VW Aircraft Engine Building

by Robert S. Hoover copywrite 2000

VW Engine

by Robert S. Hoover

A used VW engine has no value other than as a core; typically between $75 and $150, depending upon how complete it is. The tin ware -- the blower housing and various parts that make up the cooling-air shrouding, are actually worth more than the case, crank & heads, especially if the thermostatically controlled air vanes are present and in good condition.

Used cylinders & pistons have no value; they are normally discarded. The wear pattern for cylinders of horizontally opposed engines is slightly oval. Since hones follow the bore, you can hone them for hours and still end up with an ovaled bore. It costs more to rebore a used jug than to buy a new one. The same applies to overhauling the pistons. The sealing surfaces of a piston are the top & bottom of the grooves in which the rings are fitted. To overhaul a piston, the grooves must be re-machined, being careful to provide the proper radius in the corners. Thicker rings are then fitted to match the wider grooves.

Honing cylinders and overhauling the pistons was the bread & butter of every competent automotive mechanic prior to 1956. These tasks were part of the typical 'ring & valve' job an engine required after 20,000 to 40,000 miles of service.

In 1956 Ford Motor Company published (in the Journal of the SAE) the results of a year's long test involving engines fitted with full-flow oil filtration systems. Filtering all of the oil every time it passed through the oil pump reduced wear on some components by as much as 600%. Overall, engines fitted with full-flow oil filtration systems lasted from two to six times longer than engines without such systems.

The next year Ford ran several of its production sedans 50,000 miles AT 100 MILES PER HOUR on the salt flats at Bonneville. (From the air, you can still see the seven mile circle they wore in the salt.)

From that day to this, all automotive engines have been fitted with full-flow oil filtration systems. Modern automobile engines routinely deliver 100,000 miles of service without major repair and a quarter of a million miles is not unusual.

Until 1992, when VW de Mexico introduced a filter/pump adapter, the Type I VW engine had no form of oil filtration and despite myths to the contrary, the average service life seldom exceeded 60,000 miles before major repairs were required. ('Major Repair' here means any repair requiring the removal & dismantling of the engine.) Catastrophic failures (ie, swallowing a valve, usually leading to throwing that rod) were quite common.

Many people advocate use of pre-1956 engine overhaul techniques on Volkswagens (ie, the classic ring & valve job). Unfortunately, not only do these techniques not apply to horizontally opposed AIRCOOLED engines, the tooling and skills are simply no longer available at an economic price; it is less expensive to install new jugs & cylinders.

Assuming the crankcase is still sound.

Early Type I VW engines are cast of AS21 magnesium-aluminum alloy. Due to the magnesium extraction process used by Dowmetal, the alloy contains trace amounts of niobium and tin. If the alloy is raised above a certain critical temperature, the metal will display 'memory' qualities. Unfortunately, the 'read' temperature is much lower than the 'write' temperature.

What all that means is that an early VW engine subjected to catastrophic failure (typically required to raise the temperature above the 'memory-write' threshold), will tend to return to its heat-stressed dimensions when raised to the 'memory-read' threshold. Unfortunately, the memory-read threshold is within the NORMAL range of operating temperatures.

This odd metallurgical quirk means that you can remachine a used crankcase and return it to spec with regard to alignment & bore only to see those specs CHANGE when you run the engine. And those changing specs typically result in a catastrophic loss of oil pressure which usually trashes the engine in short order.

Having only three main bearings (#4 is actually a pulley bearing) and being of the 'boxer' type, catastrophic failure tends to overheat (and over stress) the center main-bearing web. This is especially critical in the VW engine because the center main bearing web provides the only passageway for oil to reach the right side of the engine. Once that web has been heat-stressed, normal operating temperatures is enough to cause sufficient distortion to open up that critical oil passage and prevent sufficient lubricant from reaching the right-hand side of the engine.

Once the memory property was recognized, the alloy used in the crankcase was changed. Crankcases cast of AS41 do not display the memory property.

If you do not know the provenance of an older, used VW engine (ie, of AS21 alloy) it would be extremely unwise to consider it as a candidate for use in an airplane. Even if align-bored and decked so as to return the crankcase to spec, if you don't know the engine's history you can't tell if it has been heat-stressed. Since the only reliable test for the memory property is to do all of the required machining and then blueprint the engine after being heat-soaked for 1 hour @ 250 degrees Fahrenheit, it is usually less expensive to build your flying VW engine on a later model AS41 crankcase.

VW Engine - Dismantling I
by Robert S. Hoover

If you intend to convert a used Volkswagen engine into an aircraft powerplant, before devoting any time or thought to it as an airplane engine it would be wise to focus on the reality of its automotive origins. One of the best tools for this purpose is Tom Wilson's excellent "How to Overhaul Your Aircooled Volkswagen Engine," available for about $15 from most VW after-market retailers as well as most auto parts houses such as J. C. Whitney.

When you acquire a donor engine its potential value is zero. To determine its worth you must dismantle and inspect the engine. If it proves unsuitable for use in an airplane it may have some value to the owner of an antique bug or bus.

Your donor engine should be full of oil. Check the dip stick, if so fitted. On Type III's the dipstick is mounted remotely and usually is not sold with the engine. But if your donor engine came off a Type III, the oil filler/dipstick fitting will have been removed and the oil will have run out of the crankcase. IF the engine was stored 'dry' you may have a lot of rust to deal with.

But IF the engine IS full of oil, keep that fact in mind. We'll drain the sump at the proper time but until then try not to tip the engine too far or the oil will run out the annular ring behind the pulley.

If the donor engine has an oil bath air filter, deal with it first. Remove it, dispose of the oil, clean it and store it for resale. This is a pricey, desirable item since it works better than a treated paper filter (but is frowned upon by the environmentalists because of the oil it uses).

If the engine has the typical upright style of blower housing, get your flashlight and look under the right cylinder bank to see if the thermostat is still installed. Yes is good. (After-market VW parts dealers encourage kids to throw away this critical part of the engine's cooling system.) If the thermostat is missing and if you have access to other potential donors, walk away from the thing.

Begin dismantling the engine by unbolting the thermostat from its bracket. Use a 13mm box-end or socket. Once the thermostat is free of the bracket, unscrew the thermostat from the operating rod. Put the thermostat in your parts-box along with the bolt; it is sorter than other the other 8x1.25 bolts and is specific to the thermostat installation. (Keep any washers with it.)

Follow the instructions in Tom Wilson's book or most any other VW manual in removing the blower housing & dynamo. (Some of the manuals fail to mention the thermostat, hence my reason for doing so above.)

Leave the oil cooler in place for the time being but strip everything else down to the block, including removal of the generator tower, fuel pump and distributor.

If you have trouble removing any of the cheese-head screws (6x1.0), try heating them then turning them out with a pair of vise-grips. Real 'Vise-grip' brand vise-grips are the thing to use; the imported copies typically lack hardened steel jaws and will not grip the small screwhead securely.

If the two screws holding the cylinder shrouding to the heads are stuck, be very careful not to shear them. You'll need these threaded bosses to hold your own cooling tin when the engine is installed in the airplane. These screws usually come free if you remove the valve cover, pull the rocker arm and heat the roof of the valve gallery(!) in the vicinity of the threaded boss.

To remove the tin-ware that encloses the lower portion of the pulley you must remove the pulley to come at the screws. There are two openings in the stock pulley that allows a bar or screwdriver to pass through the hole and bear against a shelf cast into the engine, thus preventing the pulley from turning as the pulley bolt is backed out.

The pulley is a tight fit to the crankshaft and seldom comes free without help. There is a special puller for this but a pair of long-bladed screwdrivers, applied on either side of the pulley and rocked alternately, will 'walk' the pulley off the hub. Not very quickly, but it it will eventually come free without damage to either pulley or engine.

Once the pulley is off IMMEDIATELY thread the pulley bolt back into the crankshaft in order to protect the threads.

With the pulley out of the way you may remove the last of the tin-ware.

IF the flywheel is still attached it is your next item, or the pressure plate that may be bolted to the flywheel.

The flywheel is secured with a single large bolt. The pilot bearing is mounted int he head of the bolt. The bolt -- called a gland nut -- is 36mm and you must use a suitable socket. DO NOT succumb to the instant experts who tell you how to remove the bolt with a cold chisel and hammer.

There are patent fixtures that will lock the flywheel in place while the nut is being removed but they do absolutely nothing to hold the ENGINE in place. The gland nut is torqued to 215 lb-ft and you can toss the engine all over the shop without loosening the nut.

The proper anti-torque tool is nothing more than a 5 foot length of 2x2x1/4 angle iron, drilled on one end to match two of the pressure plate holes. Make the holes 5/16 and use the pressure plate's own bolts (or any two 8x1.25 bolts, 20mm in length). Be sure to drill the holes in the proper flange of the angle iron. (Study the problem for a minute. Note the location of the lower engine mounting studs relative to the central gland nut. There is only one suitable orientation for the anti-torque tool.)

With the anti-torque tool attached to the flywheel and extending toward the LEFT side of the engine (relative to the driver, always), STAND on the anti-torque tool whilst LIFTING the piece of pipe you've slipped onto the handle of your 3/4" breaker bar... to which you've affixed the 36mm socket.

At a distance of 4 feet the average man can generate between 800 and 1600 lb-ft of torque, more than enough to deal with the gland nut... unless it was installed by one of those 'expert' mechanics with a toolkit consisting of three sledgehammers and an air wrench.

Once the gland nut has been removed the flywheel may not want to leave home. Convince it to do so by GENTLY rocking the anti-torque tool. Careful of your toes; it is a heavy flywheel for such a light engine.

All this while you've probably been working with the engine on the floor, hopefully atop a thick pad of cardboard. Now I want you to lift the engine up about six inches. This is quite easy to do if you take it just 1-5/8" at a time... which happens to be the thickness of a 2x4. You'll need about TWELVE pieces of 2x stock, at least 12" long.

To raise the engine, lift one side and place a piece of 2x4 under the bosses cast into the underside of the cylinder head. Then do the same to the other side. Work from side to side until the engine is high enough to accept a container suitable as an oil drain pan.

The VW engines holds 85 fluid ounces of lubricant. A quart is 32 oz; I'll let you do the math. Just be sure your container can hold the oil, plus enough margin for slop.

To get at the sump bolt you may be able to reach under the engine -- if it's high enough and if you have a 21mm box end wrench. Or you can stack those other four pieces of 2x4 BEHIND the engine and carefully tip it up so it's standing on the bell housing, giving you easy access to the sump bolt.

Allow the engine to drain as long as possible then REPLACE the sump bolt. There is lots of residual oil trapped in the push rods and oil galleries. It takes as long as a week(!) for it all to drain out. The residue amounts to only a few ounces but that's more than enough to make a mess if you don't take it into account.

With the engine up in the air, build a pallet of blocks under the CRANKCASE so as to leave the heads free but the engine solidly supported.

Provide yourself with two containers each large large enough to hold a cylinder head. That's a cube about 13" long (including the studs), 7" wide and about 6" high.

The heads are secured by eight nuts fastened to studs that pass through the heads, alongside of the cylinders and into threaded bores in the crankcase. To remove the heads, first remove the valve covers. Next, remove the rocker arm assembly as a unit. Then remove the four push rods and stand them in a can; they are full of oil, which is going to drain out. Don't worry about position or orientation -- if the engine ever goes back together it will be with new cam-followers and a complete wear-in cycle.

With the valve gear out of the way, remove the eight nuts AND their related washers. Put them in the bucket with all the other hardware (except the valve gear, which remains with the head for the time being)

The head may not want to come free. You may coax it a bit with a rubber mallet but it it is well and truly stuck, don't worry about it; go remove the opposite head.

If your heads are stuck, find a cardboard box large enough to fit down over the entire engine(!), plop it over the thing, stick a shop light under the engine and go do something else. The light will heat the engine -- the ENTIRE engine -- and once warm, the heads will usually come free. (And if they don't, hit them harder :-)

VW Engine - Dismantling II

by Robert S. Hoover

When the head comes free, stop. Spend some time examining the condition of the combustion chamber, piston and cylinder. You are looking for gross evidence of damage, such as scoring on the cylinder wall, cracked or broken valves, signs of foreign-object damage (ie, nicks, pits & gouges in the piston & chamber). Such evidence is sufficient grounds to reject the engine simply because there are better candidates out there, waiting to be found. But if this all you have or can afford, take the time to make notes describing the damage. Much of this forensic evidence will be lost as the dismantling progresses but it is vital that we know which cylinder(s) was/were involved when we get down to checking the crank and rods.

Removal of the heads has also freed the pushrod tubes. They go into the discard bin. They may look fine and might even be fairly new but it is impossible to clean all the residue from the INNER folds of those accordion pleats. So toss them. New ones are about a dollar each and must be etched & painted before use.

Removal of the push-rod tubes will allow the lower shrouding to come free. On older engines the lower shrouding is nothing more than a simple, rather in effective deflector plate. You may save it, if you wish, but you will not be using it on an aircraft engine. When installed in an airplane, you must use the tighter lower shrouding introduced on the Type III engines -- the so-called 'Kool Tin,' similar to that found on real aircraft engines, the Corvair and the later model VW engines. The use of tighter lower shrouding on the cylinders, which contribute only 17% of the waste-heat load, forces more air to flow down through the fins of the heads, where most of the waste heat is produced.

The cylinders will usually pull free of the pistons if you give them a good tug. If they're stuck into their spigot bores, try the heat trick again. Indeed, throughout the dismantling process, keep in mind that to the engine, what you consider a nice day is to an engine, the same as hell having frozen over. Engines exist on a plain of reality far removed from human perception. A comfortable temperature for an aircooled engine is about the same as when your hair would burst into flame, and they don't really start to work up a sweat until your fillings are about to melt.

Seek harmony with the machine. Warm it up (and try to keep it that way). It makes dismantling ever so much easier.

Once free of their cylinders the pistons will clack and clank about, gouging the sealing surface of the spigot bores. Don't allow them to behave in this fashion.

See the wrist pins? Okay then, see the HOLES where the wrist pins are hiding? See the wire clip? Remove it, please. Both sides of the piston. Needle nose pliers do a nice job of it.

Keep the best four of the wrist pin clips as Emergency Spars but toss the others.

To remove the piston from the connecting rod you must drive the wrist pin out of its bore. Here again, you allie is heat. How hot? Until your spit sizzles. (Seriously; it's a pretty good standard.) Use a wooden dowel to push the wrist pin out of the bore. If you need to pound on the thing, do so VERY judiciously -- the connecting rods are designed to resist loads PERPENDICULAR to the axis of the crankshaft. At full extension, they bend with surprising ease when pounded on from the side.

You apply the Noah Principle in removing the pistons -- two-by-two. When a piston is fully extended on the right bank, it's diagonal cousin will be fully extended on the left, so move over there and deal with that piston. In most cases, you will be heating one while removing the other.

(To rotate the crankshaft, remove the bolt, wedge the pulley onto the crankshaft and twist.)

(Save the pistons. They are made of very good quality castable aluminum. I used junked pistons to cast the intake manifolds on many of my engines.)

With the pistons removed, locate a pair of cylinder stud nuts, provide yourself with two box-end wrenches of suitable size, and remove the sixteen head studs from the crankcase. It is much easier to do now than later.

This is also a good time to remove the lower engine mounting studs.

Being careful to protect the end of the crankshaft (installing the gland nut is a good idea), stand the engine on its tail and remove the sump plate and oil pump screen. (That isn't a filter, by the way. The screen is only there to protect the oil pump from injesting a 'chunkie' -- residue from a worn out lifter, valve or rocker arm.)

Now remove the oil pump.

The oil pump will present a problem if you do not have a suitable puller. Do NOT attempt to pry it from the case, you'll damage the crankcase, the pump body or both. If you don't have the proper puller, use the two-nut trick and remove the STUDS holding the pump in position.

With the engine still standing on its tail, remove all of the fasteners along the lower parting line. Be methodical. Start at one end and work your way to the other.

Continue up and around the nose of the engine, removing the parting-line fasteners as you go. Don't worry about anything coming apart; the engine is solidly bolted together by the six main bolts and the two smaller ones that insure proper sealing around the end of the cam.

Once you are done, check your work.

I know you did a good job and that checking is probably a waste of time. But do it, please. One good method is to touch each stud or bolt-hole with your finger, working right around the engine.

Now you may remove the two small nuts down in the 'corner' nearest the flywheel. When everything is in the parts can, remove the six large nuts and their related washers... but thread two of the nuts back onto the center pair of studs.

You may now split the crankcase. Volkswagen has provided a number of leverage points for this purpose. Tapping on the studs with a plastic mallet will usually start the split, which will progress as you work back & forth between the lower-front and upper-rear leverage points.

