Cool and Quiet and Trouble Free

Guidelines for Evaluating and Installing Wet Exhausts

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The most popular sailboat exhaust system today is a wet exhaust system which includes a waterlift muffler. This system offers many advantages and seems deceptively simple. Almost all engines are cooled with seawater, either directly or though a heat exchanger. The seawater must be discharged after it has picked up the engine heat, so it is logical to inject it into the engine exhaust. This cools the engine exhaust so it can be routed through the boat without too much concern for the parts of the boat that it passes near and through. Wet exhausts are the best choice for the majority of sailboats, but they can cause trouble if not properly designed, installed, and maintained.

At first glance it looks like all that is required is to plumb the parts in series in the proper order. That approach, however, will likely cause trouble.

We assume that naval architects and boat builders know how to design and build a wet exhaust system. We speculate that wet exhaust problems have come mainly from boats that have been modified during repair, or converted from other types of exhausts by owners or technicians who did not thoroughly understand wet exhausts. That could easily happen for two reasons. First, not all boats are configured to allow a system to be installed which complies with the guidelines; and second, the requirements are more complicated than they appear.

The following outline lists common wet exhaust fault modes. The most serious problems with wet exhausts involve seawater working its way back into the engine, where it gets into the cylinders and flows past the rings into the crankcase. This kind of water penetration may require engine rebuilding or replacement. In extreme cases after flooding the engine, a defective system can even flood and sink an unattended boat.

Water in engine fault modes
(See Figure Four.)

1. Siphon faults
    1. Water siphons from the cooling water seacock past the raw-water pump into the injection elbow when the engine is off. It fills the muffler and floods the engine.
    2. Water siphons backward up the exhaust piping, fills the muffler, and floods the engine.
2. Heavy weather faults
    1. Following seas force water back up the exhaust system where it fills the muffler and floods the engine. The use of a stern-deployed drogue can aggravate this problem.
    2. The boat heels or pitches enough to make the muffler higher than the engine, so water flows from the muffler into the engine.
    3. The boat pitches enough to get the raw-water intake out of the water frequently and for long enough periods to starve the exhaust system of the cooling water it needs causing the plastic and rubber parts to overheat and fail. Dan and Cathy Haupert (featured in this issue on Page 24) had this problem in heavy weather aboard the Catherine L.

Other failure modes

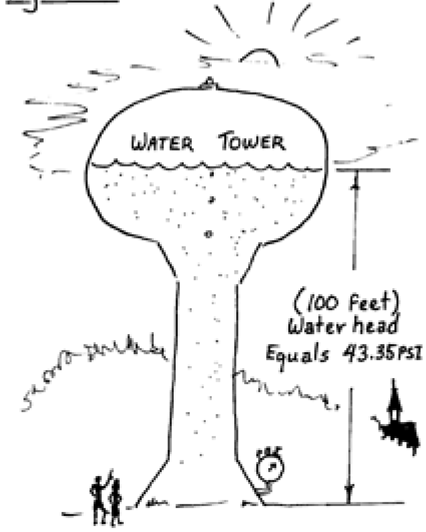
1. The raw-water circuit fails from:
    1. Plugged intake.
    2. Plugged raw-water filter.
    3. Pump impeller failure (most likely of all failure modes).
    4. Plugged water line from pump to injection elbow (pieces of impeller).
    5. Plugged injection elbow (rust, scale, pieces of impeller).

If the raw-water circuit fails, the exhaust system will overheat very quickly. Most of the exhaust parts on most boats will not withstand the overheating caused by a raw-water system failure. The following can occur before the engine overheats enough to get your attention:

a. Hoses burn out.
b. Muffler melts, if plastic.
c. Muffler liner separates, if plastic or rubber- coated steel.

