Engine
(Final Assembly)
(2010)

6/23/2010:

Transmission:

Three of the seals arrived. The fourth seal (output shaft) is coming from Canada. I started with the seal on the shift mechanism – interesting problem. It was easy to press the new seal into place, but the (brass?) shaft had to be inserted from the inside out (against the bevel of the seal) and there isn't much of a chamfer on the end of the shaft. So I used a screwdriver to carefully depress the seal lip to clear the shaft. I next installed the shift mechanism into the housing and proceeded to check the clearance of the adjusting screw. I followed the procedure in the manual, but must have miscalculated, because after making the adjustment the output shaft would move. I remeasured, recalculated, and readjusted. This time the output shaft was fine.

Next, I tried the seal for the input shaft. I slipped the seal over the shaft. Then while pushing down on the seal with my fingers to the left of the shaft, I used a small hammer to tap the seal on the other side of the shaft. Once started, I could just progressively tap around the shaft until the seal was flush with the housing. Expecting the seal to seat against a shoulder, I continued to tap on the seal until it was well below flush. I forgot to check beforehand whether or not there was a shoulder for the seal to seat against! Now I'm in trouble! I went back and looked at the drawings and sure enough the drawings showed that the seal was suppose to be flush. So now I've got to disassemble the case again to remove the seal and start again. After removing all the bolts, I tried tapping of the output shaft to open the case (recommended procedure). Unfortunately, the gasket material that I used (Permatex Ultra Grey) was more tenacious than the original, and it wouldn't budge. So I had to wedge a putty knife between the mating surfaces to get it free. Once started, the case came apart easily; however, this process did scratch the surface a bit.

Ok … remove the output shaft, unbolt the transmission shaft, remove the input shaft, tap out the seal. Then, clean up the old gasket material and reassemble – this time using the Three Bond stuff that I used for the oil pan (less adhesive strength). Finally, I installed the remaining two seals flush with the case.

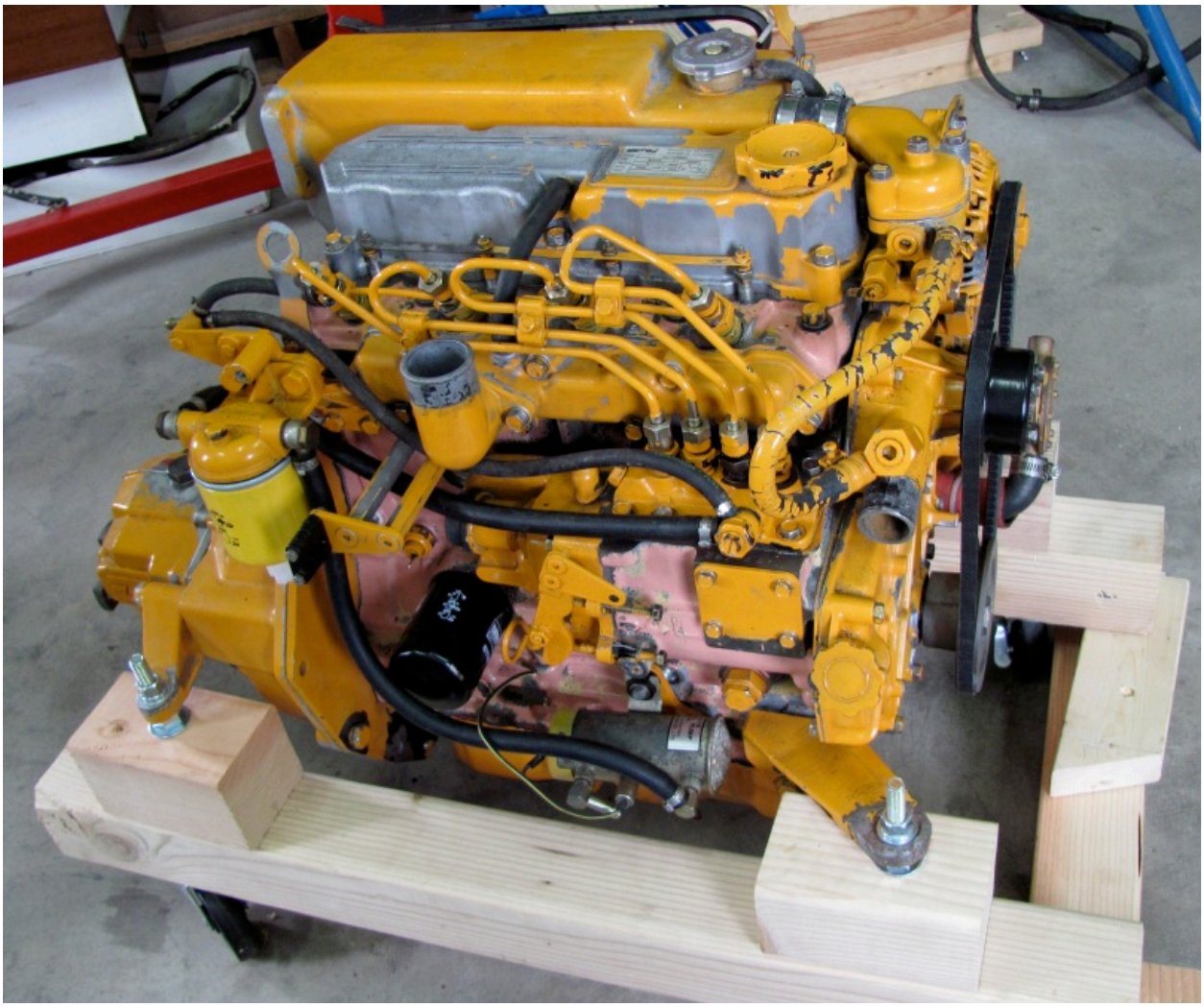
I've been waiting quite awhile for the fourth seal, so I finally called Transmission Eng. about it. They volunteered to try to get the seal locally. I gave them the numbers off of the old seal and they sent me a replacement in a couple of days. I installed it with no difficulty. With the help of a neighbor, we torqued the output flange to spec and the transmission shaft nut to 42 ft-lb.