And that's as far as you should go without being at the workbench, or if the engine is NOT installed in a fixture. (A VW engine fixture costs about $25 and is available from all of the VW after-market retailer, or from J. C. Whitney. The fixture comes in to parts, the 'bow' which bolts to the flywheel end of the crankshaft (and for which you must provide a suitable bolt top replace the lower mounting stud) and the pivot, which bolts to your work bench and accepts the shaft of the 'bow'.

Working on the bench, and ideally with the case in a fixture (bolted to the left case-half), you may rotate the engine so as to place the parting line in the horizontal position and remove the right-hand side of the crankcase by lifting it straight up.

The cam followers will tumble out of the right-side of the case and fall into the left side. IF this were anything other than a tear-down-for-inspection you would have used a pair of hair-pin-looking clips to hold the lifters in their bores. But in this case, the odds are that we will discard not only the lifters but the cam. Here's why: The cam and lifters must be perfectly compatible in their metallurgy so as to wear at the same rate. Most reground cams and reground lifters are

NOT polished & hardened; the reground parts are NOT compatible and wear at an accelerated rate. A VW cam is relatively inexpensive, as are new lifters. It is the grossest example of false economy to use rebuilt parts in this case when new parts are available.

The crankshaft is the main object of our interest -- and the reason for tearing down the engine. But before we can do anything with it we must remove the connecting rods. Fortunately, Volkswagen has provided you with a crankshaft jig. Two of them, in fact. One looks very much like a flywheel, the other like a pulley.. but either will do to support the crankshaft in a vertical position while we remove the connecting rods.

But before touching tools to the work, find your note book and log the connecting rod numbers relative to their pistons.

Treat each rod as an individual unit, keeping its cap properly oriented and retaining its own nuts or bolts.

The rods will probably need to be overhauled. That involves grinding away a portion of the cap at the parting line and re-machining the big-end to a perfect circle. The bushing on the little end will be replaced, oil holes drilled, then honed to a tight sliding fit on a standard wrist pin. (Serious engine builders match the pin to the individual rod.)

The connecting rods will also be checked for balance, straightness, twist and big-end thickness or 'cheek.' But if you plan to build anything larger than about 110cid, you will not be able to use the stock VW connecting rod. It is too short; it violates the 'Ricardo Rule', the ratio of rod length to stroke throw (long stroke with a short rod means the rod approaches 90 degree angularity, resulting in excessive side-loading of the cylinder and accelerated wear).

Remember those notes you took after removing the heads? While it is not uncommon to find bent and twisted rods in an otherwise perfectly healthy engine, if such is found in conjunction with other evidence of mechanical failure, it is fair to presume the rod has been excessively stressed and should be replaced. As it is, all of the rods for you AIRCRAFT engine will be magnafluxed as a matter of course. VW rods are sturdy mild steel forgings and have no history of metallurgical failures. But in manufacturing 22,000,000 VW engines there is a good deal of latitude in the quality of their components. Magnaflux is relatively inexpensive and the confidence it provides is cheap at the price.

VW Engine -- Cleaning III
by Robert S. Hoover

Re-reading this, I see I've forgotten to remove the oil cooler. It should come off after the oil has been drained from the engine. If it is the older upright style it has little value but if the donor engine was fitted with the later 'dog-house' type oil cooler, it may be used on an aircraft engine installation so let's treat it in a friendly fashion by filling it with solvent and sitting it aside until it can be flushed clean. (Your push-rods must also be flushed.)

I also forgot to mention the dowel pins used to position the bearing shells in the crankcase. Find them (five, please) and put them in a Special Place. Ditto for the cam plug (ie, that little metal cup). Clean all sealant from the cam plug and store it in that Special Place with the dowel pins.

The purpose for all of this is that before we can inspect the components of your donor engine to determine their suitability for use in an aircraft engine, the components must first be cleaned.

Cleaning Steel Parts
Steel parts are cleaned using either lye (sodium hydroxide) or trisodium phosphate. The traditional 'hot tank' formula was a solution containing lye. Be advised that lye will dissolve both aluminum and magnesium.

Lye is available from grocery and hardware stores. Oven cleaners usually contain some amount of lye, as do most drain cleaners. Lye is a powerful caustic. Don't just read the instructions, follow them. Gloves and suitable eye protection should be worn when working with lye.

Trisodium phosphate is usually found in the paint department of hardware stores. Some soaps used in dishwashing machines contain trisodium phosphate.

Many janitorial supplies contain either lye, trisodium phosphate or acids, from hydrochloric to phosphoric. Read the labels. Many communities have banned the sale of certain chemicals in the mistaken belief that doing so will protect the environment. Yet those same chemicals remain available in janitorial supplies and
household cleaning agents.

I clean most steel parts by boiling them in a solution of trisodium phosphate, discarding the solution onto my compost heap. Remove any rust by carding (ie, using a scratch wheel) or with phosphoric acid, which is available in the paint department of most hardware stores. A saturated solution of acidic brine is also an effective de-rusting agent.

Once steel has been decreased and de-rusted it must be protected by either plating, painting, waxing or oiling. Since an aircraft engine spends it's life exposed to the elements cadmium plating is the best protection but paint, if properly applied, will also serve. Paint the parts by laying them out on a screen. Rattlecan gloss black enamel does well enough if but you should really look into the air- brush trick. Allow the paint to dry then do the opposite side. Once dry, BAKE the paint (2 hrs @ 170 degrees Fahrenheit [ie, in a 'low' oven]) and allow to cool to room temperature before handling. Since this chore is liable to fill your home with fumes it is a task best done in the shop. If you don't have an oven in your shop, make one by lining a cardboard box with tin foil and placing a recessed lighting fixture in the bottom on a metal tray. Install a 100W lamp in the fixture. Such fixtures are equipped with an over-temperature control that breaks the circuit when the temperature reaches about 180 degrees Fahrenheit. It will turn itself back on once it has cooled to about 150. (Such a 'hot box' is a standard shop tool. Not only does it bake paint, it does a fine job preheating parts for dis-assembly.)

The baking is the secret in achieving the most durable finish using paint. If you are unable to bake parts painted with enamel, they can take up to two weeks(!) to cure properly, depending on temperature and humidity, and may take years to achieve the same hardness as a baked finish.

All threaded fittings must be chased with a suitable die before being used so don't worry too much about getting paint on the threads.

Cleaning Nonferrous Parts.
Methyl Chloride, the active stuff in paint remover, is the classic 'cold tank' solution, usually mixed with kerosene or diesel fuel. For most of us the most common source of methyl chloride will be in the form of carb cleaner. A five gallon pail of the stuff will accept your heads (once dismantled) one at a time. It may also be used on your crankcase but the problem here is finding a suitable container.

Methyl chloride will dissolve even baked-on deposits in the combustion chamber, which should give you some idea as to why you don't want to get it on your skin.

After soaking a part in carb cleaner it is rinsed in solvent then blown dry. The 'solvent' I'll mention frequently is common white mineral spirits paint thinner, to most of us. Do not use gasoline. The modern-day stuff sold under that name contains carcinogens that can be absorbed through the skin. Kerosene, diesel fuel and even JP5 may be pressed into service as a solvent but all are more hazardous than mineral spirits and typically cost more.

Now let's go CLEAN something :-)

CRANKCASE. To properly clean a used crankcase you must have access to all of the internal passageways. Begin by removing the oil pressure control valve and the volume control valve (if so fitted). You'll probably need to fabricate a special screwdriver for this task. Be very careful to save the aluminum washer(s). These are difficult to find and you may have to reuse them. Put the parts cap-screw, washer, spring & piston in that Special Place where you stored the main bearing dowel pins.

It is standard aircraft practice to modify the oil control/pressure valve cap screws by welding on a small steel tang that will allow the cap screw to be secured with safety wire. As with all other hardware, the cap screws must be plated or painted.

In a properly built engine the piston-type oil pressure & control valves are normally replaced by ball-type valves after installing a suitable valve seat. Due to the pulsations of the pump, piston-types tend to wear the bore rather rapidly and once worn, may cock far enough to become wedged. This can cause all of the oil to be by- passed to the sump. Robbed of oil pressure, a catastrophic failure is only minutes away. Ball-type valves, which are the standard in the industry for this purpose, have none of those faults, plus they provide a wider range of control than does the piston type.

(When working with Volkswagen engines it is important to always keep in mind that you are dealing with 1930's automotive engineering technology. By modern standards, the Volkswagen engine has a host of potentially lethal faults.)

If you do not plan to modify your oil control/volume valve(s) to ball types, be especially careful when cleaning the bores. Do NOT use any form of abrasive nor a metal brush on the bores of the valves, which must form a perfect fit to their pistons.

The myth of the Volkswagen's reliability, largely created by the Doyle-Dane-Bernbach ad agency, is perpetuated by a host of technically incompetent 'experts,' any of whom can kill you with their bum dope. In his enormously popular book "How to Keep Your Volkswagen Alive..." the late John Muir tells his readers to scrape the cylinder with a Scout knife followed by 'polishing' the piston with sandpaper(!) '...and your troubles will be over.'(*) As will the useful life of the engine. In fact, Volkswagen provides oil pressure/control pistons in two over-sizes to compensate for wear in the cylinder.

(As a point of interest, the reliability of any high-maintenance vehicle is primarily a reflection of the maintenance it receives.)

All of the oil gallery sealing plugs must be removed. They are soft aluminum plugs, easily removed by drilling then threading a sheet metal screw into the hole and pulling the plug with a slap-hammer. Since these plugs will be replaced with threaded plugs it is standard practice to tap the bores now so that the cleaning can remove any swarf.

Since the threaded plugs will see as much as 200 psi, particular care is taken in the tapping. (Installed with high strength Lok-tite, the threaded plugs are modified by filing a smooth, shallow scallop into their tops into which the parent metal of the crankcase will be straked using a round-nosed tool. I'll go into this in more detail when describing the engine's assembly.)

Lacking a suitable container for cold-tanking your crankcase, the next best option is a large tub, a good detergent such as 'Simple Green', plenty of hot water and copious amounts of elbow grease.

When cleaning the crankcase you must pay particular attention to the parting line. This is a gasketless seal, a rather remarkable feature in a mass-produced article from the 1930's.

Unfortunately, the sealing surface is a bit narrow by modern standards and is susceptible to leaking due to corrosion (on the lower parting line), minor scratches and 'shop rash' that occur in normal handling. So handle the crankcase with abnormal care. Insure ALL of the old sealant is removed, not only from the parting line but the area around the cam plug, main oil seal and the drain-back channels associated with the #4 bearing and cam plug.

When water is involved in the cleaning process you must insure the parts are perfectly DRY on completion. This is best accomplished by concluding the cleaning process with a boiling water rinse (and I mean literally boiling) followed by blowing all of the passages dry with compressed air.

Heads, Crank, Cam, Rods and Oil Pump

HEADS. The heads require further dismantling before being cleaned. See my posting in the archives of the VW engine group for the dismantling procedure.

(http://www.escribe.com/aviation/vw/index.html?mID=6186)

Given their importance, I prefer to treat heads as a special case, cleaning and overhauling them as a task apart from a major overhaul. Since your exhaust

valves will need replacement or reseating about every 200 hours, you will find it more practical to provide yourself with four heads, all of equal chamber volume and
valve geometry. This allows you to swap the heads and overhaul the pulled units at your leisure.

When dismantling used heads it is normal to discard the exhaust valves. (The relatively small (8mm) stems of VW valves are one of the weakest links in the engine's design, a fact easily confirmed by comparing them to the 10 and 11mm valve stems used in the Porsche or the half-inch [13mm] stems found in many aircraft engines.) You may also discard the stock adjusting screws, if so fitted. The remaining steel parts are to be cleaned as a group using carb cleaner & solvent, then lightly oiled and kept together for inspection. The head goes into the pail of carb cleaner for an overnight soak followed by a solvent rinse. In cleaning the heads do not use a wire brush in the chamber. We must inspect the chamber for cracks between the valve seats and the spark plug hole. Wire brushing can conceal such cracks.

CRANKSHAFT. The Woodruff key that aligns the pulley is removed using a BRASS drift no wider than the key to tap downward on the outboard end of the key. The front of the key will rock down, the back will rock up and you will eventually be able to remove WITH YOUR FINGERS. (Don't bugger up the Woodruff keys. They are a critical fit in their slots, both on the crankshaft and the parts they are used to align.) Put the Woodruff key in that Special Place along with the main bearing dowel pins.

The cam- and distributor-gear are a shrink-fit on the crankshaft and serve to trap the #3 bearing. These parts are removed using a suitable press or puller. Do NOT try to do this job without the proper tools. A screw-type puller is available from most after-market VW retailers for about $30. Use only solvent on the crankshaft. If inspection shows that a regrind is both required and possible, we will give it a better cleaning before sending it out (and an even more serious cleaning when we get it back)..

Dismantling the crankshaft involves removal of the timing gear, distributor gear, the spacer between them and the Woodruff key which aligns them. You have already removed the Woodruff key for the pulley. The last items that need be removed are the four dowel pins that align the flywheel.

Put all of the parts removed in that Special Place.

(If the flywheel dowel pins refuse to come free, grasp them with a collet-type puller and vibrate the pulley-end of the crankshaft while maintaining a steady pull on the collet. Use an air hammer fitted with a round-nosed tool, inserted into the threaded bore and making firm contact with the bottom. Wrapping tape around the tool to protect the threads is a good idea. If you don't have a collet-type puller, take a large pair of cheap import vise-grips, close the jaws and jig them true in the drill press or mill and drill a hole about .008 smaller than the dowel pins, centered on the jaws. Now use the modified vise-grips as your collet. [The jaws of most imported visegrips are not hardened and may be easily drilled.])

CAM. Clean the cam with solvent, oil it and put it aside for inspection.

CONNECTING RODS. If the rods are caked with baked-on oil you may boil them in TSP. Normally, a simple solvent wash is sufficient.

OIL PUMP. Wash the oil pump with solvent and inspect the pump body for scoring. On a proper overhaul the old oil pump is normally discarded.

The best oil pump for the VW engine is the stock unit made by Bilstein. Over the years, Volkswagen used nine different oil pumps in the Type I engine. The oil pump is specific to the cam gear, with later model (ie, larger) pumps requiring the use of a dish-faced cam gear.

Avoid after-market oil pumps, especially those having a cast-iron body. To insure proper sealing of the pump's inlet, the oil pump body is a .003 interference fit in the crankcase. The different coefficient of expansion between cast iron and magnesium alloy makes such pumps a very poor choice.

Notes:
Heat accelerates chemical processes. Cleaning parts is largely a chemical process. Always use the hottest temperatures practical. (A few charcoal briquettes and a 'hobo' stove will keep a pot of TSP solution simmering for hours.) If you are unable to heat your cleaning solution, or when it is unwise to do so, you must schedule additional soaking time to give the process a chance to work.

Cleaning parts calls for a surprising variety of brushes and scrubbers. I use a variety of rifle, pistol and machine-gun bore-brushes in both bronze and fiber. Cutting the bristles of a regular paint brush to about 1" will provide enough stiffness for scrubbing.

Do not use steel wool on aluminum or magnesium parts. Microscopic fragments of steel become embedded in the softer metal and cause electrolytic corrosion.

The dismantling, cleaning and inspection of a used engine takes considerably more time and consumes far more materials than most realize. In a majority of cases this labor and expense will be wasted, for after going through this lengthy, messy and exacting procedure you may find the parts should not be used for an engine on which you must bet your life.

(*) pg 79, 1972 Edition (rev. 1974), "How to Keep Your Volkswagen Alive! A manual of Step by Step Procedures for the Complete Idiot" by John Muir and Tosh Gregg

VW Engine -- Inspection

by Robert S. Hoover

VW Engine - Inspection of used parts

The two basic forms of inspection are sensory and meteorological. Sensory inspection means using your sense of vision, touch and hearing. Meteorology is the science of measurement. To inspect a part metrologically is to measure it and to compare those measurements to some standard.

Visual, tactile and aural inspection techniques are based on experience. Until you have seen and handled a large number of bad parts it will be impossible for you to make more than a gross distinction. Do the best you can. If unsure, condemn the part.

The use of precision measuring instruments requires less experience than sensory inspection techniques but the minimum suit of equipment needed to accurately blueprint even a lawnmower engine costs about as much as a new car. In light of that fact I'll mention only the most basic measurements.

You won't find a lot of literature about the process of pre-overhaul inspection largely for the reasons cited above. Books are of little value when hands-on experience is required, as in the case of sensory inspection, whereas meteorological methods, being a science in its own right and having its own lexicon, is supported by a vast library of information, little of which lends itself to quick & easy explanations.

I'm not trying to baffle you with bullshit here; people having a commercial interest in homebuilding already feed you more than enough of that. I'm just telling it like it is; as I see it, based on more than forty years of experience.

VW Engine Specifications.

Obtain a copy of the original VW Workshop Manual for the vehicle from which you pulled the donor engine. This is a large, thick book having blue or black leatherette covers and embossed silver lettering. Reprints (in English and other languages) are available for about sixty dollars.