1. Corrosion can cause failures of
    1. Injection elbow.

Figure Two: WATER HEAD



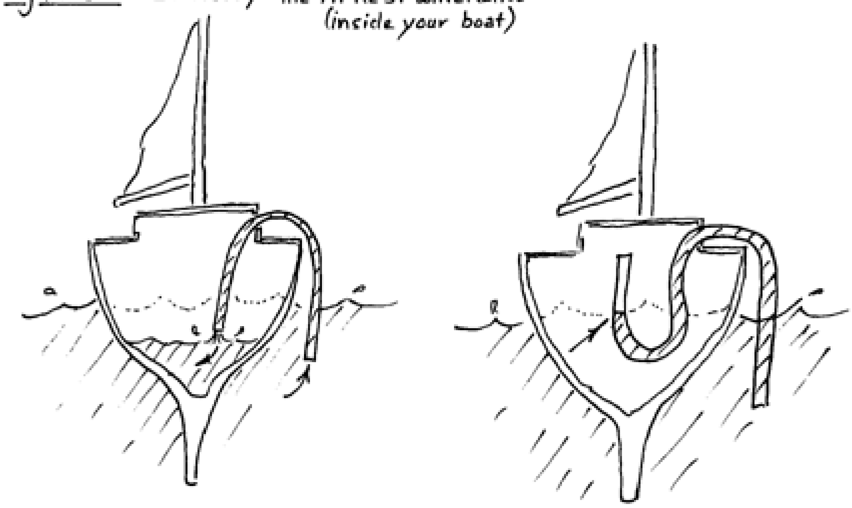
    2. Exhaust hose (it is wire-reinforced).
    3. waterlift muffler(if steel).
2. Freeze damage
    1. If the muffler is steel.

Wet exhausts are not foolproof, but given proper design, installation, and maintenance, they are a good choice for most sailboats.

Siphoning, velocity pressure, water head

Siphoning, velocity pressure, and water head (pressure) are three concepts that are important in understanding wet exhausts.

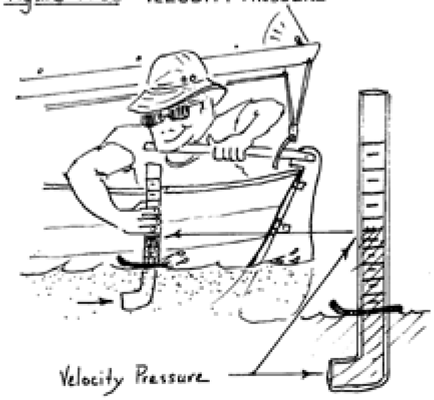
Figure One: SIPHON / THE AT-REST WATERLINE (inside your boat)



Siphoning will occur when you put a small hose overboard, suck on it until it is full of water, and then bring the inboard end into your boat below the water level. (See Figure One.) The water will flow up the hose and down the other side, filling your boat until it sinks. No pumping is required. Any bilge pump thru-hull that is ever below the waterline can cause siphoning after the bilge pump fills the piping with water. The pump shuts off, and the flow reverses. This is a fairly common problem. Think in terms of the heeled waterline, the waterline with full cruising stores, the waterline when the boat squats under power, or a combination of these factors.

Water head is a way to describe the pressure in a system. In this term, the word head equates to height. The pressure at the base of a water tower is a function of the height of the water in the tower. (See Figure Two.) Sometimes very low pressures are described in terms of inches of water column. These pressures can be converted to pounds per square inch, which is the more familiar unit of measure. The conversion is 27.68 inches of water column equals one psi.

Figure Three: Velocity Pressure



Velocity pressure is a way of expressing the speed of a fluid in terms of the pressure it causes when it strikes something. This phenomenon is used to make simple speed-measuring devices that measure the height of a column of water caused by the velocity of the water flowing past it. (See Figure Three.) Note, six knots is equal to a velocity pressure of about 19 inches, and in Figure Three the pressure is measured directly in inches of water column.

Figure Four shows a complete wet exhaust system and is similar to other diagrams published on this topic. The discussion which follows is absolutely unnecessary if you have a boat that allows the specified features, including dimensions, to be followed faithfully.

The important point is that some good old boats were not designed with this type of exhaust system in the first place, and either their machinery spaces will not allow the installation of this type of exhaust per the specifications of Figure Four, or the persons making repairs or modifications did not completely understand the requirements. You may want to check your boat to see how closely your current layout complies with the requirements of Figure Four.