8/29/2010

Engine:

With the transmission back together, I can finish assembling the back end. Bolted the starter to the rear plate and mounted the rear plate to the block. Next, bolted the flywheel to the hub on the end of the crank. The manual recommends using studs in the hub to align the heavy flywheel while the bolts are fastened. I was able to accomplish this with one of the long bolts that I bought to mount the block to the engine stand. Next bolt the damper plate to the flywheel. Bolted the transmission to the bell housing, using general torque specs in the back of the Mitsubishi manual. One of the bolts was longer than the others, and I soon found out why. Evidently, one of the bolt holes was stripped when assembled at the factory and a longer bolt was used to catch more threads.

With transmission on the bell housing, I greased (White lithium) the spline, and mounted the bell housing to the engine rear plate. Now that the bell housing is in place, I have the four mounting pads I need to bolt the engine to a frame. Built a frame out of 4x4's and added 4 casters. Then bolted the engine to the frame so that I can roll it around.



This set up isn't as stable as I would like for running the engine, but when I put the frame up on blocks (clearing the casters), it's fine. Just to be sure that the engine would turn over, I inserted two bolts into the crank pulley and using a 3' bar rotated the crank about 20 degrees.

Cooling system:

The parts from McMaster Carr came in a couple of days after ordering them. So now I can mount the raw water pump – no problems there. I then tried the O-rings that I ordered for the heat exchanger. Although they are the right diameter, the cross section is bigger and this causes a problem. They are fine for the front end, where you just have a simple end cap, but the rear end cap has a baffle that is designed to separate the inlet water from the outlet. The thicker O-ring doesn't permit the baffle to seal against the tube bundle. I squirted a little water into the top hose fitting and it leaks out the bottom hose fitting – not good. When I removed the end cap, I saw that the role pin used to align the baffle with the tube bundle was now damaged – the thicker O-ring prevented the pin from engaging the alignment hole in the tube bundle, so it bent. Fortunately, William Bros. (local machine shop supply) had a 5/64" role pin that worked as a replacement.

While the end caps were in place, I did pressure test the raw water side of the heat exchanger. Using some hose and fittings from the local hardware store, I attached a pressure gage to one of the end cap hose fittings and the air compressor to the other hose fitting. I filled the tube bundle with water and applied about 7 psi – no leaks. I realized then that this test was not sufficient. It's possible that the O-ring can seal the tube bundle from the coolant side; the pitting at the rear end of the exchanger would probably not allow the O-ring to seal the coolant from the outside.

So I decided to fill the pits with epoxy. I decided to use some G-flex with Cabosil from West System, thinking that the added flexibility of the G-flex would better tolerate the expansion of the aluminum. I machined a wooden plug just a few thousands smaller in diameter than the heat exchanger housing. I removed the exchanger from the engine. I mixed a batch of epoxy/Cab to peanut butter consistency and troweled into the pits, and then inserted the plug with some wax paper as a release. The next day, I removed the plug and cleaned up the squeeze out. Worked well.

In the mean time, the parts from Vetus arrived (about 2 weeks instead of the projected 8 weeks). So I bolted the heat exchanger housing to the block (my 3 year old granddaughter helped with this), installed the tube bundle with the new O-ring in the rear and one of the larger O-rings in the front (where it doesn't matter, and gives me a spare). This time I pressure tested the coolant side of the system – pressure gage on the outlet of the coolant pump, air compressor on the coolant inlet to the heat exchanger housing, fill with water (no antifreeze), and pressurize to 7 psi – no leaks. Drain the water – from heat exchanger and block as well. This reminds me that I need to install a valve at the block drain plug to make draining the block less messy. Bronze? Stainless? I'll have to think about that.

The previous owned did not use the stock Vetus hose from the coolant pump to the heat exchanger. The stock hose passes in front of the V-belt and maybe there isn't enough room in the engine compartment for this. The custom hose was anything but ideal. It ran around the back of

the engine using a multitude of galvanize pipe fittings and different size hoses. I decided to run a single hose under the engine in front of the oil pan. I hope this will be ok – it does block the auxiliary oil fill cap, but I don't believe that will be a problem. I ordered the hose (1 3/8" ID from Go2Marine.com, as well as fuel hose and a cartridge for the primary fuel filter. Installed the hose and filled the system with 50/50 water/ethylene glycol premix – almost 2 gal. There is a metal ledge about 3/8" below the bottom of the filler cap tube, that makes it easy to gage the fill level.

Raw water system:

I was able to get the proper size O-ring for the raw water pump from MC – a spare can in with the Vetus order sometime later. I installed the raw water pump without a hitch; however, I decided to confirm that I installed the impeller correctly – vanes bent in the opposite direction to pump rotation. So which way does the pump rotate? Looking aft from the front of the engine, the prop turns counter clockwise for forward motion. The transmission input shaft turns in the opposite direction to the output shaft, and the input shaft is connected directly to the crank. So the crank rotates clockwise. The pump is connected to the power takeoff, which is connected to the crank through 3 timing gears. So the pump must rotate counter clockwise. So I pulled the pump cover and checked – sure enough, the vanes are bent to the right – good. Now the bad news … When I removed the pump cover, one of the screws (just the end) broke off in the housing. It must have been corroded – should have replaced them all. I was able to drill out the tip and chase the treads (8-32). I reinstalled the existing screws, but they should be replaced, or I need to replace the stock cover with a Speedseal. I attached the existing Vetus hose from output of the raw water pump to the lower hose fitting on the heat exchanger end cap. The previous owner used this same hose but spliced in a section of hose for a siphon break. I will have to install a siphon break too, but I'm going to wait on this until I get the engine into the boat. Next, I installed the raw water/exhaust injection fitting to the heat exchanger with the gasket that came from Vetus and attached the short section of hose that connects the heat exchanger output to the injection point. Finally, I ran a short section of exhaust hose just for the engine test.

Lubrication:

Not much to do here. Removed the oil pan drain plug just to be sure no coolant leaked into the pan from the pressure test. Filled the crankcase with oil.