Under no circumstances should you put any faith in the specs found in the 'Official Service Manual' published by Robert Bentley Inc., and distributed by Volkswagen of America, Inc. through its dealers under various 'VW' part numbers. The 'service manual' is in fact an abridged version of the real manual. In addition to numerous typos, the 'service' manual does not contain all of the specs you'll need to blueprint your engine. (This 'official service manual' bullshit is typical of the misinformation that surrounds the Volkswagen.

CRANKSHAFT.

Any discoloration due to excessive heating, or any scoring of the journals or of the radiused corners between the journals and the flanges that leaves the metal looking rough, torn or granular, is sufficient cause to discard the crankshaft.

Nominal journal diameter, both mains & rods, is 55mm with two undersizes (-0.25mm & -0.50mm) of bearing shells commonly available. After-market VW retailers may also carry undersize main bearing shells as small as -1.5mm (!!) but any regrind of more than twenty-thou (ie, approximately half a millimeter) tends to reveal stresses in the forging, requiring careful annealing and straightening of the crank before the final nitriding and polishing. Unfortunately, many regrind shops that cater to the kiddie trade ignore such details. The decision to use a crankshaft reground to such an extent should be based on the competence of the outfit doing the regrind. If you're not privy to the finer details of such work and a regular customer at such a shop the wiser course is to pass on any crank having mains that mike 2.1540" or smaller.

If the crank mikes okay and there is no obvious scoring of the journals, inspect them with a 3x loupe. All used crankshafts are scored to some degree. Rub a copper penny across the journal. It will highlight the scoring, allowing you to make a better determination as to its extent. If it isn't too bad, you may be able to get by with polishing the journals rather than regrinding.

A gross check for a cracked crank is to remove any bolts & washers, suspend the crank from a rope or copper wire and tap one of the flanges GENTLY with a steel hammer. It should have a clear ring, like a bell. This test will only detect a LARGE crack.

Inspect the pulley-end of the crankshaft for any evidence of damage. You will need to magnaflux the crank to detect any small cracks associated with the Woodruff key ways and even so, you may miss one if it has originated in the root of a thread in the nose of the crank. (The usual crack-failure mode begins with a crack initiated by the sharp bottom of the cut threads in the internal bore on the nose of the crank. The crack then
extends to the lower corner of the Woodruff keyway and along that corner to the stress-relief groove adjacent to the #4 bearing, which the crack follows. The usual fix is to remove the internal threads, polish the bore smooth, drilling it deeper so as to put the threads adjacent to the greater thickness of metal in the vicinity of the #3 bearing, and to use a tap having the SAE standard radiused thread-form rather than the sharp-vee'd metric thread form.)

Check the crankshaft for runout after miking the center main for roundness. With a used crank you will have to compute runout rather than measure it directly.

CAMSHAFT

Volkswagen used the same cam for all of the Type I, II and III engines having displacement of 1300, 1500 and 1600cc. The cam gear is different on later engines but in functional terms, the cams are identical.

The camshaft is made of high density cast iron. It is riveted to the cam gear. Check the rivets for looseness and replace if required. Check the gear for chipped teeth and general wear. Since the cam rotates at one-half the speed of the engine, its bearing surfaces wear very slowly and are usually well within spec. But the thrust face often wears at an accelerated rate and must be checked. Also check for runout.

Visually inspect the lobes for asymmetric wear and discard if the tip of the lobe shows a pronounced slope. Using a surface plate and gauge, check to see that all lobes have the SAME lift. The total lift isn't especially important, assuming it is within spec.

CONNECTING RODS

As with the crankshaft, any sign of excessive heating is grounds for tossing the rod.

Visually check for bends and twist. The proper tool for this indexes on the big-end bore, not the cheeks (which are subject to asymmetric wear). A surface plate will provide evidence of gross bending and when used in conjunction with a wrist pin, of gross twist. Bent & twisted rods can be straightened but the equipment to do so without creating other problems isn't found in the average shop.

Torqued to spec, you can use an inside mike or snap gauge to check the big end. Typically, any rod with more than 30,000 miles of service will require rebuilding.

The small-end bushing should accept a wrist pin at room temperature with a tight sliding fit. Turned so the wrist pin is vertical, it should slide out of the rod under its own weight taking three to five seconds to do so when lightly oiled, slightly faster when dry. Anything looser, the rod must be re-bushed & honed.

PUSH-RODS

Check for straightness by rolling the push-rods on a surface plate.

Look for any bright wear marks on the shaft of the rod. Discard the rod if any such mark is deep enough to catch your thumbnail.

Check to see that the ends are securely straked into the pushrods. A loose end may be restraked but before doing so, dismantle the pushrod to try and determine why the end was loose. Usually, the rod-end was not properly aligned when the push-rod was assembled, gouging a scallop in one side of the tube's interior wall. Discard such push-prods; it'll only come loose again.

If the push-rods are otherwise okay and if you are not planning to build a stroker rig some means of flushing the rods with solvent. The push-rod tubes are also oil galleries and since the VW engine was not fitted with an oil filter, on used parts all of the oil galleries and passageways must be scoured & flushed to remove the metallic debris which settles there under normal use.

OIL COOLER

If you plan to reuse an oil cooler it must be flushed or overhauled. The reason for this is that, lacking an oil filter, metallic particles generated by the engine in normal use end up distributed throughout the engine, collecting in any region of stagnant oil flow. The oil cooler provides several such areas and can trap a remarkable quantity of debris... which will end up in the bearings of your freshly overhauled engine unless you do something about it.

The usual flushing procedure uses the adapter plate normally used for pressure-checking the oil cooler but connected to a small parts-washer pump and quantity of CLEAN solvent, which is filtered during use. This same arrangement is used to flush push-rod tubes. A more plebeian arrangement is to rig a pair of buckets to work as a syphon, raising/lowering them as needed to reverse the flow. Another method is to fill the oil
cooler with MEK, plug the holes, put it on a rocker table and let it slosh, periodically pouring out and refilling the solvent.

(The older style upright oil cooler was simply dismantled [it is brazed together] and treated like any other radiator, rodding out the core then reattaching the upper and lower 'cans,' albeit with hard solder rather than soft, due to the pressures involved.)

If you buy a rebuilt dog-house or Type III oil cooler, it would be wise to flush it with MEK. Many after-market 're-builders' merely clean & repaint the exterior.

CYLINDER HEADS

With the valves removed and the head chemically cleaned, inspect the combustion chamber adjacent to the spark plug hole. You are looking for ANY crack between the spark plug bore and either valve seat or between the valve seats.

If a crack is found, do not use the head. Although seemingly innocuous, such cracks cause the valve seats to become loose. Once you lose the valve seat you will probably lose the entire engine.

If the heads have been bead-blasted or the chambers wire- brushed, you will need a dye-check to detect any cracks. (Many lo-buck re-builders often use bead blasting and various surficants to deliberate conceal such cracks.)

Using a good light and inspection mirror, examine the valve guide bosses for cracks, especially in the exhaust port. Discard if any are found. (The problem here stems from the fact the exhaust valve guide wears about 4x faster than does the intake guide, and many lo-buck re-builders do not heat the head when replacing the guide. Overstressed by inserting the valve guide cold with a hydraulic press, when the engine reaches operating temperature, the cast boss often cracks. And once cracked, the guide is no longer supported.)

Examine all of the studs. Replace any which are damaged, eroded or loose. Be especially critical in your examination of the two 6mm studs used to secure the intake manifold on single-port heads. (Single port heads do fine for aircraft applications. Most of the better breathing capacities of dual port heads do not begin to show on the charts until the rpm is beyond the useful range for most propellers. Plus, single port
heads are much less prone to cracking, due to the greater thickness of metal in their casting.)

Inspect the threads in the spark plug hole. If a steel insert or Heli-coil has been installed, discard the head. (This threaded bore is critical with regard to heat transfer, not mechanical strength. Helic-coils and 'head-savers' do not provide the proper heat-flow.) [The proper repair for a stripped spark plug bore is to hog out the bore to a generous cone, re-weld then remachine the head..]

Examine the head for any cracked, broken or missing fins. A broken fin can be repaired but the cost is difficult to justify in less than wholesale quantities.

There should be a small steel air dam wedged into the fins in the middle of the head on its lower side. This air dam is a critical part of the cooling system.

Measuring from the machined bosses adjacent to the combustion chamber, check the depth of the sealing surface. It should be about 0.515". Renewing this surface is a valid overhaul procedure but doing so alters both combustion chamber volume and valve train geometry. The key factor here is that the sealing surface depth must be EQUAL for both heads. If the sealing surface depth on your heads is different, the 'high' head may be machined to match the other but if the depth is 0.550" or more you will run into problems when setting the compression ratio and in the valve train geometry. If you are an experienced engine builder, these are minor points. (But if you were an experienced engine builder you probably wouldn't be reading this :-)

Inspect the gasket sealing rail around the valve gallery. It should be glass smooth with a slight chamfer on either edge. Inspect the valve guides for tightness and their bosses for cracks. Use a glass to examine the valve spring seating surface. The valves tend to cut a groove into the softer cast aluminum. This not only wears out the head, it upsets the valve train geometry and effects the engine's volumetric efficiency. If the spring seating surfaces are not uniform, you may be able to have them re-machined, depending on the extent of the wear. Here again, this is a case where both heads must be identical. Standard practice is to install a specially machined steel washer for the valve springs to bear upon.

Finally, inspect the sockets for the valve cover bail. The stock stamped steel valve covers are the best choice for aircraft engines by a wide margin, even though the CAA inspectors in some countries insist the valve covers be secured with bolts(!) The stock valve cover is not only lighter in weight and less expensive, it actually transfers more heat than does the typical cast aluminum valve cover. The spring steel bail is easily safetied, should that be an issue. (In many countries the civil aviation functionaries are clerks rather than pilots or mechanics and often insist that you follow procedures designed for certified engines that may be grossly impractical and even unsafe when applied to a Volkswagen engine. Even so, it is always wise to satisfy their bureaucratic requirements. Once they are out of the hanger you may do whatever you wish.)

(New cylinder heads, complete with valves & springs, cost about $125 per head. These heads are manufactured at Volkswagen's plant in Puebla, Mexico. On average, about four out of every five NEW heads will fail one or more of the inspections outlined above, usually due to problems in the basic casting but occasionally from cracks in the valve guide bosses or damaged/missing studs. For this reason I've found it extremely unwise to purchase new heads via mail order.)

ROCKER SHAFT, ROCKER ARMS & HARDWARE

The rocker shaft is a round steel bar, ground to a precise diameter. It wears quite slowly. But it does wear, and does so asymmetrically due to the load placed on the rockers.

The area protected by the rocker shaft towers is not subjected to wear and may be used as a standard of comparison.

When a rocker shaft accumulates wear on its lower surface, it may be turned over and reused. When wear has accumulated on both the upper and lower surfaces, it should be discarded.

Rocker Arms

Look for scoring on the bottom of the bore for the rocker shaft. If scored, discard.

Insure the oil passageway is clear from the push-rod cup to the bore and from the bore to the adjusting-screw bore.

Resist the urge to replace your perfectly useful plain-bearing rocker-arms for those fitted with needle bearings. Needle bearing rockers require more oil than the stock system can provide to the right bank of cylinders. There are several modifications that speak to this problem but most of the folks selling needle rockers conveniently fail to mention them, stressing instead the ease with which you may unbolt that old
fashioned stuff and bolt on their newer, lighter and stunningly more expensive product.

Hardware

Your valve train hardware consists of a set of eight flat washers, four warpy washers, four hairpin-like clips, four adjusting screws, four adjusting nuts, the two rocker shaft towers and their associated pairs of nuts & washers.

IF any of the large washers, flat or warpy, have accumulate enough wear so as to catch your thumbnail, replace them. Ditto for the hairpins.

Stock VW valve-train hardware is perfectly suitable for the rpm you'll see in an airplane. Complaints about the inadequacy of this hardware are almost always linked to a combination of high rpm and inadequate lubrication, the latter fault typically stemming from excessive clearance in the cam-follower bores.

VALVES

It does not make good sense to put used valves into an aircraft engine. When the history of a flying VW engine is known, there is little harm in refacing and reusing the intake valves, assuming all other factors so indicate. But the failure mode of VW exhaust valves having 8mm stems is such that the wiser course is to never reuse them under any circumstance.

VALVE KEEPERS & SPRING RETAINERS

If, when tested on a new valve, the old keepers are perfectly tight, they may be reused. But keepers are so inexpensive it makes little sense to use old parts.

Failure of the valve spring retainer is extremely rare. Spring retainers accumulate wear at two points; inside the forcing cone and where the spring contacts the retainer. I don't know of a spec for wear in these areas. Lacking a published spec, I compare old parts to new parts, discarding any old part more than .0015 'out' when compared to the new part. Normally, I would use new retainers as a matter of course but since I prefer to used parts of equal mass, and since I no longer have access to the stacks in the parts departments of the local VW dealers, I am forced to sort through old parts to find a set of eight that perfectly match in weight & size.

Early VW engines used a different, weaker spring retainer. These should never be used in any engine over 1200cc, nor with the later model valve springs.

VALVE SPRINGS

Valve springs are another case where it would prefer to use all new parts but due to the wide variation in tolerance, you must sort through two or three dozen springs to find eight that are a prefect match.

The stock spec for VW valve springs is 126 pounds (measured at a compressed height of 31mm), with a range of plus OR minus four and a half pounds (ie, 126, +/-9). I don't worry about the actual poundage so much, although for a low rpm engine LESS is better (this is exactly opposite to the rule for high rpm engines). What I work to achieve is eight valve springs identical within a pound or less, with a compression of at least 120 pounds. This works out quite well for valves of stock diameter.

You may check your valve springs by rigging digital bathroom scale on the workbench with a lever arrangement to fix the compression height. When properly calibrated (the handmaiden of meteorology :-) the typical electronic scale is surprisingly accurate.

CRANKCASE

Inspect the crankcase for cracks, especially at the base of the #3 cylinder bore (ie, on the clutch-end of the crankcase). Also check the oil pressure sensor boss. The latter is often cracked when the oil pressure sensor is over-torqued. The former is subject to cracking because of an inadequate depth of metal in the casting at that point, a problem that has been rectified in crankcases of recent manufacture (at the Puebla plant).

On the interior, look for any evidence of catastrophic damage, such as gouges caused by a bent or broken connecting rod. Be especially critical when inspecting the center main bearing web.

Feel the main bearing saddles. If the nomenclature of the bearing shells has been embossed into the case deep enough to catch your fingernail, the crankcase must be align-bored.

Inspect the eight cam-follower bores for chips and cracks. Measure or gauge their bores. (You may use a new lifter as a gauge, using the 'wiggle' test.)

With the crankcase torqued to spec, use an inside mike or snap gauge to measure the main bearing bores. Stock is 65mm with the usual metric tolerance.

In measuring the bearing bores of a used engine your main purpose is to determine if the crankcase has already been align- bored. If it has, the next question is 'How much?' and is another align-bore even possible, if needed. Personally, if it's already been align-bored and needs another, I wouldn't consider it for use in an airplane. But it's up to you; you are the Mechanic-in-Charge.

Using snap gauges, determine the bore and profile of the oil pressure control valve cylinder (and of the oil volume control valve, if so fitted [ie, 1971 & up]) You may use the original piston for a gauge, if you wish. A bore score & light will aid in your inspection here.

The odds are overwhelming that the cylinder will be worn. Since VOA has abandoned support of aircooled Volkswagens, you will have considerable difficulty finding an over-size piston (VW offered two). One alternative is to mike a batch of after-market oil control valve pistons. The quality of after- market stuff is rather shoddy and you may find a 'fat' piston that meets your needs. But the most practical option is to have
the piston-type valve converted to a ball-type. Machine shops that specialize in VW engine work are familiar with this procedure and the cost is generally very modest.

When a crankcase is modified to use a ball-type oil pressure control valve, the oil volume control valve (ie, the valve located on the far end of the main oil gallery, adjacent to the flywheel) is not needed and may be blocked closed.

Since greater engine durability inherently enhances safety, and since the single, most effective means of improving the durability of the VW engine is to provide for full-flow oil filtration, I've not built an engine without this feature since the mid-1960's, when I first learned of its benefits. (As a point of interest, all modern engines are fitted with full-flow oil filtration.)

A new Universal Replacement Crankcase from the Puebla plant presently costs about $350 here in southern California. You can spend more than that reconditioning a used crankcase and still end up with a piece of crap unless the work is done by a competent shop, which are outnumbered a hundred to one by the other kind.

(The prices I've mentioned in this article are valid as of October, 2000, for southern California.)

VW Engines -- Parts Overhaul & Blueprinting I
by Robert S. Hoover

Component VW Engine - Blueprinting & Overhaul

In previous articles I've addressed dismantling a donor engine, cleaning the parts and performing a gross inspection of those parts once cleaned. The next step is to overhaul your collection of worn, used parts to make them suitable for use in an aircraft engine. But unless you've got a shop full of equipment and have some experience with Volkswagens or other air-cooled engines, the wiser course is to have the overhaul work done by someone having the proper tools and experience.