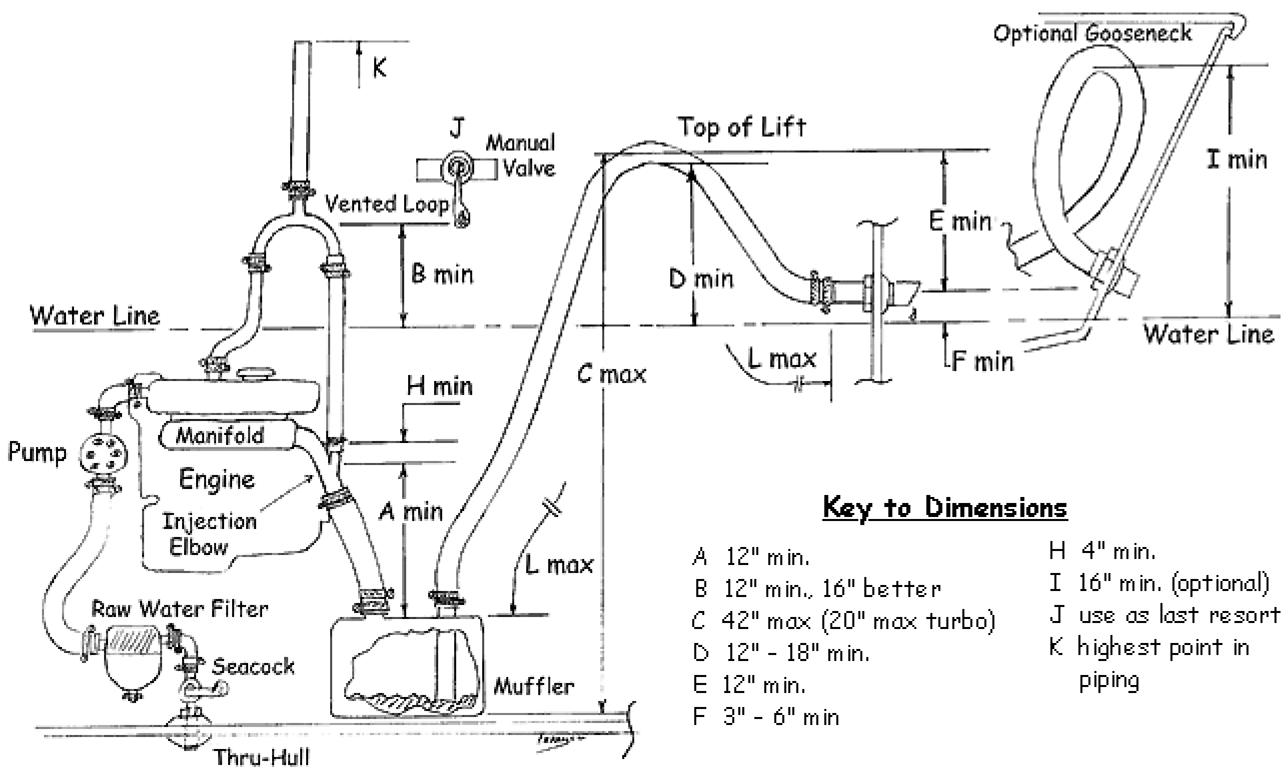
In studying your boat and the diagram, note that features are positioned relative to each other and relative to the waterline. You can find the waterline in your machinery space by making a siphon like the one shown in Figure One. Remember you are finding the at-rest waterline by this method. Sailing, heeling, powering, pitching, and rolling will all change it.

Now let's follow the water into the boat and back out again. The water enters by a thru-hull and seacock and flows through a raw-water filter. The thru-hull may include a scoop. If there is a scoop, it will develop some velocity pressure when the boat is moving. (Six knots produces about 19 inches of water column pressure.) An allowance may be needed when considering other aspects of the system design if there is a scoop facing forward. Some systems are built without the filter, but it is a good investment because it protects the raw-water pump. The water flows through the raw-water pump and either through a heat exchanger or two, or through the engine itself. After leaving the engine, it is discharged into the exhaust.

The injection point should be 4 inches (minimum) below the exhaust manifold exit point. (See Dimension H on. Figure Four.) This distance is required to keep the steam and other nasty chemicals created at the injection point from attacking the exhaust valves. The engine manufacturer knows this and will provide an arrangement that protects the engine.