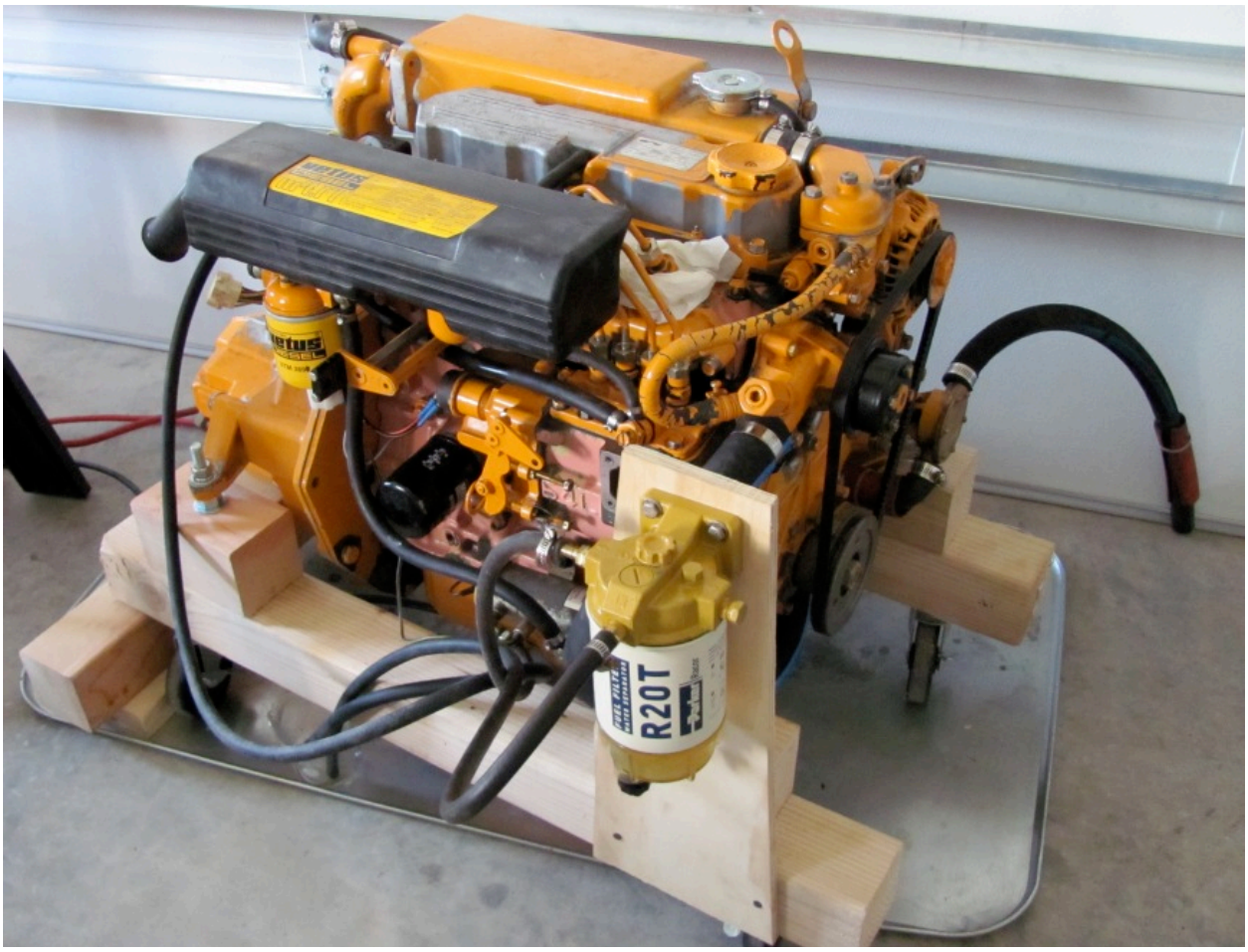
Electrical:

When disassembling the engine, I took great care in labeling all the wires. There is also a wiring diagram in the Vetus operation manual. So things went well until it was time to hook up the battery. I knew that a heavy cable ran from the starter to the battery positive and that the negative connected to the block, but I couldn't remember or figure out where the control box got power. The wiring diagram shows the battery but doesn't indicate where the connection is made. Fortunately, I took lots of pictures, and in one of them, I could see that the primary positive feed came from the alternator – make sense now that I think about it, since the alternator must charge the battery.

Fuel system:

Disassembled the primary fuel filter (Raychor 230) and discarded the old element. Housing was pitted, so I removed all the fittings, bead blasted it (Carson's shop), and painted the outside with Cat Yellow. Cleaned the lower (plastic) water separator as best I could. The plastic has been etched, however, so you can't really see inside. Maybe it should be replaced? I'll use it as is for now. Replaced the element with a 10 micron cartridge. Attached the filter to a plywood mounting bracket on the wooden engine frame. Ran fuel hoses

Engine test:



Well all the major pieces are in place, so it's time to finish up some odds and ends and test the engine. Gary Johnson stopped by to help. Rolled the engine to the front of the garage, where I could run the exhaust to the driveway. Ran a hose from the raw water pump inlet to a bucket of water with a garden hose for refills. Filled the primary and secondary filter elements with fresh diesel and screwed them in place. Ran the fuel input and return hoses to a 5-gal jug containing 2-gal of fuel. Filled transmission with ATF. Removed the battery from my van and connected it to the engine common and the two hot lines (starter and alternator) to the battery positive through a battery selector switch. Disconnected the banjo fitting at the high pressure fuel pump. Turned the ignition switch to "ON," which activates the lift pump, and purged the fuel lines to a glass beaker. Fuel was clean, so I attached the banjo fitting with new washers to the fuel pump, and

bled the fuel lines at the secondary filter and at the high pressure fuel pump inlet. Turned the ignition switch to “glow plugs” for about 6 sec and then to start. The engine cranked but would not start.

After several additional attempts, we switch to debugging mode. Air inlet – not much can go wrong here. About 9 VDC to the glow plugs – should it be 12 VDC? We’ll let’s see if the injectors are getting any fuel. Pulled the feed line to #1 and cranked – no fuel – a little damp, but that’s it. Pulled the cover on the fuel pump/governor linkage. Linkage moves freely. Activating the fuel cut-off solenoid drives the linkage forward, as it should, we believe. So that leaves the pump itself. Is it possible that the check valves on top of the plungers are inoperative? Maybe gummed up?

9/3/2010:

Engine test (cont.):

After numerous consultations with several experts:

- Tim from Proformance
- Michael from Stauffer
- Carl (diesel mechanic)
- Carson (PSU Learning Factory)
- Randy (helpful neighbor)
- Gary (sailing buddy)

we deduced the following:

1. The manual indicates that 9V to the glow plugs is within specs. Also, Randy and I tested one of them and it got hot. We didn’t test all of them, but we suspect the problem is with the fuel.
2. The consensus is that it takes many crank rotations to purge the fuel lines, because the high pressure pumps puts out very little fuel per cycle. We did bleed the fuel lines to the banjo fitting at the inlet to the high pressure fuel pump, but not any further. This bleeding can be done with just the lift pump, but beyond requires rotating the crank.