This caveat also applies to assembly, although I'll provide some information on that subject that will at least get you started. But be very cautious here. If you have a lot of water-cooled engine experience you are especially vulnerable because only about 50% of what you know can be directly applied to an air-cooled
engine. The differences are subtle. Most stem from the fact some areas on air-cooled engines normally run as much as 200 degrees hotter than the same area on a water-cooled engine. Others reflect the fact a VW engine is a sandwich of magnesium alloy crankcase, aluminum heads and a layer of cast iron jugs in the middle. Such an engine reflects a different design philosophy than its monbloc, water-cooled cousins. The bottom line is that what works with a big-block Chevy or Ford is often dead wrong literally for a VW, Corvair or Lycoming. So be cool. Pay close attention to the VW specs. Many of them look wacky as hell compared to specs for similar components on water-cooled engines but the folks at Volkswagen knew what
they were doing, as more than 22,000,000 air-cooled veedubs have shown.

BLUEPRINTING

To 'blueprint' a component means to compare the dimensions of the machined part to the original blueprint. The purpose is to insure your collection of parts will fit together. Just that. Nothing exotic at all. Engine assembly, on the other hand, focuses on how well that collection of parts fits together. Many times, they don't. An overhauled rod that comes in on the high side of spec, when mated to a reground crankshaft that comes out on the low side, may result in a bearing clearance that is out of spec. Your overhauled engine is 'worn out' before it's even assembled!

VW after-market retailers cater largely to the 'kiddie' trade, mechanically naive youngsters who will only own their Volkswagen bug or bus thirty months, on average. During that time they will buy a lot of parts, since due to poor

maintenance on the part of the previous owner, the bug or bus they acquire will be in a woeful state of repair. Unfortunately, their lack of experience prevents them from knowing good parts from bad. Shopping mainly by price, they will buy a lot of junk. But the robust nature of the VW design allows an engine built from junk parts to run. Not very well and never very long but loudly and with enough chrome to satisfy this curiously American Rite of Passage. After about two and a half years the kiddies sell
their VW to the next youngster in line, buy a Toyota and get on with their lives.

The VW-specific magazines and VW after-market retailers depend upon this 'churn' of new, naive owners for their survival. Unfortunately, in buying shoddy goods the kiddies have largely driven quality goods out of the marketplace and grossly inflated the price of those that remain.

You will discover the effects of this for yourself when you blueprint a batch of after-market parts, a high percentage of which fail to meet minimum factory specs.

OVERHAULING THE CRANKCASE

Align-boring.

In normal use the main bearing bores of the VW crankcase get pounded out. Careful measurement of the original 65mm diameter bore typically reveals a four-lobed shape having two major 'lumps' and two shallower departures from a circle. Overhaul of the crankcase involves reaming the main bearing saddles back to a true circle the so-called 'align-bore'.

For a competent machinist, an align-bore is a relatively trivial task. The pulley-end and clutch-end of the crankcase casting have accurately machined surfaces which will grip and locate a bushing turned to a suitable size. The boring bar or reamer rides in the center bore of the bushings. Given the short length of the crankcase a boring bar 1.5" in diameter provides adequate stiffness and the work is easily accomplished on a lathe having a 12" swing.

If you elect to do this job yourself the major chore is fabricating the boring bar. The rake angle and nose radius of tools ground for aluminum work equally well on magnesium alloy. The depth of cut needed to clean up the out-of-round condition is typically twenty thou (0.50mm). Anything more and you'll probably have to deepen the holes for the bearing studs.

Sets of oversize bearings come in 0.25mm steps (about .010) for all valid combinations of ID & OD. In addition, the #1 bearing comes in two widths & flange thicknesses to accommodate refurbishing the thrust face, a necessity when adjusting the end-float..

Shops that do a good deal of VW machine work have tools and machines dedicated to the align-boring task. The price usually quite reasonable and some will sell you the required bearings as part of the package.

Decking

'Deck' is both generic and specific. In the generic sense it means any level surface parallel to the axial plain of the crankshaft. (I'll mention another 'deck height' with regard to assembly.) The deck I am speaking of here is the shelf around the cylinder's spigot-bores, upon which the base of the cylinder bears when the engine is assembled. Decking is the companion to align-boring; if a crankcase needs the one, it usually needs the other.

One of the oddities of the VW engine as compared to the typical water-cooled monobloc design is the torque specs for the head studs. On older engines fitted with the fat 10mm studs, the torque spec is 23 ft-lb. On the later model engines fitted with the smaller 8mm head studs, the torque spec is just 18 ft-lbs.

That's at room temperature, of course. At normal operating temperatures the tension on the head studs is equal to that produced by approximately 170 ft-lb of torque(!!)

In the design of the original 985cc Volkswagen engine, Xavier Reimspiess took into account the vastly different thermal coefficients of the aluminum heads, the cast iron cylinders and the magnesium alloy crankcase. As the engine reaches normal operating temperature the heads and case not only expand faster, they expand farther. In effect, they try to expand away from the jugs, which are just ho-hum old cast iron things that hardly notice the temperature change. But with the case and heads held captive by the studs, the thousands of pounds of force produced by thermal expansion appears as tension in the studs. That tension is what keeps the heads from leaking.

How important is all this? Far more than you realize. Back in the mid-1950's the only thing that could void the warranty of a new Volkswagen was failure to return to the dealer for the 300- mile post-sale service. The customer was simply told that it was part of the break-in procedure. But a vital part. Because the major service item was to re-torque the heads. After that, they were generally fine for the next 30,000 miles or so, at which time most would need a valve job a relatively minor chore on a VW.

While proper head torque insures adequate sealing thanks to the remarkable difference in thermal expansion, over time that impressive amount of tension causes the cast iron jugs to swage themselves into the softer metal of both the head and case. And of course, doing so reduces the tension on the studs. With less tension, the jugs tend to 'shuffle' as they heat and cool, accelerating the wear of the deck surface and leading to leaks in the compression chamber and at the crankcase. Which is why machining the deck height back to truth is a standard part of overhauling a used crankcase. But there's a bit more to it than slapping it in the mill and making things flat.

Case deck height is one of the factors that determine how far the heads are positioned from the centerline of the crankshaft. That distance impacts your valve train geometry as well as the engine's volumetric efficiency.

So you don't just deck the thing, you make sure each deck is precisely the same distance from the centerline of the crankshaft. If you don't, the stack-up of errors can rob your engine of as much as 10% of its potential power.

Case Savers...

...are steel barrels having threads both inside and out. The outer thread is coarse, suitable for threading into a soft non-ferrous magnesium alloy. The inner thread matches the thread of your studs.

Hot rodders started using case savers on VW engines back in the 1960's. Volkswagen got around to it in the 1970's. If your crankcase doesn't have them, it should.

If you want to do this part of the job yourself you can either buy or make the case savers. (They cost about a dollar each; you'll need sixteen of them.) Just be sure to do a proper job of drilling & tapping the crankcase you want those puppies installed perfectly true otherwise your head studs will be pointing in all directions and the asymmetric loads imposed on the crankcase will cause cracks around your crooked case savers.

Welding & Deep Studding

Turn your crankcase up on it's nose, sump toward you and examine the area to the right of the #1 main bearing boss. See that deep depression under the #3 cylinder? That's where it's going to crack if you open the case up to accept larger jugs.

And even if you don't :-)

See the upper stud for #3? The one nearest the clutch-end of the case? The threaded bore does NOT go all the way down to that thicker section of casting adjacent to the #1 main bearing saddle. And on older engines #3 runs hotter than any of the other cylinders.

Remember the thing about thermal expansion and the tension on the studs? Guess what happens next :-)

Cracks under #3 cylinder have been a problem since the introduction of the 1500cc engine, bored out or not. The usual fix is to preheat the case and use TIG to fill in the depression, adding a thick layer of new metal atop the too-thin casting. Then you drill the upper-front (on Volkswagens 'front' is always relative to the vehicle; the clutch is on the front of the engine, the pulley is on the rear) stud deeper and re-thread it,
replacing the short upper stud with a longer lower stud. Since the case must be align-bored after being welded upon, filling in the depression is usually done in conjunction with align-boring and other crankcase overhaul procedures, usually for a single fixed price.

But as with the case-savers and so much else, Volkswagen learned its lesson. On new, Universal Replacement crankcases the design flaw under the #3 spigot bore is gone. That area is now cast solid.

Full-flow Oil Filtration System

A full-flow oil filter is the smartest money you can spend on a VW engine since it will literally double its useful life.

The procedure is quite simple and fully illustrated in Bill Fisher's "How to Hotrod Volkswagen Engines." (Although published in 1970, much of the information in this book will never go out of date.)

The procedure involves pulling the plug from the pump-end of the main oil gallery and threading it to accept a 3/8NPT fitting.

That's it.

To filter the oil you block the output of your oil pump with a suitable threaded plug or set screw and replace the stock pump cover with one having a threaded outlet. Such covers, in either cast iron or aluminum, are standard items at any after-market VW dealer. For best protection you should use a pump cover that incorporates a relief valve Gene Berg Enterprises sells a good one and you should use aircraft quality hose & fittings.

Once you have plumbed access to your lubrication system the oil filter may be installed anywhere within reason.

Best of all, such an installation makes it a snap to add an oil cooler.

Ball vs Piston

If your crankcase is used, chances are the cylinder(s) for the oil control valves are worn beyond spec. Oversize control-valve pistons are available but they are difficult to find and offer only a symptomatic fix. The thing wears because it's badly designed to begin with. A permanent fix is to get rid of the piston by converting the valve to a ball-type.

The problem is caused by the pulsations produced by the oil pump, which is in fact a low pressure hydraulic pump easily capable of putting out 300psi on a cold morning. The pulsations cause the piston to work up & down at a rate determined by the rpm and the spring under the piston. The constant up & down motion is what wears out the cylinder and the best fix is to replace the piston-type valve with a ball-type. But here's the interesting thing: When the engine is fitted with a full-flow oil filtration system the hoses and filter canister act like an hydraulic accumulator. By the time the oil reaches the control valve the pulsations are gone(!) That means you needn't worry about this problem IF your oil control valve is a proper fit in its
cylinder and IF you are running a full-flow oil filtration system. And as a point of interest, the pressure relief valve incorporated in the Berg pump-cover mentioned above is of a ball-type.

To install a ball-type valve you must install a seat for the hardened steel ball. For late model cases with the large (10mm) oil gallery I knurl a section of 7/16" x .063 4130 tubing, chamfer the end to provide a seating surface for the 5/8" diameter ball and cut the kurled tube to a length of about 3/8". The existing oil inlet hole is drilled & reamed to provide a steep interference fit to the knurled tubing, which is pressed into place, coated with sleeve retainer, using a stepped drift. The stock spring must be replaced by one slightly longer. There are a variety of springs which will work, including most of those included in after-market 'high pressure' kits.. A batch I bought from J. C. Whitney years ago provides about 60 psi when starting, 45psi running and 10 psi at hot idle. (Minimum idling oil pressure for the VW engine is three to five psi, another artifact of its 1930's origin.)

All of the good VW machine shops can convert your piston-type valve to the ball type.

Bigger Jugs, or Every Boy's Dream :-)

If you wish to increase the displacement of your engine the best method is to install larger cylinders. In theory, all you need do is bore the crankcase & heads to accept the larger jugs and build the engine around them. In theory.

In reality, while the above describes the procedure pretty well there are a host of problems associated with designing your own engine -- because that's what you're doing when you depart from the factory specs. You're saying you are at least as wise as the thousands of man-years of experience embodied in the stock design. But you're not. Neither am I ...and I've been building large-displacement, high-output Volkswagen engines since Jonah was a Seaman Deuce. So be very cautious here. The realities of building a big-bore engine are far removed from the quick & easy procedures advocated by the VW-specific magazines.

With regard to reliability -- and to me all else takes a backseat to that when I'm halfway between Palomar and Avalon -- the major problem with bigger jugs is the simple fact that as the interior volume gets bigger, the sealing surface gets smaller. Stock jugs have sealing surfaces as wide as .3" while some big-bore jugs are as thin as .11". A set of 90.5mm jugs, with a sealing surface of about .130 appear to offer the best
compromise between increased displacement and proper sealing.

Slap a set of 90.5 jugs on your engine and you get a displacement of 1776cc, the so-called 'Liberty' engine.
Unfortunately, despite claims to the contrary, that 12% increase in displacement does not mean a 12% increase in thrust.

(Stock displacement is actually1584cc, hence the 12%)

If you're using the stock cam your torque peak is down around 2000 rpm and is already falling off at the speeds most of us run. With a 1776 (or even the 1834) you do see some improvement in power but you can forget the fantastic claims from those folks selling you such engines. The real difference as seen by your prop is seldom more than two inches in either pitch or diameter. (A different cam can change that. I'll have more to say about cams later.)

To install larger cylinder barrels the spigot bores in the crankcase and heads must be machined to the larger diameter. While the operation itself is a straight-forward bit of machine work, it is extremely important that the proper clearance be provided. If the re-machined spigots are too small you can get scuffed pistons and broken rings but if too large the jugs will 'shuffle' as they heat & cool, destroying both the case-deck and the combustion chamber sealing surface. The usual rule is .001" of clearance for each inch of bore, rounded up, with the usual work-tolerance of about -0, +.0015". I've taken the time to mention this because I've seen hundreds of perfectly good engines turned into junk by incompetent mechanics.

An automotive machinist commands a higher salary than a mechanic and for that reason it is rare to find a mechanic, especially today's 'Volkswagen' mechanics who is a competent machinist. Yet many VW mechanics use portable tools to align-bore crankcases and open up heads & cases for larger jugs. Alas, it is extremely rare to find a mechanic who reforms these tasks correctly, not with regard to the operation of the portable tool itself, but in setting and sharpening the cutters. A common failing is to cut the heads and crankcase to the SAME diameter when installing 92mm jugs, telling their mechanically naive customers they do this on purpose so the cylinders won't stick in the crankcase. Like a bad architect planting ivy, such mechanics use lots of high temperature RTV to seal the obvious gap. A maximum useful life of about three
months is typical for such engines. (Big-bore engines are defined as 'racing' engines and do not enjoy the protection of the 'Normal standards of craftsmanship' included in most automotive Consumer Protection legislation. Over the years this loophole has attracted thousands of incompetent mechanics and machinists to the after-market VW racket.)

If you are a novice engine builder you can skew the odds of success in your favor by having all of your machine work done by a shop that specializes in VW automotive machine work, even if you must ship the parts to the shop. Weighing less than 25 pounds and making up a cube only 14 inches on a side (ie, without the studs), a VW crankcase is easy to package and ship. The same applies to your heads and crankshaft. Here in southern California one such shop is Riddle Machine Company aka RIMCO, 520 E. Dyer Road, Santa Ana, CA 92707. Their phone number is 800-331-4775

CYLINDER HEADS

At the very least, your used heads are going to need the seats stoned and new guides for the exhaust valves. Chances are they can also be made to cool better. To accomplish this minor miracle all you need is a tool that can get down between the fins to remove any casting flash and a few drills and burrs to clean up the cooling air passageways nearest the exhaust valves.

The best tool for getting down between the fins to remove the casting flash is a pneumatic riffler fitted with a coarse file but a variable speed saber saw driving a long, coarse-toothed woodcutting blade can be made to serve. You'll need long drills and burrs to get into the corners of the air passageways near the exhaust valves.

If you open up your heads to accept larger jugs you can make a significant improvement in your engine's breathing ability by unshrouding the valves. See Bill Fisher's book for a well- illustrated how-to. The use of a template will help you keep the chambers equal.

Your most critical task in setting up your heads is a two-fold chore. One part is to insure all of your valves have equal stem height. This speaks to your valve train geometry. The second is to make the volume of all four combustion chambers equal to within .5cc or better. These two tasks are a set since the usual method of adjusting chamber volume is to sink the intake valve... which increases it's stem-length. Normally, you cc the chambers then clock your valves, chucking them into the valve grinder and facing off the stems as required.

VW Engines - Parts O'haul & Blueprinting - II
by Robert S. Hoover

CONNECTING RODS

I don't do rods. I don't have the tools for it. I wait until I've got a couple dozen cores then haul them up to Jack Riddle's shop and trade them in for rebuilt's. With 24 rebuilt rods to pick over, chances are I can find a set that comes pretty close to the same length and are in the same weight group. Then they go over to the balance shop where each set is re-balanced to .5 grams or better across the set of four.

When a rod is overhauled, its finished dimension, measured from the center of the journal to the center of the wrist pin, will usually be different from the factory spec by some small amount. Ideally, all of your rods should be exactly the same but there is some variation with even new stuff from the factory. In building a good engine you must take even these small deviations into account.

