted to the vessel's structure. Choose either

Risers rigidly attached to an engine must be supported to ensure that both move in unison. The struts shown here achieve this goal elegantly with adjustable, articulated ball ends.

flexible bushings of an appropriate hardness for the weight being supported or sprung brackets for overhead support.

All exhaust system supports, particularly those with brackets welded to dry portions of risers, must be adequately insulated or isolated so they will not become a burn hazard or ignite nearby combustible material such as timber, fiberglass, or insulation. These too are subject to the 200°F-threshold guideline. I routinely record temperatures in excess of 400°F (204°C) on brackets without adequate isolation or insulation under heavy engine loads.

Exhaust Gases and Monitoring

The importance of keeping exhaust gases out of the cabin and accommodation spaces cannot be overemphasized. Any exhaust leak, whether it's from a diesel- or gasoline-powered engine, is dangerous. The exhaust plumbing must be continuously gastight from the engine to the through-hull discharge, which ideally should be located at the intersection of the hull and transom or as far outboard as practical in the transom. *Nothing*—no other exhausts, or deck, HVAC discharge, bilge pump, or other drains—should be plumbed into this line.

Exhaust runs that discharge through the hull side should include a deflector just forward of the exit, to induce water to flow away from the exhaust opening. I've encountered cases where water is forced into an exit, particularly of an engine or genset that isn't running, when the vessel is at an

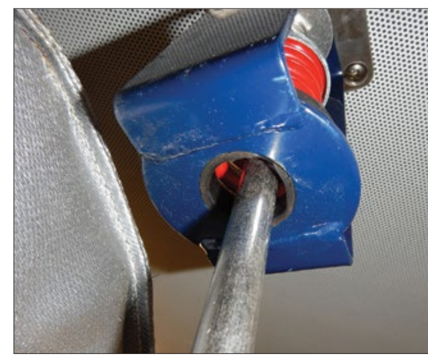
Exhaust systems can serve as a means of transmitting vibration through a vessel's structure. Silicone hump hose is one way to isolate the two.

unfavorable attitude or in the planing transition phase.

Every inboard-powered vessel should be equipped with carbon monoxide detectors in every sleeping or accommodation space, and be in compliance with ABYC A-24 "Carbon Monoxide Detection Systems." (For more on CO detectors, see my recent article on liquefied petroleum gas systems, "Best Gas," PBB 169.) Even on vessels that have no CO-producing systems, people have been killed by the gas drifting downwind from a vessel whose generator is running, and into an open hatch or port aboard the victim's vessel.

Wire the CO detectors so that they cannot be inadvertently turned off with a panel switch or circuit breaker. Using a fuse or protected circuit breaker, wire it directly into the vessel's "24 hour" bus, one that is continuously energized. Alternatively, CO/smoke detectors powered by an internal battery may be used; however, batteries must be replaced regularly. (For more on CO and smoke detectors, see "Where There's Smoke," PBB No.137.)

Wet-exhaust-system-temperature monitoring is among the most commonly overlooked of ABYC standards.



When supporting larger dry sections of exhaust components with overhead sprung brackets, align the support's shank so it does not make contact with the unsprung portion of the bracket.

Exhaust temperature alarms are comparatively inexpensive and well worth the investment; on many occasions, clients have told me that such alarms saved their boats from significant damage and expense.

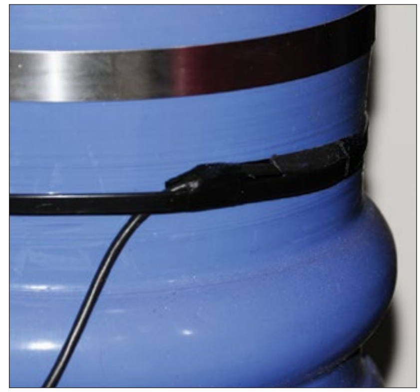
Many mixing elbows are equipped with mounting pads for surface-temperature-sensor installations. While these pads are convenient and tempting to use, it takes a long time for an elbow to heat up because of its mass and jacketed design. The approach I've come to trust over hundreds of installations relies on a nonwater contact thermistor strapped to the *exterior* of the exhaust *hose* immediately downstream of the mixing elbow.

Because it's highly sensitive and quick-acting, the thermistor will register a temperature increase on the surface of the hose (the preferred threshold is 165°F) long before any damage occurs, and long before the engine overheats, assuming engine cooling water flow has also been interrupted. An externally mounted thermistor requires no holes in the exhaust plumbing for installation, and it will not deteriorate, as it's not exposed to hot seawater and exhaust gases. Yet another benefit is it can be easily tested; this should be done annually with a heat gun and infrared pyrometer.

It's not unusual for users to inadvertently test thermistors if they forget to reopen the engine's water-supply seacock after checking and cleaning seawater strainers. In most cases, the alarm will sound within 30 seconds of starting the engine, enabling operators to shut down the engine long before the exhaust system and, in many cases, even the raw-water pump impeller are damaged.

In this installation, the builder wisely included a flare to divert water away from the exhaust discharge while under way. Flares are especially important for engines not running while under way, such as generators, sail auxiliaries, and wing engines.

One final and vitally important lesson about exhaust systems: always follow engine and generator manufacturer



Far left—*It takes longer for heat to reach a wet-exhaust temperature alarm mounted on a jacketed, double-wall mixing elbow, delaying detection of cooling water loss.* ***Left***—*With a threshold of 165°F (74°C), a thermistor strapped to the hose immediately downstream of the mixing elbow should react in less than 30 seconds.*

guidelines. Manufacturers typically have very specific exhaust system requirements. Make sure you understand those for the engine you are working with, and don't assume an exhaust system design is correct just because it's original equipment. In the rare cases where an exception is sought (virtually unheard of), it should come only from the engine manufacturer, not a dealer, and it *must* be in writing.

Failure to follow such guidelines could lead to engine damage or, worse, exhaust leaks and the health hazards they pose, or to exhaust system overheating, flooding, and fire. Most likely this damage won't be covered by warranty. Every engine and generator manufacturer I know excludes from coverage water entry into cylinders via the exhaust system.

PBB

About the Author: *For many years a full-service yard manager, Steve now works with boat builders and owners and others in the industry as Steve D'Antonio Marine Consulting. He is an ABYC-certified Master Technician, and sits on that organization's Engine and Transmission and Hull and Piping Project Technical Committees. He's also the technical editor of* Professional BoatBuilder.