So, the plan is be more diligent about bleeding the system. First we noticed another bleed fitting on the high pressure fuel pump. This fitting is not mentioned in the manual, but it clearly connects to the pump fuel gallery. We bleed this with pressure from the lift pump – it needed it – lots of air bubbles. Next we disconnected the fuel pipes so that we could see the output from the pump. After a number of cycles we could see fuel coming from port 1, then from port 2, and finally (after bleeding the gallery again), fuel was visible at port 4. Now we reconnected the fuel pipes to the pump but not the injectors. After numerous cycles, fuel appeared at the injectors. So, we tightened all the fuel pipes and tried to start the engine again. This time the engine tried to

fire, but all we got was a whiff of black smoke out the exhaust. A couple more tries just resulted in a dead battery.

I decided that the old van battery wasn't up to the task, so I bought a new one. I thought about upgrading to a heavy duty commercial diesel battery but it was a lot more money and it wouldn't fit in the van. (I'm hoping to use the new battery in the van, since it will be a long time until I need a battery in the boat). The new battery didn't improve things much, so we took a careful look at the wiring. We're running heavy wire but it's fairly long (5 ft or more) and passes through a switch. The voltage at the starter was 9V or less. So we eliminated the switch and shortened the wiring to about 1 ft. Big difference. Now the engine cranked over rapidly. Now the engine billowed out a lot of black smoke and wouldn't run without the starter. So it's back to the drawing board.

After another round of consultations, the possible causes are

1. Air intake blockage – discounted since the intake is clearly unobstructed.
2. Incorrect injector timing (fuel injected at the wrong time), which can be caused by
    - Incorrect timing gear installation, or
    - Thickness of shims under fuel pump incorrect.
3. Incorrect valve timing (valves opening when they should be closed
4. Insufficient compression (air not heated enough to ignite fuel)

Since I don't have a compression tester (I ordered one online today), we decided to check the injector timing. This requires removing from the fuel pump the check valve for #1 cylinder and reassembling the pump. This operation is not particularly difficult, but keeping dirt out of the pump is a real challenge. Next you connect the fuel pipe to the #1 port on the fuel pump and run it to a beaker. The principle is that without the check valve, fuel from the lift pump will pass right through the high pressure pump to the beaker. At the exact point of injection, however, this flow will be stopped by the piston in the pump. So you turn on the lift pump and turn the crank until the fuel flow stops. At that point, the TDC mark on the crankshaft pulley should be 17 degrees CCW from the timing reference on the timing gear cover. We performed this test several times, and concluded that the timing was off (retarded) by almost 5 degrees. So the fuel is entering the cylinders late. But why? The same shims were used, and I was particularly careful to align the gears correctly. Well they must be checked. So it's off with the timing gear cover. Now, it takes dozens of crank revolutions to bring all the gear alignment marks into position, and sure enough they are correct. There are numbers stamped into the gears, making it very difficult to do it incorrectly. Now I've got a mess! The gasket is ruined and glued to the housing with HighTack. How will I clean this up without getting dirt in the gear train? Also, can I buy a replacement gasket? Darn.

Well, now it has to be the shims, but how can that be? If I were missing a shim, the timing would be advanced not retarded. It's impossible to inadvertently add a shim – they are a custom fit and no spares were provided. Testing indicates that the shim thickness must be reduced by about 0.020". Is it possible that the shims are bent or debris got between the shim and the pump? Seems unlikely, but I'll check it this weekend.

9/20/2010

I have yet to understand why the injection timing isn't to spec. The timing is controlled by the thickness of the shims under the injection pump, so one possibility is that the thickness of the shims is incorrect - but these are the original shims (shims and pump shown in the pic below).

So maybe something is wedged between the shims? But I checked and the height of the fuel pump above the housing is the same as the thickness of the shims. So it appears that the injection

timing was set to 12 deg instead of 17 deg from the factory. Michael, from Stauffer, suggests that maybe Vetus specified this timing for their engines. I asked John Miller from Vetus about this – will check and get back to me (10/28/2010: I just learned today that John is no longer employed by Vetus). I could also ask Mitsubishi if this particular serial number was configured differently. Michael also said that he doubts that the difference in timing would prevent the engine from starting.

Removed the rocker arm cover and checked the valve timing. One or two values were off by about .001 or a bit more, but that's it! I made the small corrections, but it's certainly not a problem with the valve timing – still could be compression loss, either through a leaky valve or rings. Got the compression tester (Star tool co. in Wisconsin). Since compression is related to engine rpm, the manual suggests checking the rpm while doing the compression test. The engine tach doesn't seem to be working (oh boy, another project!) so I borrowed a tach from Carson. Had a hard time getting a consistent reading, but the best I can tell the starter turns the crank at about 250-300 rpm. The manual calls for 290. Pulled all the glow plugs and tested compression on #1 – peaks out around 550 psi. This is a bit hard to believe since the spec calls for about 455 psi max. At zero psi the gage reads about 50 psi, so I suspect the gage. Tried #2. First test showed about 600 psi (I don't believe it) and after that the gage stopped working. The adaptor that I bought with the gage is equipped with a Schrader value – like you find in an automobile tire. This particular valve has a very light spring to allow air to enter the value with very low pressure drop, but to act as a check valve, holding pressure in the gage. Unfortunately this value is a bit fragile and relieving the pressure rapidly can damage the value. Of course there was no manual included with the device that tells me this. I only find out when I call tech support. The good news is that tech support was very helpful and sent me replacement valves and a new gage at no charge. Even though I suspect the gage, I think it's very likely that the compression is good.

Since I've checked all the likely culprits, I made another round or calls. This time Michael and Tim (from Proformance) both mentioned that diesels need high starting RPM to get the air temperature hot enough to fire the fuel. Michael wondered if the transmission was putting too much load on the engine. I have noticed that the crank seems to bind initially, there might be something to that. Carson said that maybe the battery wasn't generating enough cranking amps. Can't check the transmission easily, but I tried hooking up the car battery in parallel (short leads), but this didn't produce a noticeable change. Well there's not much else to try, while waiting on the replacement gage, so I decided to test the engine again. I replace the glow plugs (testing each of them this time – all got hot) and reinstalled the timing gear cover. Even though the gasket was torn, it will seal well enough for the test. I reinstalled the high pressure fuel pump and returned the check value, spring, and washer to #1 injection port. By the way, it's very important to keep these parts submerged in diesel fuel when not in the pump to avoid corrosion. The clearances on these parts are very tight and even the smallest pit can ruin them. You're not even suppose to touch them with your fingers – of course I only learned of this after the fact!