Stock VW rods are marked with matching numbers on the rod & cap. Record these numbers. (See my comment about documentation under 'Pistons & Cylinders.')

When you have fixed on a set of four rods and recorded their numbers, measure them to determine the distance between the big end and the little end. I use a jig for this, accurate to tenths but that's really gilding the lily. A beam type caliper accurate to a thou should work just fine. Your set of four should all be within .001"

(What happens to the rods I find unacceptable? Keep in mind the fact that parts I consider unacceptable for an aircraft engine aren't junk; they usually exceed the factory spec's by a fair margin. But they're not good enough to risk your life upon. Most eventually end up in engines for bugs or buses. But the truth is, I don't use a lot of VW connecting rods. The length of the stock VW rod is 137mm (about 5.4") meaning any stroke longer than 73.8mm will violate the 'Ricardo' rule, resulting in excessive side-loading of the cylinder and a dramatic increase in the wear rate. Most of the engines I build are big-bore strokers. For longer strokes you must use longer rods, either specially made 'stroker' rods or modified Chevy rods.)

RAP ON BALANCING

When the VW engine was designed in the 1930's the conventional engineering wisdom of that age said horizontally opposed engines were inherently balanced. Scant attention was paid to mass balance and none at all to dynamic balance.

The phlugoid motion phenomenon, a principle cause for the center main bearing web to pound out, and which may be largely eliminated by the use of a counter-weighted crankshaft, was not quantitatively defined until the late 1940's. The benefits of dynamic balancing in production-run engines was not fully appreciated until the early 1950's. The reports detailing the miraculous increase in engine durability stemming from full-flow oil filtration first appeared in 1956.

With regard to the Type I engine, Volkswagen chose to ignore all such advances. The production tooling was fully amortized, the resulting product, although technologically dated and not especially durable, was widely accepted and the margin of profit was high. Rather than incorporate newer technology Volkswagen chose instead to periodically bore & stroke the basic design.

Modern specs for dynamic and mass balance are an order of magnitude better than anything Volkswagen used. The plant at Puebla in Mexico observes modern standards and produces better engines than any that ever came out of Germany because of it. The 1600cc 'crate' engines fresh from the Puebla plant typically dyno 68 to 75 hp for juicers, about 3hp less for solids.

A balanced engine is more efficient. This higher efficiency results in more power for the same amount of fuel. But most important, a balanced engine is significantly more durable. All modern engines are balanced.

PISTONS & CYLINDERS

In an earlier article I pointed out that it is extremely unwise to try and re-use old cylinders & pistons. I'll assume you've bought a new set of jugs, ideally after examining them to make sure they are of the same weight group.

Unbeknownst to most novice engine builders, components do not come ready for installation. They must first be cleaned and inspected. This is especially true of VW piston & cylinder sets, which are typically preserved & packaged for export and warehousing prior to sale, a period that may span years.

Paperwork

Once the pistons have been dismantled and marked you may clean them and the jugs. To keep track of the parts as the work progresses you must begin with a bit of paper work.

Central to building a proper engine is keeping track of what you do. This documentation doesn't amount to much a few pages in a notebook but the information is absolutely vital if you want to build the best possible engine.

Weight Groups

Pistons come in several weight groups. The weight group is identified by a dot of colored paint on the piston's crown. Some manufacturers also provide a + or - sign to indicate if the weight is above or below the median for that weight group. The usual weight group is 10 grams (about 0.35 ounces). If all of your pistons were marked + and had the same color of paint dot it is fair to assume their weights would be +/- 2.5gm. Indeed, many after-market VW parts retailers brag in their catalogs about sorting through their stock of P&C sets to make up 'selected' sets, for which they charge a premium. Unfortunately, the rejects are often stuffed back into the cartons in a totally random fashion. It isn't uncommon to open a carton of mail-order jugs and discover your new pistons come from more than one weight group, meaning you're going to have a hell of a time balancing them.

(The joke here is that those premium priced 'selected' pistons must STILL be balanced. To any competent engine builder plus or minus two and a half grams across a set of four is really saying they aren't very well balanced at all. The usual standard is on the order of +/- 0.1gm)

Dismantling the Pistons

Make up four baggies and four paper tags marked 1 through 4. These are 'works numbers' designed to keep the piston, rings and cylinder together as you work on them. (As with the numbers on your connecting rods, the works number you will apply to your cylinders & pistons has nothing to do with the engine's cylinder number designation.)

To mark the cast iron cylinders, use a file to cut a small notch in the upper most of the 'flat' fins, one notch for #1, two notches for #2 and so on.

Push the piston out of the cylinder. Mark the piston using a steel stamp or scriber, putting the number on the INSIDE of the piston in an area which will not be machined away during the balancing process.

Remove the rings one at a time and make a sketch of their profile and orientation. Keep this sketch with the engine's documentation package. (Piston rings come in a wide variety of shapes & thickness. There appears to be no long term standard even among rings from the same manufacturer.) Put the rings and piston pin into a baggy along with the appropriate number tag.

Your pistons must be statically balanced AFTER the initial pre-assembly of the engine.

(It's relatively easy to match a set of four to 0.1 gram using nothing more sophisticated than patience, an accurate scale and a suitable tool to remove the excess metal from the appropriate places. The piston is weighed along with its pin and its mass 'as received' recorded. Once you know the lightest of the four you simply remove metal from the other three until they are of equal weight. Pistons are provided with 'balancing pads' where metal may be removed without effecting the structural strength.)

After being cleaned, the pistons must be measured to determine their head thickness. This is done using a surface plate and suitable gauge. Push the pin partly out of the bore, place the crown of the piston on the surface plate and measure the distance from the top of the pin to the surface plate. Record this dimension.

Cleaning & Painting the Cylinders

After being cleaned of all preservative, the cast iron cylinders must be CLEANED. This is another area where a huge question mark forms over the head of novice engine builders :-)

As received, the walls of the cylinders are contaminated by honing grit. It is the mechanic's task to remove this grit. If you're a pro you have a special ultrasonic tank for this task. The rest of us must resort to the old fashioned method.

The old fashioned method of cleaning honed jugs is to scrub them with copious amounts of hot water using Bon-Ami (brand name) non-chlorinated scouring powder and a new synthetic sponge.

Household scouring powders often contain such lovely stuff as ground glass(!) sand and other abrasives. Most also contain chlorine, something you don't want any where near cast iron. Bon-Ami contains diatomatious earth, chalk and washing soda (ie, calcium carbonate), which happens to be the same stuff found in commercial compounds used for scouring honed cast iron cylinders.

Natural sponges often contain sand and bits of limestone from the sponge's skeleton. It's best to use a synthetic sponge.

It takes about twenty minutes(!) per cylinder to scour them properly by hand. Scrub up & down the bore, not 'round & round.

Have a can of WD-40 immediately at hand as you do the final boiling water rinse. The jug especially the freshly scoured bore will IMMEDIATELY begin to rust as it dries. So don't let it dry. Spray the bore with WD-40 as you complete the boiling water rinse, using it to displace the water as you carry the jug to the work bench, where you should immediately swab the bore with oil. Don't worry about the exterior; a little rust isn't going to do any harm.

Scour all four jugs.

Rig a broom stick or similar bar to support the jugs above the bench. Using solvent, flush their exterior to get rid of any WD-40 or oil.

Prepare a 1" wide bristle-type paint brush by cutting away half the bristles at the ferule. What you need here is a brush having bristles as long as those found on a 1" brush... but only half an inch wide. And no one makes such a thing at a price you can afford. (I use those cheap Chinese brushes, purchased a carton at a time, discarding the brush after use.)

Mix four parts of flat-black Rustoleum (brand name) paint with one part of thinner and use your long, narrow brush to apply the paint between the fins, reaching all the way to the bottom.

Is this coming across? Probably not :-)

Your jugs are cast iron. They are going to spend the rest of their natural lives hanging around the nose of an airplane, maybe in a hanger if they're lucky but for most the best they can hope for is a leaky canvas cover.

That means they're going to rust. And rust is a very good insulator, as any welder will tell you.

If you build a proper engine it is going to cost you at least a couple of thousand dollars... or a couple of hundred hours of your time. Or both. The paint is an inexpensive way to protect that investment and to insure the engine will work as well as it should.

Why the modified brush? Because you can't spray paint between the fins. By the time you get enough paint on the bottom you'll have runs all over the place. (Go on; try it.) So you need to apply the paint with a brush. But you can't use just any brush; it must be a small one, in order to fit between the fins, but the bristles must be long, in order to reach the bottom of the fins. And while there are such brushes artists and sign- painters use them they are not commonly available and are very expensive.

As for thinning the Rustoleum, paint forms a thermal barrier, the thicker the coating the better the insulator. We want to use the thinnest coating that is practical to apply... which works out to about a 4:1 mix. (You are the Mechanic-in-Charge experiment with the mixture and use what works best for you.)

Why Rustoleum instead of high temperature stove paint? Stove paint derives its high-temperature properties from clay or metallic salts, both of which make wonderful insulators even in a very thin coating. If you use such paint on your cylinders or crankcase it will cause the engine to run hotter than it should. Plus, high temperature paint isn't especially good at protecting the surface from rust, as the owner of any barbecue or wood- stove can tell you.

And finally, the jugs don't get hot enough to require a high temperature paint. Rustoleum flat black does just fine up to about 450 degrees Fahrenheit. If the barrels of your jugs get that hot you will have a far more serious problem on your hands than paint-work.

(Can't find those itty-bitty cans of Flat Black Rustoleum? Then use Gloss Black... but use naphtha or gasoline(!) as the thinner. The higher evaporation rate will cause the enamel to dry with a dull finish, which does a better job at radiating heat.)

In painting your jugs be careful to not get any paint on the machined surfaces. (Yeah, I know... me too. Just clean it off.)

Let the paint dry then inspect for holidays, touching up any you find. You may harden the paint in your hot box if you wish.

VW Engine - Parts O'haul & Blueprinting - III
by Robert S. Hoover

VW Engines – Component Overhaul & Blueprinting

Measuring Cylinder Length

Once your jugs are cleaned & painted there is less hazard in handling them with your bare hands. But cast iron jugs are brittle. If you drop one, you'll shatter the fins, making it unsuitable for use in an aircraft engine... and not all that good for use in a car :-) So be careful. When you have to handle them, do so one at a time.

You need to know how long your cylinders are, measured from the deck lip at the bottom to the upper sealing surface. The easy way to do this is to stand them, sealing surface down, on a surface plate and measure the height of the lip.

The length of your cylinders should match to within .0015" with a tolerance of plus or minus a thou. If any exceed the nominal length by more than two thou or so you're going to have to do something about it. The usual fix is to chuck the fat jug into the lathe, using a suitable fixture, and turn down the deck-shelf lip.

What you're trying to do here is come up with a set of parts that will position the heads the same distance from the centerline of the crankshaft. A cylinder that is a different length than its partner means that the torqued-length of the head studs will be different. At operating temperatures the amount of tension in the studs will also be different. This will lead to sealing problems but uneven torque is also the thin end of the wedge with regard to engine durability. Once the engine has gone through a few cycles of heating and cooling the studs will loosen up.

Virtually all builders of automotive engines do not put any importance at all on such 'unimportant' details. But it is largely the attention given to such details that accounts for the difference between an aircraft engine and the engine in a car.

Record the length of your cylinders in your documentation package. (All of this dimensional data will be used when we assemble the engine.)

Measuring Piston Ring Gap

Piston rings are made of cast iron and are extremely brittle. You should gain some experience on junk pistons & rings before handling the real thing. A patent piston ring expander is a wise investment.

Your pistons are fitted with three rings. The upper two provide the compression seal, the lower is the wiper-ring, oil-scraper-ring or whatever.

When your engine is running the interior is filled with a dense fog of atomized oil that coats every surface. The purpose of the oil-scraper ring is to wipe that film of oil off the cylinder wall as the piston descends. Cast iron has a granular structure. More than enough oil to provide lubrication will remain in the structure of the surface.

Most of the sealing between piston and cylinder does not take place between the face of the ring and the wall of the cylinder -- that junction is primarily to provide the compression needed to hold the ring in position. The major sealing task is performed by the top and bottom of the two compression rings where they press against the upper and lower surfaces of the ring-grooves in the piston.

If there is too much oil on the cylinder wall, it will be squeegeed into the ring-grooves and prevent the compression rings from forming a proper seal with the piston. The traditional name for this problem was 'over-oiling' and its undesirable effects were defined before the turn of the last century. By the 1920's the need for some type of oil control ring on the piston was recognized and the result is as you see. (You'll find several papers on this topic in the NACA archives from the early 1920's.)

The fit of your piston rings is at least as important as that of your valves. Get a leaky valve, you can pull the head and set things to right but with rings you only get one chance. So be cool. You are the Mechanic-in-Charge.

Before getting into the measurement, sit down with your piston rings and stone the edges of their gaps. If you examine these edges with a 10x loupe you will see they are extremely sharp and often show feathers of metal. Using a fine grain whetstone or Arkansas stone, stroke all four sides of that sharp edge. Don't get carried away here. A single stroke or two, with the stone at about a sixty degree angle, is all it takes.

Your cylinders may have some amount of taper; they are typically wider at the top. (And if they aren't now, they soon will be.) The gap of your piston rings is always measured at the narrowest point of the cylinder. By convention, on VW's we use the bottom of the cylinder barrel. Not the very bottom but a point about 3/4" up from the bottom.

Insert a ring into the cylinder barrel and use the piston to push it square to the bore. Measure the gap with feeler gauges.

Ring-gap varies according to the diameter of the bore and for the VW engine, which is assembled to closer specs than the typical certified aircraft engine, the usual allowance is .0045" to .005" per inch of bore diameter. You can get away with a wider gap-allowance but you can't go any smaller without running a very real risk of scoring the bore.

Compute the gap-allowance for your jugs and measure the gap.

If the gap is TOO LARGE and you only have one set of rings to play with, you need to understand that the engine will not produce as much power as it could, that it's going to use more oil than it should and it won't last as long. The magnitude of these effects depends on how far the gap departs from the norm. If the gap is twice as wide as it should be, I'd go shopping for another set of rings. If it is between 1.5 & 2 times larger, I MIGHT use the rings... if I had no other options. Anything less than 1.5 larger than the optimum gap, you can probably live with.

If the gap is TOO SMALL, make it wider. There are patent tools for this task or you can make a ‘ring-holder' from two pieces of wood, large enough to clasp the ring and having a notch giving access to the gap. GENTLY clamp the assembly in a vise and open up the gap with a Swiss file. Don't try doing this with the ring held in your hand. Even the best machinist can't keep the resulting surface square.

After opening up the gap, stone the edges as described above.

Gapless Rings

Total Seal (and others) manufacture what are called ‘gapless' piston rings, including sizes that will fit most after-market VW pistons. Such rings use a patenting sealing ring that overlaps itself. A set of gapless rings costs about sixty dollars and have slightly different requirements with regard to adjusting their fit.

Some engine builders swear by them. I've used them on some high rpm, high-output engines with good results but haven't noticed sixty dollars worth of improvement when used in the typical low rpm chugger built for an airplane.

OIL PUMP

You should be using a new Bilstein oil pump.

Volkswagen oil pumps come in two basic flavors, those used prior to 1970 and those from 1970 and later. Their main difference is the size of the oil inlet hole, which matches the oil inlet in the crankcase.

Your pump should match the crankcase. I've never tried using a small-hole pump in a large-hole crankcase. It would probably work but I don't see much sense in it. But don't try using a big-hole pump in a small-hole crankcase. The misalignment of the holes causes the pump to suck air.

Volkswagen has used four different oil pumps since about 1960. As a general rule, each time they bored & stroked the basic engine they have increased the oil pump's output by going to a pump having slightly longer gears.

Volkswagen produced over 130 different types of vehicles and their industrial engines are used in hundreds of applications from the Zamboni ice-rink resurfacing machine to grain drills, auxiliary generators and so forth. Because the same basic engine is used in all, to insure compatibility the physical size of the engine is fixed. To fit longer gears to the oil pump, the pump body had to project deeper into the crankcase casting; if it projected outward the newer engines would not fit in many applications. In 1970 when the size of the pump gears were increased from 19mm to 24mm (ie, the introduction of the 'big-hole' pump), the pump body projected so far into the case it interfered with the cam gear. To provide more room, Volkswagen adopted a cam gear having a dished face.

When Volkswagen adopted an external oil cooler in 1971 (ie, the so called 'dog-house' cooler) they increased the size of the oil pump gears to 26mm to provide additional flow through the oil cooler.

If you're using an early crankcase having a small oil inlet hole the pump you should be using has gears that are 19mm (about a three-quarts of an inch) in length. You will need to use a flat-faced cam gear with this pump.

If you're using a new crankcase or one manufactured after 1970 you should be using a big-hole pump having gears 26mm in length (a little over an inch). You will need a dished-face cam gear.