The injection point must also be located relative to the waterline. If it is high enough above the waterline, a vented loop is not required. The minimum height varies depending on which authority is consulted. We found minimums from 6 to 16 inches recommended. This may be because a scoop at the thru-hull can raise the water level in the piping, leading to the injection point when the boat is sailing (engine off). In addition to allowing for velocity pressure, it is necessary to allow for maximum loading, rolling, and pitching motion

Figure Four: Dimensions



If the injection point is closer to or below the waterline than the allowance, there is the potential for a siphon to form. This siphon is prevented from forming if the raw-water pump does not leak. There is the risk, however, that it will leak. Small leaks may occur at the rotor sides or tips, and the common failure mode for this pump is for the lobes on the impeller to break off and be carried downstream to do mischief elsewhere in the system. The lobes don't all break off at once, so the pump may deliver enough water to keep the engine cooled, but it will leak when the engine is not running. Even a fairly small leak can, over time, flood the muffler and then the engine.

The vented loop shown in Figure Four breaks this siphon. The top of the arch of the loop should be at least 6 inches above the waterline. Some authorities say 12 inches minimum, with 16 inches being better. Remember, if you have a scoop at the thru-hull, it will raise the level of the water in this part of the system by virtue of its velocity pressure. As mentioned above, depending on how fast your boat is, you need to allow for this. At the top of the arch of the vented loop there must be either a siphon break valve, or an additional tube extended from a tee.

In saltwater service, the siphon break valve may become clogged with salt crystals and either become inoperative (not break the siphon) or leak constantly. The constant leak failure mode can result in spraying seawater around in the machinery space. This seawater is needed to cool the exhaust. For these reasons, some authorities recommend dispensing with the siphon break valve and locating a tee in the line vented higher up, such as in the cockpit.

Even if there is a tee, with a tube extending from it to a higher location, it is necessary for the top of the arch in the vented loop itself to be positioned 6 to 16 inches above the waterline. If it is not, a siphon may still form in some circumstances. In other words, extensions from the tee don't count against the 6 to 16 inches requirement. The extension tube from the tee should extend higher than any other point in the system. This can be a problem in some boats.

Before we leave this part of the system, we should mention that a cranking engine is pumping water into the exhaust system. If it cranks a lot and does not fire, the muffler may fill up with water and eventually flood the engine. Some authorities recommend closing the cooling water seacock during prolonged cranking such as when bleeding air out of injectors, the first start after lay-up, or when troubleshooting a reluctant engine. As soon as the engine starts, quickly open the seacock again. If the muffler has a drain, it could be left open instead until the engine fires and then be quickly closed.

The distance from the injection point to the muffler inlet is specified by various authorities as 10 or 12 inches minimum. This is intended to be both a minimum length and a minimum vertical distance. We think that on some significant number of good old boats this is the dimension that will be most difficult to comply with.

On *Mystic* (Jerry's C&C), the machinery space will not allow the muffler to be much lower than the exhaust outlet because the bottom of the boat slopes up sharply behind the engine. Worse, the boat was designed for an Atomic 4, which has the exhaust on the port side. The Bukh Pilot 20 diesel that was fitted later has the exhaust on the starboard side. The original muffler platform was used, so the muffler is on the opposite side from the exhaust. Moving the muffler platform would have been complicated because the cockpit drain and raw-water thru-hulls and seacocks occupy the space where the muffler should go on the starboard side. That may be why the mechanics who did the conversion to diesel did not put the muffler on the same side as the exhaust. When our boat heels to starboard, the muffler is elevated above the engine, providing an opportunity for it to pour water into the engine.

Ideally, the muffler would be mounted directly behind the engine exhaust so it is not elevated above the engine as the boat heels. We were told by one knowledgeable person that Dimension A is also the minimum distance the exhaust gases must travel to ensure that they are cool enough to enter a plastic muffler without damaging it. This seems logical. All the cooling will not occur at the exact point of water entry, and the process of heat exchange will take some time, and therefore distance, to be completed.

As we said, the space for an 8 to 12 inch (minimum) vertical drop from the engine to the muffler is not available on some boats. There are two possible solutions to this problem: both involve some manner of exhaust riser. Where a short riser is required, engine manufacturers can provide an exhaust riser that is a water-jacketed exhaust pipe which lifts up and turns back down. After the downturn, the jacket water is injected. Contact your engine manufacturer about this option. If you have room for it, it may be a very good way to obtain the minimum drop distance.