Well it all went together well. Attached the governor linkage and spring, closed it up, and bleed the fuel lines. Every time I shut down, I remove the fuel intake line from the fuel can. This introduces air into the fuel lines. So, first you need to bleed the secondary filter, then the banjo fitting at the high pressure pump, then the bleed at the fuel pump gallery and then the output of the pump injector ports. This also flushes any dirt that may have found its way into the pump

output ports during injection timing tests. Now attach each fuel line to the pump (but not to the injectors just yet). I'm installing them one at a time now because it allows me to tighten them with the crow's foot and torque wrench. If you attach all four at one time the nuts get in the way and the wrench won't fit. Ok now purge the lines to the injectors and tighten the pipes to the injectors. Ok, now will it start?

Powered the glow plugs for about 30 sec and cranked the engine. Started right up. No black smoke. Although it seemed to need more throttle to idle properly. It ran for maybe a minute and then stopped. Further attempts to start it fail – just black smoke again, but it's clear that the starter is not cranking fast enough. Why? The battery has a good charge. Tried turning the crank over manually – won't budge even with a long pry bar – oh boy, it's seized up.

So the question is what's seized? Tear down the engine yet again – I'm getting pretty good at this –1/2 hr and I've got the bell housing off – nothing wrong with the trany. About 3 hrs. later and I'm looking at the crank and bearings. I removed three of the four main bearings, but I still can't turn the crank – bearings looked good – lots of oil. I then pulled connecting rod caps from #1 and #4 and the cranked turned easily by hand. Further inspection showed that #1 bearing was totally galled and #4 showed excessive wear. Evidently, these bearings didn't get enough oil. Looking back at my notes, I see that the clearance for #1 & 4 was .001" and .003" for #2 & 3. That's within spec, but I can see why #1 & 4 had a problem. I also noticed that the sides of one of the rod bearing caps had a number of scratches – not sure why, but it will need to be fixed.

Pulled the crank and took it to DL Automotive for evaluation. They suggested that in the future, I pre-pressurize the oil gallery before starting the engine. A small oil tank connected to the oil pressure sensor port, apply air pressure – should do it. Leave the valve cover off and check the flow out of the rocker arms.

Upon reflection it appears that the problem was due to two connecting rod bearing having insufficient clearance and lack of oil (soon enough). The assembly lube was just not enough. This offered enough resistance to prevent the starter motor from turning the engine over fast enough to fire the fuel – hence the black smoke. So I'm waiting on DL. If they can clean up the crank without having to regrind it, that will be great. In either case, I'll need to order new bearings and some gaskets. Maybe new shims, if I decide to change the timing.

In the mean time, I started to look at the alternator to see why the tach isn't working. After disassembling the case, I realized that this might be a bit too ambitious on my part, so I took it to Milesburg Auto Electric (guy who helped me with the starter).

9/28/2010

Parts arrived from Stuffer. Dropped off bearings to DL Automotive. They promised to check the bearing clearances in a couple of days. Then it's back to assembly, two of the gaskets are coming from Japan (front and rear plate), so I can only go so far.

I built a device for pre-pressurizing the oil galleries.

A 2 ft section of clear PVC tubing (about 1.5” diam.) and pipe fittings to reduce it to 1/8” pipe fitting at one end and air hose at the other. The idea is to attach the device to the block in place of the oil pressure switch, fill the pipe with oil, and apply air pressure to pump the oil into the block.

DL says to use 50 psi and wait for oil to emerge from rockers. Oil pan and timing gear cover can be in place.

DL reminded me to be sure to lubricate threads and under the heads of the head bolts.

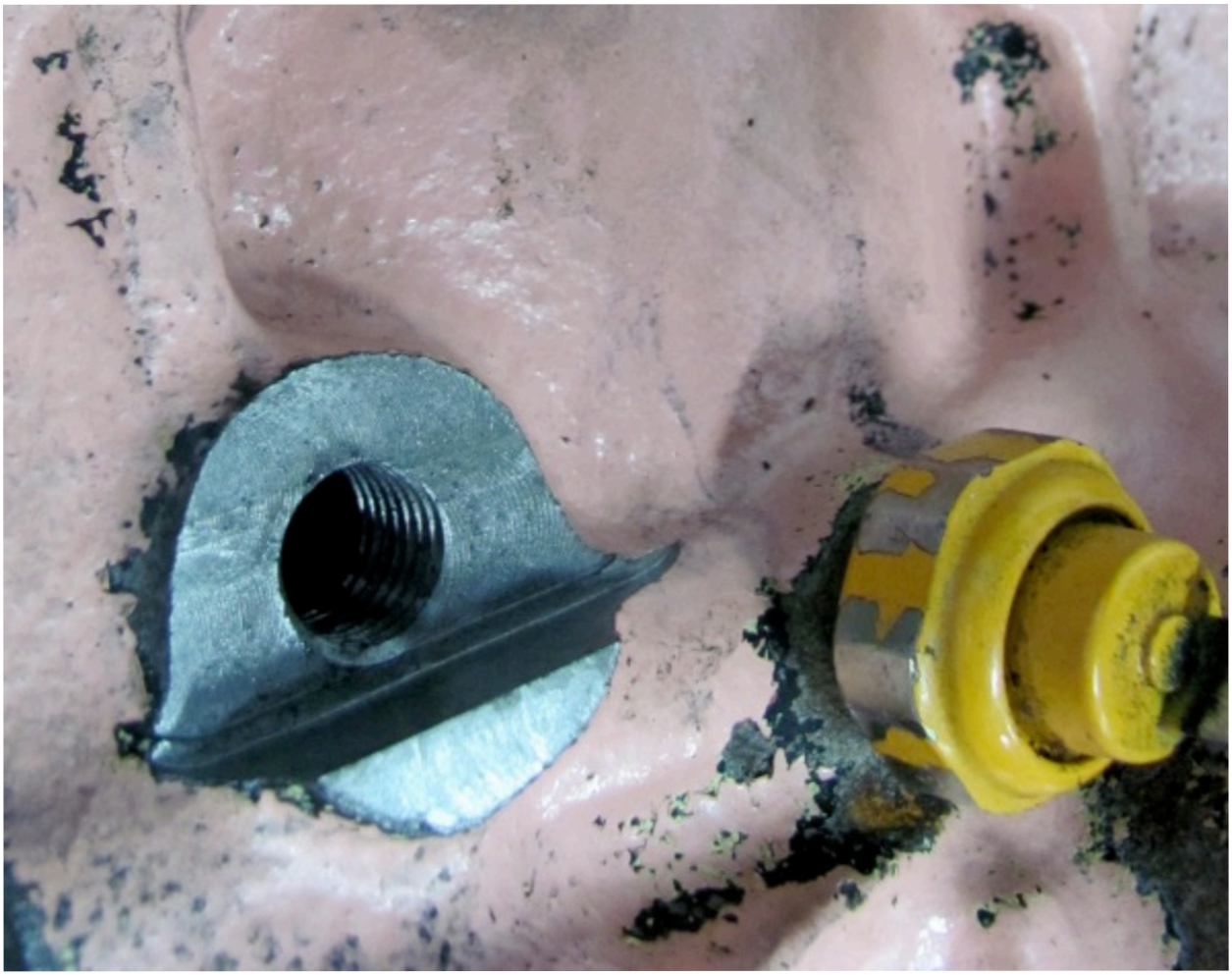
While working on the block, I noticed a hairline crack where the coolant drain plug enters the block. Oh boy! Will it leak? I tried to apply Locktite to the crack, but I doubt that this will help. My research on the web indicates that crack repairs in cast iron are problematic. Need to check with Carson and DL.