The stock VW oil pump can deliver pressures up to 300psi and flow-rates approaching 5gpm. You don't need any more, regardless of what you read in the ads for after-market pumps.
After-market pumps typically gain room for larger gears by projecting beyond the crankcase, making them too large for many applications. Indeed, many after-market oil pumps for use in early, small-hole cases have gears so large the small diameter of the oil pick-up tube can not provide sufficient flow, resulting in cavitation and a sharp drop in oil pressure and flow as the engine speed increases.

The crankcase bore that accepts the body of the oil pump is 70mm (about

2.756"), with a tolerance of plus zero, meaning it's okay to machine the bore a tad smaller but never any larger. The body of the oil pump on the other hand is ALSO 70mm but with a tolerance of minus zero, meaning it can be machined a little LARGER but never any smaller. Such a tolerance inversion for mating parts results in an interference fit. That means you'll have to press the pump-body into the crankcase to install it and use a puller to remove it. It also means the thing won't LEAK, which is the whole idea.

Unfortunately, it is not uncommon to find after-market VW oil pumps having a body diameter as small as 2.745" Such a pump is nothing more than expensive junk. It is such a loose fit in the crankcase that it actually rattles. Another notorious leaker is the extremely popular - and very expensive - after-market pump having a cast iron body, which leaks because of its coefficient of expansion is not compatible with the crankcase.

Blueprinting the Pump

Although the quality of the stock Bilstein pump is generally very good it never hurts to check. Begin by insuring the OD of the pump body is at least 2.755".

Dismantle and clean the pump. Inspect the edges of the gear teeth. Using a hard Arkansas stone, lightly stroke the edges on the ends of the teeth.

Reassemble the pump. Using feeler gauges, insure there is no more than .003" radial clearance between the gear teeth and the pump body.

Using a straight edge and feeler gauges, determine the axial clearance between the pump gears and the pump body. This clearance must be reduced to zero. To accomplish this, lay a piece of #320 or finer carbide paper on a surface plate or other truly flat surface and flood it with WD-40 or kerosene. Place the pump body atop the sandpaper and rub.

If you merely rub the pump body back & forth the resulting surface will NOT be flat, it will be canted at a slight angle. To produce a flat surface you must introduce pseudo-random motion to the rubbing. One way to do so is to rub back & forth a given number of strokes with one hand then rotate the pump body ninety degrees in a clockwise direction and do the same number of strokes with your opposite hand.

Blocking the Outlet

If you're going to use the pump with a full-flow oil filtration system you will need to block the normal outlet using a socket-head aluminum plug (ie, a straight threaded plug, not a pipe-threaded plug). Use a 7/16" plug an small-hole pumps, a ½" plug on the later models. If rebuilding a used crankcase, these are the same coarse-threaded plugs used to seal the main oil gallery after it has been cleaned. Install the plugs with Loctite and allow to cure before use.

OIL PUMP COVER PLATE

If you are using a cast iron after-market oil pump cover such as the Berg or BugPak it will need to be chamfered and flatted. Use a file or coarse stone to chamfer the edges. Pay particular attention to the edges of the oil outlet hole, which should be perfectly smooth and well radiused. (The Berg pump covers are especially bad in this regard.) To flat the plate, use the same procedure as for flatting the oil pump body.

RAP ON 'HANDY' WORK

I've been accused of not being able to keep my hands off a freshly machined part. It's true. I like the feel of them. I pick them up and handle them and examine them with a loupe and dress their edges. Working in the shop, I wear a rather grubby old shop-apron that comes equipped with a couple of files, a scraper and some bits of carbide paper.

I've found that most problems start small. And prevention is better than cure. Like with stoning the gaps on your rings, the feather of metal you (probably) removed was too small to see with the naked eye. But such feathers of metal tend to be hard, if ferrous, and break off, if non-ferrous, and despite their almost invisible nature, give rise to problems.

So I get rid of them. Not just on the ring-gaps but on every single part of the engine. I do this with stones and hollow-ground machinist's scrapers and #600 carbide paper. I do this throughout the entire engine-building process, whenever I encounter such an edge. This probably adds an hour or two to the building of the engine and I really can't say if there is any benefit at all. But that's how I was taught and that's the way I do it and, for whatever reason, my engines do seem to age more gracefully than most.

As a point of interest, many engine builders brag on how FAST they can throw an engine together. At some of the lo-buck rebuilding shops the assemblers are paid piece-rate. The faster they can assemble an engine, the more they can earn. Everything is done with air tools, there are no trial fittings and they wouldn't recognize a torque wrench if it walked up and pee'd on their leg. But they can turn out three engines an hour and there is a line of kiddie-customers waiting at the door.

You and I have a big advantage over those piece-rate slaves. We're only building

ONE engine. The one right in front of us. The only boss is YOU. And you are the only customer. So take as long as it takes. Build the very best engine you can. Do it right, you only have to do it once. Do it right and you can look forward to years of trouble-free flying.

VW Engine - Component O'haul & Blueprinting - IV
by Robert S. Hoover

Note: The original piece on blueprinting & component overhaul ran to more than fifty pages and had to broken into smaller sections to satisfy the Network54 forum software. In dividing the article this part on Cylinder Heads was misplaced and is presented here wildly out of sequence.

CYLINDER HEADS

At the very least, your used heads are going to need the seats stoned and new guides for the exhaust valves. Chances are they can also be made to cool better. To accomplish this minor miracle all you need is a tool that can get down between the fins to remove any casting flash and a few drills and burrs to clean up the cooling air passageways nearest the exhaust valves.

The best tool for getting down between the fins to remove the casting flash is a pneumatic riffler fitted with a coarse file but a variable speed saber saw driving a long, coarse-toothed woodcutting blade can be made to serve. You'll need long drills and burrs to get into the corners of the air passageways near the exhaust valves.

If you open up your heads to accept larger jugs you can make a significant improvement in your engine's breathing ability by unshrouding the valves. See Bill Fisher's book for a well-illustrated how-to. The use of a template will help you keep the chambers equal.

Your most critical task in setting up your heads is a two-fold chore. One part is to insure all of your valves have equal stem height. This speaks to your valve train geometry. The second is to make the volume of all four combustion chambers equal to within .5cc or better. These two tasks are a set since the usual method of adjusting chamber volume is to sink the intake valves... which increases it's stem-length. Normally, you cc the chambers then clock your valves, chucking them into the valve grinder and facing off the stems as required.

PAPER WORK

As with your pistons and cylinders, your heads require distinctive works numbers. I use the last four digits of the crankcase serial number plus an alphabetic suffix, typically A for one head, B for the other.

To mark the heads I use steel stamps, placing my marks near the casting cartouch in the valve gallery, along with my own personal mark ‘HVX' which I put on all parts of all of the engines I build. I mark the volume of each chamber adjacent to the exhaust port on the outside of the valve gallery below the bail socket.

Since each head has two intake and two exhaust valves you will need to be able to keep them apart. I observe the convention of calling the left chamber #1 and the right chamber #2, when looking into the combustion chambers, intake port up. When a valve needs to be marked, I write the information on the head of the valve with a marking pen.

During its useful life your engine will require several valve jobs, how many and how often depending on how much you ask of your engine. To do a valve job you must remove the heads. Unless this is done in the shop you are going to contaminate the engine to some degree. If you do your own work a valve job may take only a few hours. If the work is done by others it could take a week, during which your engine, however carefully wrapped and covered, is hanging out there off the nose of the plane.

For optimum serviceability, when building your engine it is best to make up two sets of heads, identical in all respects. The second set is stored, unassembled and well greased. When a valve job is called for, assemble your spare heads, swap them for the leaking heads and overhaul the pulled pair at your leisure. Your second set of heads would be numbered -C & -D. Or whatever.

TOOLS

You should have or have access to, a valve grinding machine for doing the valves & their stems, and a set of piloted stones and the motor or adapter for doing the seats.

Even if you don't plan to do any head-work you STILL need to CC your chambers. Chamber volume is a critical factor in setting the compression ratio.

CHECK YOUR STEM HEIGHTS

Before spending any time trying to cc your heads, after the seats are stoned do a quick check of the installed height of your valve stems. If any stem is more than sixty thou off from the others, take another look at the valve seat; it may need to be replaced. Or you could have a ‘fat' valve. (Replacement carbon steel VW valves are coming in from Brazil and the quality isn't anything to write home about. Indeed, if you're using those Brazilian TRW-brand valves, you might want to shop around for something better. At the very least, dress their edges (I polish mine. Look at an aircraft engine's valves.) Valves should present a smoothly curved edge to the combustion chamber, not something so sharp you could cut yourself.

Manley stainless steel valves will work okay in your engine. Just keep the spring pressure down. Quality of imported SS valves varies wildly. If you can't examine them before you buy, keep your money in your jeans.

CC'ing THE HEADS

The term ‘cc' is the abbreviation for cubic centimeter.

To ‘cc' the heads means to measure the volume of the combustion chambers.

The standard procedure is to do measure the volume of each chamber THREE TIMES and to average your results.

To measure chamber volume, a plastic disk of suitable diameter, pierced with one or more holes, is placed in the combustion chamber onto the sealing surface (ie, where the wall of the cylinder will bear), the edges sealed with a light smear of Vaseline.

CC'ing disks in all of the common sizes are available from after-market VW parts retailers but as an aircraft builder you should have access to Plexiglas and be familiar with working it. Most plastic suppliers often have odd sized pieces of plex at give-away prices. (And equally odd colors! My 75mm disks are red.) The plastic disk does not need to be clear, merely transparent and reasonably stiff, eighth-inch stock being about as thin as you should go.

Colored water containing about one drop of liquid detergent per quart as a wetting agent is fed into the combustion chamber from a burette or calibrated syringe. Any bubbles are chased to the hole(s) in the plate, the meniscus is brought level to the top of the hole and the volume is recorded. The volume of the hole(s) is then subtracted from the total.

(NOTE: Regarding the holes; calculate their volume at the time you make the plate and etch that figure onto the plate. Thereafter, simply subtract that amount from your measured fluid volume. Volkswagen uses a disk having five holes (see the Factory Manual). Many after-market cc-ing disks have a single, central hole.)

Measuring the Chamber Volume

Basic tools includes a small plastic tub into which you dump the fluid from the chamber, a beaker or pitcher to receive the used fluid and to refill the measuring receiver or burette. When using a syringe you generally just suck a new charge up from the tub. You will need several towel.

When using a burette or manometer-type gauge the fluid is delivered to the head via a length of tubing. The barrel of a glass eye dropper makes a suitable nozzle. You may use a standard laboratory clamp on the hose but a plastic spring-clamp works just as well. Shops that do a lot of cc-ing work tend to use more durable materials – Pyrex receiver, heavy black rubber tubing, brass nozzle, screw-type valve, etc.

Fill your receiver, burette or syringe and, using a mirrored line or other method that eliminates parallax, release fluid until the receiver, burette or syringe is at the standard volume you are using.

With the disk in place, insert the nozzle or hose into one of the holes, open the valve, release the clamp or whatever and allow the chamber to fill with fluid. Chase any bubbles then bring the fluid level precisely to the top of the holes. Record the volume, less that of the holes.

If you have two disks you can do both chambers at one set-up. Otherwise, dump the contents of the head into the tub and fish out the disk. Dry the disk and chamber very carefully. Big shops use a blast of air, you & I use towels :-)

Refill your delivery system and repeat the procedure. Measure each chamber three times then average the results.

The factory manual as well as various books on engine assembly illustrates the procedure for measuring chamber volume.

Since you will be cc'ing each chamber several times as the work progresses it will save time if you arrange a suitable stand to hold the burette and a plate of some sort to hold the head in a PERFECTLY LEVEL position. When making such a stand for your heads remember that the valves are installed when cc-ing. The valves project above the level of the gasket rail. Holes or indentations must be made in your stand if you wish to support the head on its gasket rail. Some stands support the head by the exhaust port studs but tend to be less stable than those using the gasket rail as a base.

Once you get the hang of it, cc'ing a head takes only a couple of minutes.

One cubic centimeter is a rather small quantity but not too difficult to achieve across a set of four jugs (ie, +/- 0.5cc). Go any finer and you'll need a more precisely marked burette, plus the task can take up to ten times as long. Whatever your accepted level of precision, strive for consistent accuracy. (Drip, drip, drip... :-)

The volume of stock VW combustion chambers is about 53cc. Unshrouding the valves, as when installing larger jugs, makes the chamber larger. Your burette or syringe should hold at least the volume of one chamber. Chemistry supply houses can provide you with a suitable burette but be prepared for sticker shock. American Science & Surplus (www.sciplus.com) occasionally carries such items at low prices. But you can do the job with a large syringe -- or even a turkey baster(!) if it is calibrated. For a large syringe, try a veterinarian.

If the largest syringe (or burette) you can find holds less than one chamber's-worth of fluid you will have to pre-fill the chamber being measured with a solid object of known volume. A marble will work (every can of spray paint comes with a free marble :-) To determine the volume of your marble, fill the syringe about half way, read the volume, drop in the marble and read the difference. (You may shout Eureka! if you wish :-) To measure the chamber, put the marble into the chamber FIRST, then place the cc-ing plate. Fill the chamber, read the volume and ADD the volume of the marble(s).

(You may also use ball bearings but they tend to rust.)

As a card-carrying meteorologist I am legally certified to write my initials on the back of your micrometer, convert furlongs to fortnights and other neat stuff. Such as making a cc-ing burette accurate to 0.1cc using a plastic soda bottle, a length of small diameter plastic tubing, a hunka plywood and a yard stick. The last 5cc of the fluid covers about 30" on the yardstick. Half an inch, or thereabouts, is 0.1cc.

But a turkey baster works, too :-)

Adjusting the Chamber Volume

All of the magazines talk about CC-ing your heads and the better manuals actually show you how to do it. But making your chambers EQUAL is a topic I've never seen addressed in the popular press. Too complicated, or something :-) Actually, it's not very difficult at all.

If you've installed bigger jugs and have unshrouded the valves, the basic hogging out is done with rotary files. You do a couple of preliminary cc measurements to make sure you're on the right track then polish things up using abrasives and hobs. At that point your chambers should be the same to within 2cc, about the same as the factory spec. (You should have Bill Fisher's "How to HotRod Volkswagen Engines" at your elbow when hogging out the combustion chambers.)

With stock bores you should have nothing to hog. Clean up any sharp edges and polish the chambers (you ALWAYS polish the chambers) but as received, the chambers should match within +/-1cc.

Now comes the fun stuff :-) Find your LARGEST chamber and make it your standard, the volume the others will have to meet. Calculate the amount each chamber will have to be ENLARGED to equal your ‘standard' chamber. If the amount is more than 2cc you should consider shaving an edge with a rotary file and remeasuring.

Once you know how much each chamber needs to be INCREASED in volume the trick is to do so by that exact amount. You can forget your rotary files, burrs & hobs – they are too imprecise. But the diameter of your VALVES is a known quantity. You can increase the volume of the combustion chamber in easily controlled amounts simply by LOWERING your valves into their seats.

You know the diameter of your valves so use that figure to calculate their AREA. Once you know the area of your valves, calculate the VOLUME of that disk, in cubic centimeters, in .001" increments. Divide that incremental volume into the amount by which the chamber volume must be INCREASED to get the distance that valve must be LOWERED.

Now you gotta put on your Thinking Cap and figure out the best STRATEGY of chamber volume adjustment.

You don't want to sink the intake very far. It flows better if it's ‘proud,' whereas you can put the exhaust valve down a gopher hole and it will still flow about the same. But the intake is so much larger than the exhaust that lowering it only a few thou results in a significant increase in chamber volume.

The usual method is to sink the intake the MINIMUM amount (if any at all). But the smaller volume of the exhaust means it is easier to keep track of your progress. In most cases, the best strategy is to use the intake to make gross changes and the exhaust valve to do the fine tuning that allows you to end up with four chambers accurate to 0.1cc or better. (Yeah, I know; it's all a big waste of time. I'll have something to say about that later.)

Once you've figured out how much to sink each valve, MARK THEM. Write that figure on the head of the valve, along with the valve's identity (ie, ‘A2,' etc)

To sink your valves, rig your clock – your dial indicator – to the valve gallery gasket rail and use the valve's height as your gauge as you stone the seats OR face the valves. You'll be working on the basic 45 degree cone here; you'll restore the seat width and provide the standard 3-angle curve AFTER you've set the chamber volume.

(NOTE ON VALVE FACING: You can thin down your intakes to about .030 but the exhaust valves should be left full thickness, about .060. All edges should be smoothly polished.)

Even though the seats have been stoned and the valves ground you must still lap them in. Due to the risk of contamination, I prefer to do this immediately prior to the final cleaning, just before assembly. I'll mention it at the proper time but if I don't, remind me :-)

Once you've set the chamber volume, MARK THE HEADS. Stamp the chamber volume right on there. (I stamp them just below the valve cover bail, beside the exhaust port.)