Where a larger lift from the manifold is required, it may be necessary to run a dry unjacketed (very hot) insulated pipe to another location, where either a conventional exhaust elbow is fitted or a standpipe is used. See the companion article by Dave Gerr on Page 20 which deals with several special versions of wet exhausts that can be used to overcome layout problems. Remember as you contemplate variations on this theme, when the flow reverses, the drop becomes a rise, and this rise is what protects a flooded muffler from dumping into the exhaust manifold when water backs up in the hose leading from the muffler to the exit.

Dimension C is the vertical rise from the bottom of the muffler to where the hose turns back down. This is the lift. We found maximum dimensions for this lift of 40 to 48 inches, with 20 inches being cited for turbo-charged engines. Some literature seems to suggest that the height of the lift determines the exhaust back pressure in some simple way so that (for example) a 48-inch lift would give a 48-inch water column back pressure. It seems logical that if there were enough water in the muffler to fill the lift pipe, and if the pressure were slowly increased on the engine side, as perhaps in a case of cranking and not firing, this reasoning might pertain. Once the engine is firing, however, it is doubtful that there would ever be a solid column of water in the lift pipe. With exhaust gas flowing in the lift, much more complex things are happening. The flow in the lift is probably a chaotic mixture of gases and liquids. One source said that engine manufacturers know this and are not too worried about this maximum lift dimension. In individual cases, it would be best to contact the engine manufacturer and follow the manufacturer's guidelines.

Ideally, the hose from the muffler exit to the top of the lift is vertical, not slanted. The reason for this is that a vertical pipe achieves the maximum rise with the least volume. The concern here is that the water in the lift pipe will fall back into the muffler when the engine shuts down. This is a critical issue. The muffler volume must be large enough to accept the water that falls out of the lift pipe. The rule of thumb is that the muffler should have at least 130 percent of the volume of the lift pipe. Note here that if the muffler is fairly well filled from water falling back from the lift pipe, it is much more likely to cause mischief in other ways. At the upper end of the lift pipe the exhaust hose should slope down toward the exit thru-hull. Note: the intent is that everything from the top of the lift pipe either drains to the muffler or drains overboard. At least that is the way the story goes for a system without an exit gooseneck. Some authorities go so far as to say that there must be no sags in the sloping pipe from the top of the lift to the exit thru-hull. The sags would allow some water to be trapped, while a straight sloping pipe would drain overboard.

The alternative gooseneck shown in Figure Four is a variation sometimes seen where there is not only a sag, but in fact a large trap. The hose loops down and back up and down again. The gooseneck provides some added protection from pooping seas by forcing the water to lift up the gooseneck to get into the system. We found one reference that suggested a minimum dimension of 16 inches from the top of the gooseneck to the waterline. One manufacturer makes a plastic gooseneck that looks like it might take less space than a looped exhaust hose. Because the price of exhaust hose is fairly high, it might be less costly as well.

Returning to the top of the rise again (See Dimension D), the minimum dimension from the top of the lift to the waterline is 12 inches. More is better, and 18 inches is recommended by some authorities. Dimension D should be viewed as a minimum vertical dimension. Its purpose is to provide resistance to water flowing back up the hose to the top of the lift and then falling into the muffler.

The exit thru-hull should be located above the waterline. Suggestions for this dimension vary from 3 to 6 inches to the centerline of the exhaust pipe. (See Dimension. F.) The reason it is desirable for the exhaust to exit above the waterline is so it can't create a siphon. The reason the outlet is not located very high, just below deck level for example, is to help prevent exhaust fumes from coming back into the boat. Because it is fairly low however, it will be submerged by waves, and the pitching motion of the hull. The American Boat and Yacht Council (ABYC) recommends that the outlet be located near the intersection of the hull and transom because this also helps prevent exhaust fumes from getting back into the boat.

The total length of the piping from the muffler to the exit is shown as Dimension L. Very long piping runs increase back pressure. This hose should have a length of less than 30 times the exhaust line diameter as it enters the muffler from the engine. For example, for a 1.5-inch diameter hose, the run shouldn't be over 45 inches total length from the lift outlet to the thru-hull. This run is commonly much longer than 48 inches. If the run has to be longer, you may need to make the hose diameter larger. (These long runs and larger hoses will also require a larger muffler canister.) For runs up to 60 times exhaust diameter, increase the hose diameter by 20 percent. Still longer runs are possible, but you must increase diameter still more and check with the engine manufacturer about the maximum acceptable back pressure. As with any exhaust, you should use as few bends as possible with the largest radii possible; tight bends also increase back pressure.