10/11/2010

DL checked the bearing clearances and they are "all over the map!" Evidently, when Mitsubishi assembles the connecting rods, they match bearings to rods. I that way, you don't have to maintain tight tolerances on both the bearings and housings. In any case, the housing will have to be re-bored (first trimming a bit off the mating surfaces of the bearing caps to make the hole undersize), but the manual doesn't list a spec for this. Contacted Stauffer – they don't know either. They will ask Mitsubishi. The last 2 gaskets have arrived.

I talked to Carson about the cracked block. He said it will leak. Fortunately, the extent of the crack is limited to a small boss extending out from the block. You can barely see the crack at the top of the boss in the pic below.

Hence, I put the block on the mill and removed most of the boss (until the crack disappeared) and then re-tapped the hole. Plenty of metal left for threads, so it should work fine.



I remind myself to be much more careful with cast iron in the future.

10/27/10

DL is done with the rod and crank rework. DL never heard from Mitsubishi about the rod big-end specs, so they just ground the smaller ones to match the larger. All the rod bearings now have about 0.002" clearance. They were able to clean up the crank – looks good as new.

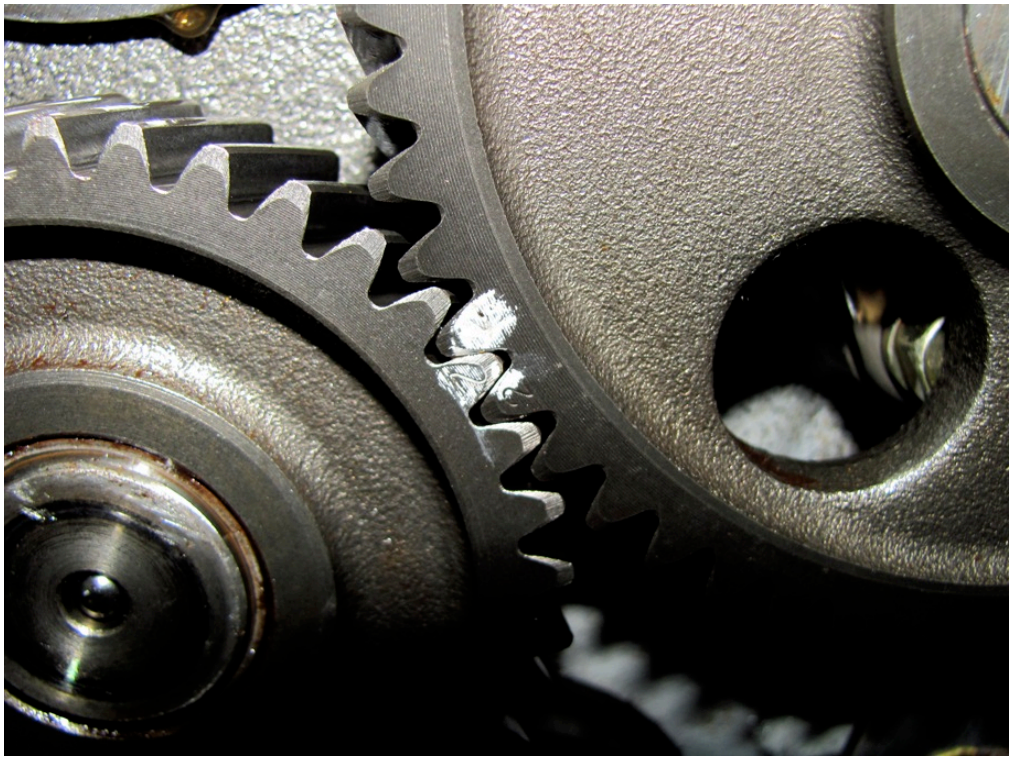
So it's assembly time again. After mounting the engine to the engine stand, I sprayed the inside of the block with CRC brake cleaner to be sure no metal chards were left over from the bearing seizure. Next I lowered the crank into position using my gantry crane, and installed the main bearing caps. (I still used assembly lube on all bearings and cam lobes.) I coated the mating surfaces of the rear cap with red RTV silicone. The front one was assemble without sealant since any leaks would just enter the timing gear area. Again it was difficult to get the covers flush with

the front of the block, but they're pretty close. Torqued the caps to spec and installed the linear seals with red RTV. Checked the endplay – in spec. Crank turns easily by hand.