TOPPING THE VALVES

After you set the chamber volume your valve stems will be at different heights and may need to be adjusted.. If you're running solid lifters or the small diameter Ford juicers you want them all within .0015" +/- .0005". If you are running Type IV hydraulic cam followers, .003" +/- .001" is good enough.

You are not concerned with the absolute height of your valves, only their height relative to one another. And since the only way to adjust that dimension now that the chamber volume is fixed is to shorten the valve stems, begin by finding the SHORTEST stem. Use the gasket rail around the valve gallery as your reference. (But see below.)

Once you've measured the stem heights, calculate the amount that needs to be removed from the three longest valves and write that amount on the head of the valve along with it's number. It will probably look something like "A2 / 3.5" That tells me the valve is from the A-head, chamber 2 and needs to be shortened by .0035"

After topping your valves, dress the edges and polish the face of the stem, if needed.

VW Engine - Component O'haul & Blueprinting - V
by Robert S. Hoover

Sending the Work Out

Valve work and head cc-ing is a specialized appendix dangling from the body of automotive machining. With the high precision required of the pallet/shim type adjusters found on many OHC engines today, a lot of dealers have chosen to not tool up for doing basic valve jobs, leaving this task for the ultra-specialists. Over the last ten years or so this has given rise to the Conventional Wisdom that valve work is somehow beyond the ken of the average mechanic. With aircooled Volkswagens, that simply isn't true. Indeed, with regard to flying veedubs think it's best that the engine builder do the valve work himself

As I mentioned earlier you're going to need a valve grinder and a set of stones for the seats to make a proper job of it. Sending the work out to another shop is a practical alternative, the success of which depends largely on how well you define the work to be done and the quality of the shop doing the work.

If there is a GOOD valve shop in your area, providing them with a written list of specs PER VALVE is usually enough to get the job done. But good work doesn't come cheap and don't expect over-night turn around..

The tolerances I've spec'd aren't especially tight. But some automotive machine shops think +/-.001" is ‘high precision.' For valve work, using an antique Black & Decker valve tool fitted with the proper stones, I have no trouble holding half a thou... .0005"

Occasionally you run into automotive machinists who think they know your engine better than you do (and may be right, with regard to cars). They often insist cc-ing your heads and setting your valve lengths to a uniform height simply isn't necessary; that you'd be wasting your money. Which is probably true if we're talking about Billy Bob's pickup or some kiddie's bug. Fair enough. Thank them for their advice... and go waste your money somewhere else. Whatever you do, NEVER use the word ‘airplane.' They'll either show you the door or double their price :-)

Once you find a good shop – and a good machinist – treat them well, for in modern-day America such things are a pearl beyond price.

INSTALLED SPRING-HEIGHT

After making all of your chambers equal in volume and all of your valves equal in height, it's time to look at the installed height of the valve spring. This is determined by the distance between the surface on which the valve spring sits and the underside of the spring retainer. If all of your retainers are of known thickness you can measure to their tops.

Your valve springs are compression springs. Their purpose is to pull the valve tight against the valve seat so as to seal the chamber during the compression stroke. On the power stroke, the pressure of combustion acting against the face of the valve seals it even better. For low rpm engines, such as used in an airplane, we don't have to worry about valve 'float' or the valve train harmonics that cause problems in high rpm engines. If you're running juicers your springs need to be a little stiffer than with solids because the spring acts to return the internal valve in the cam follower to the 'ready' position. But over all, for a low rpm engine you can get by with relatively 'soft' springs. The less energy the engine spends actuating its valves, the more torque there will be at the prop. What's even more important is that the less energy needed to actuate the valves, there will be less friction and less wear in the valve train – your engine will be inherently more durable.

As with volumetric imbalance, UNEVEN valve spring tension lowers the engine's overall efficiency. How much? I've no idea. But I know a properly built engine runs better and lasts longer. So I try to make all of the valve springs have equal tension.

You've already measured the free-height of the springs and their strength when compressed to a given standard. Now we must insure that all of the springs will have the same height once they are installed.

Here again, the task comes in two parts – determining what has to be done and figuring out how to do it.

Measuring the installed height of the springs is a straight forward task. Do so, then determine the maximum deviation from the norm. If any spring is high or low by more than .003" you should consider doing something about it.

What I do is to machine a recess around the valve guide boss to accept a thick (.090") washer. The washer is mild steel and the bottom is flatted. These are installed under all of the valve springs and prevent the spring from fretting away the softer aluminum of the head.

To adjust the installed height of the valve spring I determine the greatest height among the eight or 16 valves (ie, the heads are always as pairs) then calculate how much must be ground away from the others to achieve the same height, plus or minus about a thou. The shims are scribed on their lower surface with their identity and the amount to be removed then sent to a shop having a surface grinder and decked to the proper height. (Because the set-up cost is the major expense in surface grinding, I usually have the shims ground in batches. Flatting eight costs no more than flatting one. Over the years I'm accumulated quite a store of shims of various thickness and can usually make up an engine's worth without having to send something out.)

Another approach is to use thinner (.063") washers and to cut the recess around the guides to a depth that will give the desired installed-height.

A third approach is to use someone else's shims. After-market shims come in a variety of thicknesses allowing you to adjust the installed-height. But you must have the tooling to match the shims, or have your heads machined to accept them. Since I've made most of my own VW tooling, I'm forced to make my own shims as well :-)

As a point of interest, most engine builders simply ignore the installed-height of the valve springs :-)

(NOTE: In blueprinting the heads I check that the distance between the combustion chamber sealing surface and the valve gallery gasket rail is consistent. Then I check that all four of the valve spring seating surfaces are the same distance from the rail. With new heads everything usually checks out. With used heads it usually doesn't, which makes the task much more difficult. I haven't made an issue of this because most of you haven't the equipment to make the measurements or do anything about it should they be off. Just do the best you can.)

SWIVEL-FOOT ADJUSTING SCREWS

The valve adjusting screw used by Volkswagen has a cambered face, a segment of a sphere.

The rocker arm is an elegantly designed little lever. Forged from mild steel, it has a ball socket on one end to accept the push-rod and a threaded bore on the other for the adjusting screw. An oil passageway is drilled from the root of the ball socket to the rocker shaft bore, and from the threaded adjusting screw bore to the rocker shaft bore. After the oil passageway is drilled, the outer openings are sealed, one by swaging the other with a dot of weld. In use, pressurized oil from the hollow push-rod is forced through the drilling to lubricate the assembly.

To actuate the valve, to push it down against the pressure of the spring, the rocker swipes the adjusting screw across the stem-face of the valve in an arc having a radius of about an inch and a quarter. The valve guide isn't perpendicular to the head, it's pointing ‘downhill' toward the rocker shaft at an angle of about 9.5 degrees. (See the illustrations in the factory workshop manual. This angle is critical. For doing any serious head work, all of your jigs & fixtures must take it into account.) Because of the angled position of the valve the adjusting screw remains in contact with the stem-face even though the adjusting screw is swinging through an arc. And as it swings through that arc, it pushes the valve down about four tenths of an inch.

The adjusting screw does not push down on the exact center of the stem-face, but about half way between the center and the edge of the valve stem, at about the 3 o'clock position. Because of the swiping motion, that eccentric point of contact causes the valve to rotate. When the spring pops the valve closed, the valve will present a new sealing surface to the valve seat, equalizing wear and insuring a better seal. Similar geometry is used by the cam to impart rotary motion to the cam-followers. That motion serves to distribute the wear of these linear reciprocating parts. Without it, the valve guides and cam follower bores would wear out of spec in a matter of hours.

The problem is that adjusting screw. Or rather, it's cambered face.

A sphere can only contact a flat surface at one point. All of the pressure to actuate the valve is focused on that single, tiny point of contact. The valve doesn't mind. After all, the face of the stem is hardened. But the adjusting screw is not. And wears according.

The adjusting screw begins to wear the instant it makes contact with the valve and continues to do so until there is such an obvious gap between the two you can hear them clack as they come together. That's when you adjust the valves. And the 'When' is about every twenty hours of engine operation.

The interesting point here is that the wear produces a flat face on the adjusting screw. As the wear progresses the flat face becomes larger and the RATE of wear decreases. Unfortunately, the hammering effect of the increased gap more than offsets the slower rate of wear.

To 'adjust the valves' means to loosen the adjusting screw locknut and rotate the adjusting screw with a screwdriver so as to be an UNWORN face of its spherical tip into contact with the valve stem. No problem. Once you get the hang of it you'll be able to adjust all eight valves in fifteen minutes or less.

And then do it again about 20 hours later. And again. And again.

After the fourth or fifth valve adjustment the cambered face of the adjusting screw is no longer a segment of a sphere, it has become faceted with flats like a crudely cut diamond. The bad news is that the interface between those faceted flats forms a dull knife-edge.

Adjust the valves so as to bring one of those knife-edges into contact with the valve stem and two things happen. The first is that the narrow knife-edge wears down at a surprising rate, a matter of minutes if the edge is especially narrow. Adjust the valves and they are OUT of adjustment within the first five miles. The second thing that happens is that the knife edge exerts sufficient force to begin wearing a groove into the face of the valve stem. If you don't do something about it, the wear will reach such an extent that the valve stem will take on the appearance of a mushroom and chunks of the edge will actually break off... and find their way into your oil pump.

That's why the Volkswagen manual tells the mechanic to replace the adjusting screw ‘as required,' which works out to about every fourth or fifth adjustment.

Back in the Good Old Days, whenever that was, the Parts Guy (who was often a girl but still a Guy) kept sets of eight adjusting screws bagged & handy right there at the counter. You'd lean around the door, say ‘Adjusters?' and find eight of them in your hand, just that quick.

I should mention here that a point-contact type of valve adjuster is not a good idea. It's only advantage is low initial cost. But back then, the labor of their replacement didn't enter into it, not when a qualified VW mechanic earned less than a dollar an hour.

Periodic replacement of the adjusting screws isn't a big deal. So long as you DO replace them. Let them go and, believe it or not, they can cost you an engine. Those chunkies that break off the valve stem? They're as hard as glass and some are small enough to pass through the screen protecting the oil pick-up tube. Once they get into the oil pump, the engine is doomed.

Back in the mid-1950's the engineers at Ford of Germany came up with an adjusting screw for their engines that used a captive-ball arrangement. Everyone who owned a VW and did their own work – not a bunch, back them – immediately bought a set of those marvelous ‘elephant foot' adjusters, modified their rocker arms to accept them, and breathed an enormous sigh of relief. Not only had we just saved ourselves a couple hours a year in maintenance time, we'd removed the threat of Chunkie Attacks on our oil pump.

The captive-ball arrangement presents a flat face to the stem of the valve. The wiping motion and valve rotation is still there but accommodated by the swiveling of the spherical upper surface of the captive ball, the flat lower surface providing the contact with the valve. Now we could adjust our valves and have them STAY in adjustment for up to a year, thanks to the lower wear rate resulting from the enormous increase in contact surface area.

The Ford-type of swivel-foot adjuster restrains the ball within a metal ring. The ball is internally lubricated by a drilling that communicates with the drilled oil passageway in the rocker arm. The ball is fairly large and the metal ring that captures it even larger, making the thing too thick to fit a stock VW rocker.

So you modify the rocker.

The elegant way is to make a little jig for the milling machine and remove about sixty thou from the end of the rocker's threaded bore using a piloted end-mill having a nice radius. Once you've got things set up it takes less than a minute to modify a rocker. (Alas, my milling machine is an antique Van Norman #12. No quill feed. So I made a little rig for the lathe and used that.)

The other way is to rub the thing against the grinder until it fits.

Either way will work and the grindstone method isn't especially dangerous if you carefully flat the ground area then polish it, so as not to give cracks a chance to start.

But swivel foot adjusters are longer than stock adjusters. And you can't keep grinding away the rocker arm. So once you get the adjuster to fit the rocker arm, you RAISE the rocker shaft. How much? That depends on your valve stem length but in most cases, about another sixty thou.

Gene Berg Enterprises makes a different type of swivel foot adjuster in which the ball is smaller than the Ford type.. The Berg adjuster is shorter than the Ford type but still longer than stock. You don't need to modify your rocker arms but you do need to raise the rocker shaft a bit. Suitable shims come with the adjusters.

There is an after-market copy of the Berg adjuster but the quality is pretty bad – you'll need to stone them flat to get them to work.

I've installed perhaps a hundred sets of the Berg type on auto engines and have had a couple of failures. I mentioned the failures to Gene. He told me he'd never heard of his adjusters ever failing. He said this both times I mentioned it to him :-) (Gene has passed on. He is sorely missed.)

For airplane engines, I use the Ford type. I've never had one fail. Nor have I ever heard of one failing.

Gene Berg Enterprises advertises in the VW-specific magazines. Most after-market VW retailers carry the Ford type; I've also seen them in the Whitney catalog.

(The real advantage of swivel foot adjusters comes from using them in conjunction with hydraulic cam followers. The combination means you NEVER have to adjust the valves.)

A NOTE ON VALVE ADJUSTMENT

The ideal valve lash is zero.

We use something larger than zero because the engine expands as it reaches operating temperature. The amount of lash we set with the engine cold, typically .004" of clearance for the intake valves and .006" for the exhaust, reflects an educated guess as to how much expansion is going to take place. The above figures are the factory specs for the stock engine.

Being an inch or more wider than the stock engine, big-bore strokers need longer push-rods and the type most commonly available are made of alloy steel tubing. Stock push-rods are aluminum tubing with steel fittings swaged into each end.

For a given temperature, aluminum expands more than steel. When using steel push-rods you'll typically find the best valve clearance to be something LESS than the factory spec..

No matter what we set the lash to, it will be something else after just a few minutes of operation. Not a big 'something else' but wear is inevitable. Want to guess what that means with regard to engine efficiency?

Based on dyno runs of factory-built VW engines running both solids and juicers, the hydraulic lifters clocked an impressive increase in output right across the dial. Even a hot adjustment, tweaking the solids to near-zero lash couldn't make up the difference. The juicers simply do a better job.

You'll hear a lot of Folk Wisdom about the evils of hydraulic lifters. Most of it is bullshit. Engines fitted with hydraulic cam followers now run above 7000 rpm with no sign of float.

Aircraft engines were among the first to adopt hydraulic cam followers. Some form of hydraulic valve-lash compensation is standard on all modern engines, even those running overhead cams.

PORTING & POLISHING

Porting and polishing have become buzz-words among the hotrod crowd and have largely lost their definition because of it.

'Porting' means making the intake ports larger.

'Polishing' means the walls of cast intake runners are made smoother. (Polishing your combustion chambers and cylinder heads is a different subject.)

Studies by NACA, the SAE and other professional organizations have shown there is no increase in flow-rate for manifolds having surface finishes finer than that produced by #600-grit abrasives. Make it shine like a mirror, it won't flow any better.

Porting and polishing relates to flow rate, the theory being the better the flow, the better the efficiency. Which is generally true. But the flow rate of the typical VW aircraft engine is on the order of 100cfm, a figure so small it doesn't even appear on most of the charts.

VW heads respond well to even modest efforts to improve their flow rate. But for the rpms at which most flying veedubs rum. you'll be lucky to see a dollar's worth of improvement from a thousand dollar head-job.

A second factor here is that all of those marvelous flow-rate figures are referring to AIR whereas the physics of the FUEL/AIR charge are dramatically different.

Way back when, I built an elaborate flow-bench and spent thousands of hours learning how much I don't know about Volkswagens. Or fluid dynamics. Or physics. I learned quite a bit in the process but the most important thing I learned was that a lot of the 'experts' didn't know what they were talking about.

The ability to flow more air in a given unit of time is only a RELATIVE measure of merit in a heads ability to flow more fuel/air mix, which has greater mass and which is NOT an homogeneous fluid. Due to the greater mass and density, at high rates of flow the difference between air and fuel/air mix loses much of its significance whereas at low rates of flow the differences are profound. Flying veedubs live well below the flow-rate horizon. What works for a 9000 rpm screamer on the drag strip is usually of no value at all on your 2800 rpm chugger.

The bottom line is that there isn't a lot you can do to improve the flow rate that applies to flying veedubs. You CAN make some improvements but they aren't dramatic. Bill Fisher does a more than adequate job explaining the process in his excellent "How to Hotrod Volkswagen Engines."

DUAL PORT vs SINGLE PORT

A key point here is the ‛advantage' of dual-port versus single-port heads. Alas, at the rpms useful for an aircraft powerplant, the advantage of dual port heads simply isn't there.

That isn't to say DP's don't outflow SP's – they do, right across the board and right out of the box. The real question is ‛How good is ‛good enough' and the answer is that single-port heads are more than adequate at the relatively low rpms you'll be running.

For airplanes the most important factor is reliability. Dual port head castings are thinner in some areas and far more prone to crack because of it. While this is not considered especially important in a car it can mean your life in the air.