If, when inspecting your system, you find that your hoses are too long and should be larger in diameter according to the rules of thumb just mentioned, it would be a good idea to get an opinion on your specific system from your engine manufacturer. You may even want to check back pressure in actual operation before buying all that new larger diameter hose.

Feature J on Figure Four is a valve which is intended to be closed when sailing in rough seas. It should be able to withstand the temperatures involved (200 degrees Fahrenheit minimum) and should be located where it can easily be reached in rough weather. For this reason, it is unlikely to be located at the thru-hull and should not be thought of as a seacock. While we understand the intent of this valve, we have the following concerns about its installation and use:

1. It is not a passive device that tends to work automatically. The crew must close it when conditions warrant and must open it before starting the engine.
2. If the crew tries to start the engine with the valve closed, the best thing that could happen is for the engine not to start.

For these reasons, we consider the valve as an option of last resort to be used only if the geometry of the boat does not allow a layout that can function properly without it.

Mysteries and nuances
With the engine off:

Imagine the boat being pushed down by the stern so the exit thru-hull is submerged. Or imagine the exit thru-hull being slapped by a large wave. Combinations of these two cases will occur when the boat is pitching in a large following sea. We speculate that some interesting things will happen in this situation.

A trapped air pocket will form in the tube between the muffler and the exit. The pressure of the pocket will be a function of how fast the waves hit the stern, and how deeply the stern is pushed down by pitching. In the worst case, velocity pressure and water column pressure will add together. It is not unreasonable to assume 10 knots for the wave velocity (it takes only Force 6 for this) and, thus, 51 inches of water column pressure increase. If the stern is pushed another 6 inches below the water, the total reverse pressure would be 57 inches of water column pressure.

Now let's return to how full the muffler is when the engine shuts off and the water in the lift column falls back into it. If the muffler is not very full, air is pushed into it and out the inlet toward the engine. If seawater did not manage to push its way to the top of the lift column, the muffler does not gain any water, and the water in the sloped section from the top of the lift drains back out, ideally before the next pitch/wave slap.

If the muffler is nearly full, the pressure in the piping downstream of the muffler will force water, not air, out the muffler inlet toward the engine. Now consider Dimension A again. If this dimension is a vertical dimension, the water must lift against gravity to reach the engine. If it is a sloping horizontal dimension, the lift is not great, and the engine is more likely to be flooded. The dimension should be a vertical dimension, but in some boats that is not possible.

Figure Four shows an alternative in which a gooseneck is located at the end of the piping before the exit thru-hull. One manufacturer cites a minimum dimension of 16 inches from the top of the gooseneck to the waterline. With a gooseneck at the exit, the water must lift against gravity to the top of the gooseneck before it can enter the system to stay. This seems like a very positive improvement.

Significance of dimensions

Dimension A

12-inch minimum vertical, 12-inch minimum total, sloped downward 1/2-inch per foot minimum. (The slope is not likely to be this small if the other criteria are met.)

Minimum vertical dimension from the injection point to the top of the muffler. (Also) minimum total distance from the injection point to the top of the muffler.

Significance:

When the engine is running, this minimum total distance gives the water time to mix with the exhaust gases and cool them. This minimum is necessary to protect plastic and fiberglass mufflers from excessive temperatures. When the engine is not running, this minimum vertical distance helps retard the flow of seawater from the muffler to the engine where it will damage the engine.

If the minimums cannot be achieved, the alternatives are:

1. Use a special exhaust riser supplied by the engine manufacturer to increase the vertical distance. (Yanmar calls this a "U mixing elbow.")

2. Run some dry (hot) exhaust piping to some other location where there is space to get the height needed, and then use a mixing elbow or a stand pipe. See Dave Gerr's article on Page 20 for alternative exhaust systems.
3. In the worst case, where there is no space for any of these options, a water-jacketed or dry exhaust system may be the only alternatives.

Dimension B

12-inch minimum, 16 inches is better.

Minimum vertical distance from the waterline to the bottom of the vented loop.

Significance:

If the injection point is above the waterline (6 to 16 inches are quoted figures), you don't need a vented loop. Remember that a scoop at the thru-hull takes away from this margin, as do heeling, pitching, squatting, and loading.