Installed the oil pick up with red RTV on the threads of the lock nut. Installed the oil pan with Threebond – this time coating only the pan flange not the block. Makes less of a mess that way. Next the pistons. The rings and connecting rods were already in place. I just had to orient the ring gaps correctly, put the new bearings (top half) in place, and apply some oil to the rings and cylinder walls. Select the first piston and orient the crank so that the corresponding journal is at TDC. Insert the piston into the matching cylinder (DL conveniently stamped the top of each piston with its cylinder number), attach the ring compressor, and lightly tap the piston into place. Note that if I tighten the ring compressor as tight as possible with the tool provided, it's not quite enough. I have to use a 10" pipe extension to get the last "click." Note too that if you tap too hard on the piston you can jar the bearing loose, which is a pain. Also you have to make sure that the rod is engaging the crank journal properly. It's possible for the rod end to jam against the journal instead. Just make sure that it swings freely as you push the piston in place. Once it's seated against the journal, you can then rotate the crank while you push down on the piston (extra hands would be helpful here), until the journal is at BDC. Then install the bearing cap and torque to specs. Check the side clearance between the rod big end and the crank. Good, it's in spec. Repeat this process for the other 3 pistons. Check that the crank turns freely. It's a bit tighter now due to ring drag, but I can turn it by hand using the crank pulley (just temporarily installed for that purpose; you can't get to the crank rear hub as it says in the manual due to the engine stand).

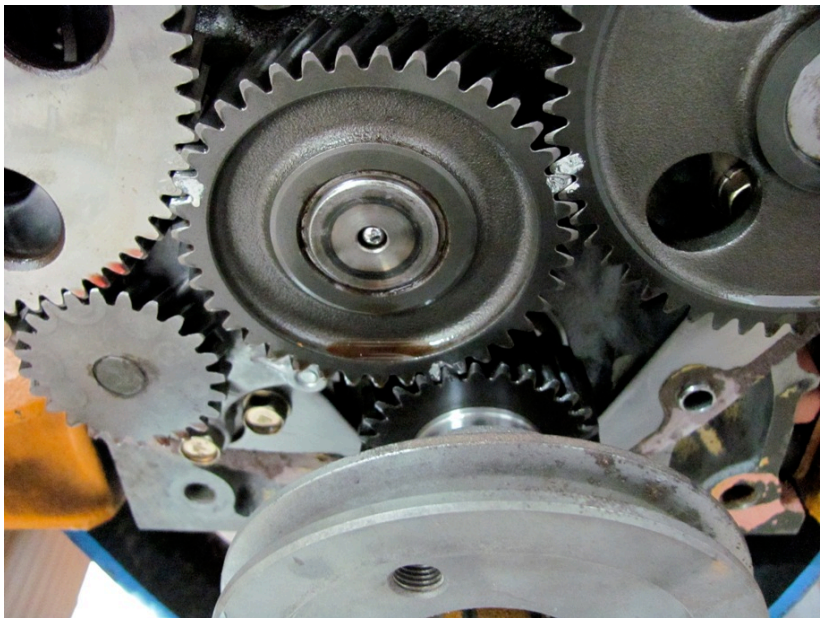
The timing gears are next. First the oil pump. Carson had suggested tearing this apart to inspect it, but I couldn't loosen the screws. I showed Carson the pump and he said that it was ok, even though there was some minor corrosion on one of the lobes. I put the special O-ring in place on the pump and inserted the pump in the block. Two screws hold it in place. Next the injection pump cam shaft (with gear already attached) is inserted into the block and tapped into place with a soft hammer. The oil pump gear meshes with the cam gear. One thrust bolt holds it in place. Next the valve cam shaft. Carefully insert it into the block so as not to damage the cam lobes. You can't see what you're doing, so it's all by feel. Once aligned properly it slides into place without persuasion. Two bolts through a thrust plate holds it in place. Turn the crank so that #1 piston is at TDC and insert the idler gear so that all the numbers line up – crank, injector cam shaft, cam shaft. The alignment of the idler gear and the injector pump cam gear and oil pump are shown below.

The alignment of the value cam gear is shown below.



The crank alignment is shown below.

Finally the complete timing gear configuration is shown below.



Attach the front plate with a new gasket and then the timing cover with new gasket.

At this point a word about gaskets might be in order. Gaskets are expensive. I paid over $200 for the rebuilt set plus another $100 or so for replacements when I had to tear the engine down a second time. Having the right gaskets is very convenient, but it might be better to use an RTV sealant instead. I think that's what a lot of shops do.

I inserted the PTO gear next. The gear rides between two ball bearings, and to the casual observer the unit looks symmetric. The manual, however, indicates that an oil hole exists on one side but not the other and specifies that the side without the oil hole faces the rear. I didn't notice this when I assembled the engine the first time. I'm glad I noticed it this time – otherwise the bearings might not get any oil. One bearing slips into the rear of the timing gear cover. A housing fits over the second bearing, and a cover plate seals everything from the rear. The raw water pump fits into the front, sealing the front end. Be sure to install the raw water pump so that the inlet/outlet ports lie below the center of the pump so that the ports are facing the right direction (inlet to the right when facing the front of the engine). Also the ports need to be oriented about 45 deg. from the horizontal so that the outlet hose clears the "fan" belt. The crank pulley completes the front end – Woodruff key, washer, lock washer, nut. To achieve the necessary torque, you need to install two bolts into the rear crank hub and keep the hub from turning using a pry bar.

Attention switches to the top of the engine. I carefully cleaned the top of the block and the mating surface of the head. I then polished both surfaces with a fine Arkansas stone. When DL replaced the valves, they machined the head to make sure it was flat and recessed the values to the original specs, so the head didn't need much work. Then, I installed the lifters. I previously labeled all the lifters, push rods, and valve caps with their position in the head (probably over kill). I installed two guide studs into the block, installed the head gasket, and lowered the head into place. Lubricated the bolts and torque them to spec in the specified order. Next, I inserted the push rods and valve caps – except I was missing one of the value caps! I kept each set in a separate bag, so I couldn't figure out why it was missing. Then it occurred to me that it might be inside the lifter. Sure enough, using a flashlight I could see the cap in the lifter, but with the head on, I can't remove the lifter. A little work with a magnetic screwdriver and I was able to extract the cap.

The rocker assembly was next. This time I made sure to loosen all the rocker arms before bolting down the rocker assemble – reduces the risk of damaging a value against a piston. I then adjusted all the value clearances. Installed the value cover to keep things clean – I'll need to remove it later when I pressurize the galleries with oil.

I need to work on the rear of the engine, so I have to remove it from the stand. For easy lifting, I installed the heat exchanger, which has one of the two lifting rings. With the engine hanging from a sling, I installed the rear oil seal (new gasket but old seal ok), rear plate (new gasket), flywheel, damper plate, and bell housing. With the bell housing in place, all four engine mounts are available, so I bolted the engine to my rolling stand.

It's starting to come together now. Just some odds and ends. First, the thermostat housing. One of these bolts holds the alternator bracket, so I can install the (new) alternator. Milesburg Auto Electric found that the original alternator was bad and not economically repairable – blown regulator, diodes, and shorted rotor. This was probably due to trying to charge a low battery. These alternators are not designed to charge a battery, only to keep it charged. If you draw too much current for too long, you burn it up.

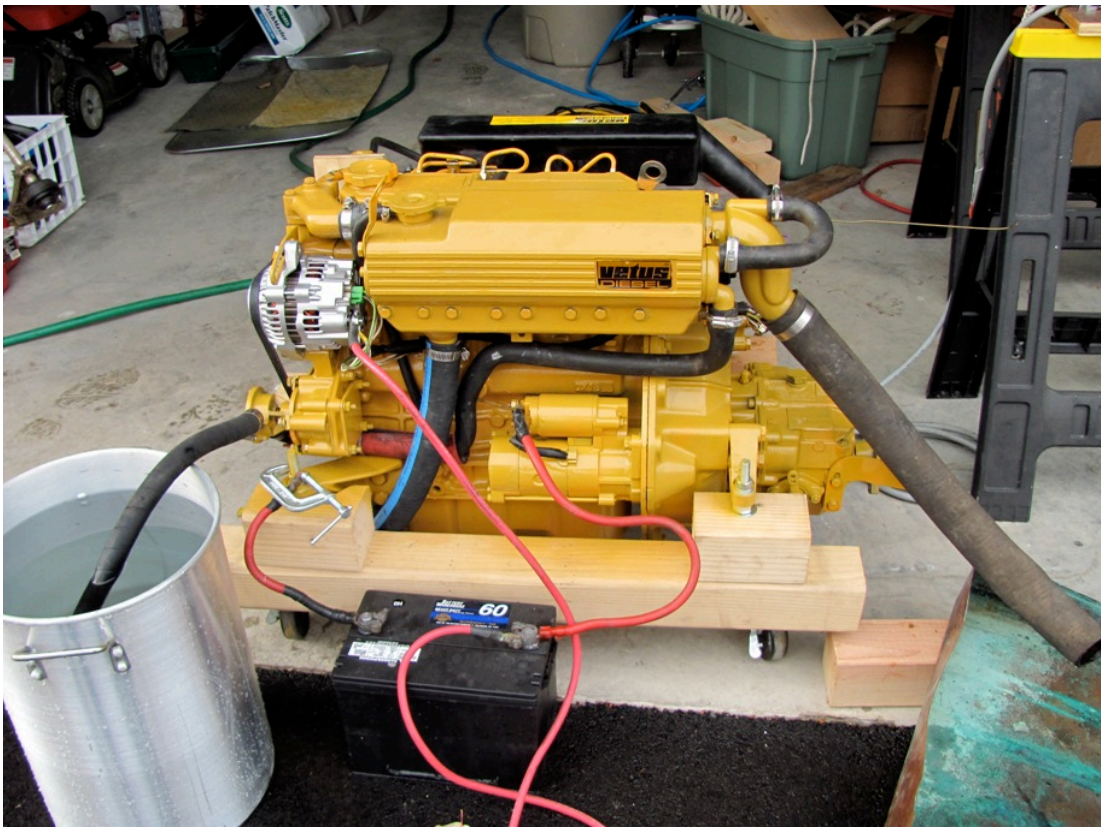
Next the fuel injection pump. I never heard from Mitsubishi or Vetus about the timing problem. Stauffer said to just leave it as is. So I cleaned up the shims, applied red RTV to all mating surfaces and bolted the pump in place. I put plastic caps on all the fuel ports when I tore the engine down (caps that I got from Proformance when they serviced the injectors). Pump with caps shown below.

I removed the caps, used compressed air to clear the ports and installed the injector pipes. Doing them one at a time allow me to use the crow's foot adaptor and torque wrench. Finally, I installed the intake manifold.

At this point, I decided to pre-oil the engine. I removed the oil pressure switch and attached the apparatus that I mentioned previously. By hanging the apparatus from the chain hoist, I was able to remove the cap and pour in the oil. Then sealing the cap and applying about 25 psi air pressure, I pumped about 2 qts. of oil into the galleries until oil emerged from the rocker arm assembly. Then I reinstalled the oil pressure switch (with Teflon pipe sealant) and torque it to spec. I also installed a small ball valve and piping to the coolant drain port, so that I can drain the engine without making a mess. I was careful not to apply too much torque to this pipe fitting so as not to crack the cast iron block. I used Teflon pipe sealant on the threads.

Before installing the rest of the fuel system (lots of hoses), I decided to paint the engine. First I covered all open ports and electrical contacts with duct tape/plastic. Then, I rolled the engine out to the driveway, put a catch pan with absorbent material under the engine, an sprayed the engine with a cleaning foam. Let it sit for 15 minutes, and washed it down with a fine water spray. I used compressed air to remove most of the water and let it dry. Once dry, I sprayed it with a can of Cat Yellow. After drying overnight, I removed the duct tape and installed rest of the fuel system and the electrical system and filled the engine with oil and coolant.

The next day, I connected the battery and ran the hoses to the fuel can, and the raw water pump to a bucket filled with tap water.



I then turned the engine to ON to activate the fuel lift pump and bled the fuel lines at three places – the secondary fuel filter, the fuel pump inlet banjo fitting, and the fuel pump gallery. You don't really need to bleed the fuel injection pipes- the injection pump will push out any air. After two 10 second cranking tries, the engine fired right up. I ran the engine for about 10 min at about 2000 RPM with an occasional stop to deal with low raw water level (had two garden hoses open full and it couldn't keep up).

Other than a small coolant leak – I was a bit too conservative in tightening the coolant drain pipe fittings – everything went well. So after about 7 months (off and on), I now have a working engine. Hooray! I will now re-torque the head bolts and check the valve timing, winterize the

engine, cover the intake and exhaust ports, and put the engine aside until I'm ready to put it in the boat. Overall this rebuild cost about $4273, compared to about $12500 new (plus tax, shipping), but the learning experience was invaluable.