A siphon break may be used in the vented loop, or a tee and extension may be used with no valve. Siphon valves may become salt-encrusted and leak. Tees and extensions should vent to a point higher than any other part of the exhaust system.

Dimension C

42 inches maximum.
20 inches maximum with turbocharger.

Maximum vertical distance from the bottom of the muffler to the top of the lift.

Significance:

When the engine stops, the top of the lift divides the water in the system. The water in the lift flows into the muffler, (which must be able to hold it all) and the water in the down-stream piping flows to the thru-hull.

Excessive lift is thought by some authorities to cause excessive back pressure. Other opinions minimize the significance of this.

Dimension D

12 to 18 inches minimum (depending on which authority is consulted).

Minimum vertical distance from the top of the lift to the waterline.

Significance :

When the engine is off, and water is being forced backward into the system through the thru-hull from following seas, or the thru-hull is forced under water from the motion of the boat, or some combination of these, this lift helps to keep water from getting over the top of the lift and draining into the muffler. Sometimes this protection is enhanced by using a gooseneck as shown with Dimension I.

Dimension E

12 inches minimum (this dimension is redundant if Dimension D is complied with).

Minimum vertical distance from the top of the lift to the thru-hull (similar to Dimension D).

Significance:

When the engine is off, and water is being forced backward into the system through the thru-hull from following seas, or because the thru-hull is forced underwater from the motion of the boat, or some combination of these, this lift helps to keep water from getting over the top of the lift and draining into the muffler. Sometimes this protection is enhanced by using a gooseneck as shown with Dimension I.

Dimension F

3 to 6 inches minimum (depending on which authority is consulted).

Minimum vertical distance from the waterline to the thru-hull.

Significance:

When the engine is off, it is desirable to have the exhaust exit point above the waterline so that it cannot start a siphon. Safety margins are eroded by heeling and loading.

When the vessel pitches, the thru-hull can be submerged, and pressure formed in the piping that will try to force air (or water) backward out of the muffler and into the engine.

Some successful layouts have been built that have the exhaust outlet lower. Powerboats sometimes have it below the water.

Dimension H

Minimum distance from the exhaust manifold to the injection point.

4 inches minimum

Significance:

Highly corrosive chemical combinations form at the injection point. The intent of this dimension is to keep these from reaching the engine exhaust valves and guides. In most cases, the engine designers will take care of this parameter.

If the dimension is too long, it may be necessary to insulate the part of the exhaust that is dry (and hot).

Dimension I

Minimum lift in (optional) gooseneck.

16 inches minimum

Significance:

Where this last gooseneck is used, it provides added protection against water flowing backward into the piping and reaching the muffler. It is interesting to note that not all authorities recommend this feature. We think it is a good idea.

Dimension L

Maximum length from muffler to exit.

30 times manifold outlet diameter. An alternative is to increase hose size.

Significance:

It may be necessary to increase the diameter of the piping to reduce resistance. See the North Sea Exhaust description in Dave Gerr's article.

From the forgoing, you can see that the issues associated with wet exhausts and waterlift mufflers are not simple, and it is possible for a boat to be configured so that a "conventional" installation is not possible. We would expect this to be more common in the case of good old boats that were not designed for a wet exhaust in the first place. We would also expect this to be more of a problem for fin-keel designs without a lot of depth from the engine compartment to the transom. In his article, Dave Gerr explains some of the other methods for dealing with wet exhausts that cannot be laid out according to the recommendations we have presented here.

A quick disclaimer

We have tried to present the most detailed information possible on this topic. The application of a wet exhaust and waterlift muffler can be complex. As we have said, not every boat has the space available for the "standard" layout. Some boats don't even have spaces that are suited to the alternative layouts. It is important to contact your engine manufacturer and the manufacturer of your exhaust components for specific parameters and to resolve any questions or doubts with these sources. One muffler manufacturer said they regularly provide this information to their customers, and it is likely that the other manufacturers will as well. We have presented this information believing that if you know the intent of each characteristic and parameter in the system, you will be better prepared to evaluate variations that may be needed to accomplish the same intent.

In the end, as in so many things on your boat, the responsibility for the safety and good functioning of your exhaust system is yours.