I use dual port heads. New, it's all I can get. They stopped making new single-ports some years ago. But I pull them more frequently and check them more carefully and discard them more often than I do with single ports.

NOTE ON CC'ing THE HEADS

Why are we even interested in chamber volume? I'm glad you asked :-)

One-hundred percent volumetric efficiency means the cylinder is fully charged with fuel/air mix at atmospheric pressure. On the typical engine, that never happens. Indeed, on the typical engine the cylinders not only fail to fill, they receive different amounts of fuel/air mix. Compressed and ignited, those different amounts of fuel/air mix result in combustion chamber pressures that are different. One piston gets a stronger push than it's neighbor. All of that is pretty easy to understand and engineers designing internal combustion engines try to keep the volumetric efficiency as high as possible, with each cylinder receiving an equal charge.

That helped. But it didn't help as much as they thought it would. It was all rather puzzling. The puzzle wasn't solved until ultra large computers could be brought to bear on the problem. What they learned was that relatively small differences in chamber volume have an enormous effect on the engine's output. Those tiny differences become significant when the fuel/air charge was compressed, resulting in relatively LARGE changes in the pressure following combustion. The higher the compression ratio (and the greater the difference in chamber volume), the more pronounced the effect. The initial charging efficiency had less to do with it than anyone imagined. Modern engines now pay exquisite attention to insure chamber volume is precisely equal..

The Volkswagen engine is an artifact of the 1930's. VW allowed the combustion chamber volume of their mass produced engines to have a range of 2cc – that is, a nominal value with a range of plus or minus 1cc. If you do nothing more than limit that range to +/- 0.1 cc you will find the output of the stock displacement engine increases by as much as 6%... but the engine will use no more fuel than before. (ie about 3hp for a 53bhp engine).

This is a significant increase since it is built in to the engine; it will always be there. It is not something added-on nor something that can wear out. Trust me here. CC'ing your heads is well worth the effort.

VW Engines - Part VI

by Robert S. Hoover

Crankshaft, mostly

Articles about engine building in the popular press paint a different picture than what you're going to read here. In the magazines there's never a problem tracking down parts, the author of the article simply orders an engine's worth of parts from the magazine's advertisers. The parts are always perfect. There are no problems of fit or finish.. Without any pre-assembly, the engine goes together in a few pleasant hours and the result is always surprisingly powerful, smooth and reliable. Such articles have the same validity as the fad diets in woman's magazines or UFO encounters in the tabloids.

Ready for a whiff of reality?

When parts are manufactured or overhauled there is a given tolerance associated with their dimensions. When we say a part if 55mm in diameter (2.1654") we're speaking of its nominal diameter. The actual diameter will be a slightly larger or smaller. For example, in grinding that 55mm journal to its finished size we allow it to be as much as four ten-thousandths larger... not very much... but a whopping twelve tenths smaller. (+.0004/-.0012). This insures a high probability the journal will mate with the majority of connecting rods.

In a production environment this sort of statistical reckoning is built in to the fabrication process. When the person doing the assembly reaches into the bin for a connecting rod OTHER PEOPLE have insured his hand will come out with a part that fits. (If you've never heard of William Edwards Deming, you should check it out.)

In building your own engine you become a one-man engine manufactory. When building an engine, YOU are all of those ‘other people.' You are business manager, engineer, machinist, inspector and assembler rolled into one. You are the Mechanic-in-Charge. If you want a good engine to come out of your efforts you must assume the responsibilities that come with each of those roles.

The reason for this article is that as a one man factory you do not have a factory full of parts to chose from. When you have just one engine's worth of parts it is vital to know the exact dimensions of each part and in which direction those dimensions deviate from the norm.

This article describes the things you have to do to achieve the best possible fit when working with just one engine's worth of parts.

CRANKSHAFT - Runout

You've received your crankshaft back from the regrind shop. Or you have a new crankshaft.

It isn't straight. No crankshaft is. Your job is to find out how crooked it is; to determine its run-out. Factory spec is .0008" - eight ten-thousandths of an inch - a respectable tolerance for maximum run-out. If your crank shows eight-tenths or more, it needs to be straightened. Good cranks generally run two to three tenths, seldom more than five. Bad cranks are literally all over the ball-park, dimension-wise and the fame of a company is no guarantee of quality.

- - - - - - - - - -

I had three bad cranks a row from a previously reputable shop. They were welded strokers built upon stock VW cores. All ran out .0025" to .003" - nearly 4x beyond bad-spec. And two of them were cracked(!), good evidence they had not been normalized and straightened after welding. I complained to the owner, with whom I'd done business for more than twenty-five years. He was embarrassed but not especially so and returned my money on the spot. If I wanted a ‘good' crank he would see that I got one. But it would take about a week.

Eh? His shop was literally filled with cranks. He'd added two new grinding machines, half a dozen welding bays and more than doubled his staff.

He'd also cut a few corners, bringing his price below that of his competition. By doing so he was able to sell all the cranks he could make to after-market VW retailers who cater to the ‘kiddie' trade, mechanically naive youngsters who shop only by price and wouldn't recognize a good crank if it walked up and pee'd on their leg.

He was selling junk. But very profitable junk.

- - - - - - - - - - - -

CRANKSHAFT - Journals

Check them. Measure them at four points. Log your measurements. The journals must match your bearings and should be reasonably round. Use the factory spec's as your guide.

- - - - - - - - - - -

CRANKSHAFT - Stroke

Yeah, I know... they said it was 74mm. Now let's find out what it really is. You'll need vee-blocks and a surface plate and a surface gage, ideally one that reads in tenths.

The real trick is HOW to make the measurements and as I alluded to at the start of this series, the proper equipment for this job costs as much as a new car. So we'll fumble through with a surface gage and vee-blocks. And of course, the surface plate – you can't do much in the way of engine building without a surface plate. It is the foundation on which all other dimensions are based.

(Part of the measurement problem is the fact I don't know what crank you're using. Stock VW crank has some tooling notches in the #2 & #3 flanges (ie, the flanges at opposite ends of the crankshaft) that are useful when aligning the crank so you can pick-off the dimensions you need. These tooling notches are missing on lots of after-market cranks. If you've some other type of crankshaft you will need to use an index wheel to determine perpendicularity.)

If you stand your crankshaft on its nose (use a pulley as a fixture) the highest journal is #3. Then comes #1. Then the center main bearing journal. Then #4 and finally #2.

You need to determine the stroke-length of each rod journal.

One method of measuring the stroke is to position the crank in vee blocks with the target journal down; next to the surface plate. With the throws of the crank perpendicular to the surface plate, measure the distance between the upper surface of the journal and the surface plate. Rotate the crank 180 degrees and measure the distance between the new upper surface of the same journal and the surface plate. Subtract the diameter of the journal from the difference between your measurements.

Example: First measurement is 74mm. Rotated 180 degrees, brought to perpendicular, measure the distance from the upper surface of the journal to the surface plate = 188mm. The second measurement includes the distance determined by the first measurement, which we may now cancel out by subtraction. 188 - 74 = 124mm. Our remaining 124mm dimension includes the diameter of the journal, so remove that, which for the sake of this example will be 55mm. 124-55 = 69mm. Which happens to be a stock crank with unground journals.

Measure & record the stroke of all four journals to within .001" (I'd like to go to tenths but you'd probably just yell at me :-)

- - - - - - - - - -

At this point you have enough information about your engine's components to lay out its basic configuration. This is the first step in the assembly of the engine and it takes place at your desk.

In your documentation package I want you to record the difference in stroke for each of your journals. In a perfect world the differences would be zero but they are not. How much they depart from perfect is a reflection of the realities of manufacturing - and of metrology. Good equipment allows you to know your engine better. With less accurate equipment, things get a bit fuzzy. But with no measurements at all, you have zero data.

Determine the shortest throw and compute the difference between it and the other three. If #3 were the shortest you should have something like this: " 0, .0015, .0005, .0003 "

Now do the same for your connecting rods. Refer to your documentation package. Using the shortest rod as your standard, calculate the difference between it and the other three.

In your journal you have the heights of the cylinders and the deck-height (or pin height) of their pistons. Using the tallest cylinder, calculate the difference between it and the other three. For the deck height of the pistons, determine the shortest deck height and use it to calculate the difference between it and the other three. Now subtract the difference of each piston to its respective cylinder and record that amount. (We're still dealing in differences here, not actual heights). Subtraction of the piston deck height difference from the cylinder height difference may result in a negative number. Be sure to record it with a minus sign.

- - - - - - - - - - - - - -

As complicated as all this sounds it boils down to three blocks each containing four figures. The figures reflect differences in the length of the parts concerned.

When you bolt your engine together you automatically add those figures together. For example, bolting a connecting rod to the crankshaft adds the height of that particular crankshaft journal to the length of that particular connecting rod. Installing a piston/cylinder set onto that combination adds them all together.

The object of this exercise is to arrange the rods and cylinders so as to come up with the same number for each crank/rod/cylinder set. Or as close to the same as you can get.

How good is Good Enough? Five thou or less. .005" across all four jugs. Less is better but worse isn't a disaster; we've got a few more arrows in the quiver. For now, just do the best you can.

Once you've calculated the Optimum configuration, record it in your documentation package. The crankshaft throws have now imposed Cylinder Sequence on your rods and jugs. From here on out we have to observe Cylinder Sequence because Volkswagen piston pins are offset by 1.5mm and are specific as to the direction of the engine's rotation. The left hand bank of pistons is installed with their pins down while the opposite bank has their pins up. In each case, the arrow embossed on the crown of the piston MUST point toward the clutch-end of the crankshaft.

(In a similar vein, VW connecting rods are offset by 1mm to improve alignment between the throws of the crankshaft and the axis of the cylinders. To properly orient the rod there is a forging mark on the shank of the rod that must be UP when the rod is in running position.)

- - - - - - - - - - -

This article marks a watershed in that having blueprinted the foundation components and defined a strategy that allows us to combine our one engine's worth of components into the best possible configuration, we now move into the tactical phase of the operation, of carrying out our overall strategy.

VW Engines - Part VII - Preassembly
by Robert S. Hoover

Preassembly

Stuff you'll need:

A tube of molybdenum CV joint grease.

The crankshaft.

The crankcase, its hardware and bearing-saddle dowel pins.

An assortment of end-play shims.

Whatever fitting & hardware goes on the clutch-end of your crankshaft.

MEK, lacquer thinner, acetone or other non-oily solvent.

Paper towels. Q-tips. Lotsa other stuff I can't remember right now.

Your new set of main bearings.

- - - - - - - - - -
(NOTE 1: Before buying any set of main bearings it is wise to read the nomenclature stamped on the bearing. Check all four. If you are forced to order parts by mail you should check to see you got what you ordered as soon as they arrive.)

(NOTE 2: Pressurized oil reaches the #2 main bearing via a drilling to the oil gallery in the right-hand case half. Volkswagen used a #2 main bearing having an oil groove on the back of the shell. The groove allows pressured oil from the right-hand case half to reach the shell installed in the left-hand case half. Each half of the bearing shell contains a depressed area having a hole connected to the oiling groove on the back of the bearing shell. Twice in each revolution of the crankshaft, drillings in the center main crankshaft journal align with the depressed areas in the bearing shells, allowing oil under pressure to enter the drillings in the crankshaft, where the oil is carried to the connecting rod journals on either side of the center main bearing. There is a similar arrangement on the other two main bearings but each delivers oil to only one rod journal whereas the center main oils two.

In recent years a cheaper brand of main bearings has come on the market.

These bearings do NOT have the oil groove for the center main. Instead, one of the shells is drilled to align with the oiling hole in the web on the right case half. These cheaply made bearings (which cost as much as the good stuff) are aimed at the kiddie market. They work fine as bearings but can not provide as much oil to the connecting rods. Even worse, it is possible to install such bearing shells in a way that prevents ANY oil from reaching the #2 main bearing.)
- - - - - - - - - - -

BEGIN WITH THE CRANKCASE

You've received your crankcase back from the machine shop. Or, you're using a new crankcase.

Using the appropriate dies, chase the threads on all of your crankcase studs. (We'll do the head studs before we install them.) With used cases there is an enormous amount of crud in the threads which will make it impossible to achieve the proper torque value. With new cases you're looking for damaged threads and loose studs. In chasing the threads our objective is to insure they will accept their nuts during assembly. You shouldn't cut any metal in this process. If you do, it means the stud was over torqued or its threads were damaged. If it takes more than finger pressure to turn the die, inspect the stud before proceeding to make sure the die is not cross-threaded. Once you've chased the threads, use a toothbrush or similar to scrub a coat of copper-based anti-seize into the threads. Wipe off any excess. Indeed, try to wipe off ALL of the anti-seize. You won't be able to do so; the copper will cling to the root of the threads. Which is what you want :-)

Locate the six 12mm nuts for the main crankcase studs. If they've been painted, chase them. Find their matching washers.

Oil for the right-hand side of the engine arrives there via a drilling in the #2 main bearing web. The effectiveness of this technique hinges upon how well the main bearing and cam shaft webs mate with each other. Dead flat, with no scratches, gouges or turned edges is good. With the crankcase split and on the bench, working with one half at a time, break & dress all machined edges using a scraper and #600 wet & dry paper. DON'T get carried away here. To insure against a turned edge you want a chamfer on all sharp-cornered edges but the chamfer is so small you'll need a 3x glass to see it. In most cases just wiping the edge with the #600 paper will be sufficient.

The structural integrity of the crankcase involves the three main bearing webs and their six studs. (The #4 ‘main bearing' was tacked on to the engine to deal with the side loads resulting from the belt-driven blower/dynamo.) The primary function of the edges of the crankcase and its twenty related fasteners is to form an oil seal. To insure that oil sealing surface can do its job we need to make sure it is flat. LIGHTLY press the flat face a clean, single-cut mill file to the sealing surface and slide it along the surface, skating around any studs and bridging the gaps. (An 8" or 10" file works best.) Any high spots or turned edges will be immediately apparent. Deal with them. I put about a sixty-thou chamfer on all these edges.

If any machine work was done to the case, get out your brushes and solvent and airgun and clean the passageways. Be especially careful to clean the dead-end drilling between cylinders 3 & 4 on the left-had case half. There's really no way to clean this drilling effectively without pulling the plug but a skinny nozzle on your airgun and a skinny brush, such as used on a coffee percolator pump, will help.

If you have any threaded plugs to install, do it now. Swab the threads with MEK. Wash the plug with MEK. Apply a SMALL amount of Loctite to the threads at the end of the plug. Use the red stuff. Install the threaded plug and wipe away any residue. Allow the Loctite to cure then come back and strake the threads firmly against the plug using a round nosed punch.

PAINTING THE CRANKCASE

The magnesium alloy used in the Type I crankcase likes to corrode. Since your engine will spend most of its life out in the weather a thin coat of paint will protect your investment. Flat black paint offers the lowest resistance to thermal radiation. If you get any paint on the sealing surfaces, clean it off immediately.

TRIAL FIT THE MAIN BEARINGS TO THE CRANKCASE

When your crankcase is cleaned, painted and dried, find your crankshaft bearings and fit them into the case.

Your main bearings must match in three dimensions. OD is the fit of the bearing into the crankcase. ID is the fit of the bearings on the crankshaft. Thrust is the fit of #1 bearing on its saddle.

At this point you are especially interested in the fit of #1 bearing, the one having the thrust flange. If you're building upon a used crankcase and if the thrust face of the #1 main bearing web has been refaced, you will need a bearing set having an oversize - that is, thicker - thrust flange. If the case has been align-bored the newly machined bore should be LIGHTLY chamfered. The #1 main bearing has generous reliefs at the junction of the flanges & bearing shell; it will fit on even a perfectly square corner. The light chamfer, which may be done with #600 paper, is to insure the flanges will fit smoothly down over the saddle.

‘Crib death' is the term applied to engines which fail during running-in, typically about five hours for the VW engine. About half the cases of crib death are due to misalignment of the main bearings, an easily avoided error of assembly.

Torque produced by the crankshaft is coupled to the engine via the bearings. (Actually, it's the ‘anti-torque' as defined by Newton's third law of motion.) Steel dowel pins are used to prevent the main bearing shells from rotating in their saddles. The center main bearing is a split type and uses two dowel pins, one in each case half, making it difficult to install wrong but the other three bearings are full circle shells and use just one dowel pin each.

Find the five small steel dowel pins, the ones stored in a Special Place. (If you are building on a new crankcase the dowel pins should be a part of the crankcase's hardware package.) Note that the steel dowel pins for the full circle bearings an NOT installed on the centerline of the bearing web but offset toward the clutch-end.

Using a cotton swab dipped in lacquer thinner or MEK, clean each of the dowel pin holes. Using a paper towel and the same solvent, clean the dowel pins themselves, the backs of the bearing shells and their saddles. (As the engine accumulates wear oil will wick between the bearing and the saddle but for proper crush during assembly, all oil is removed from these surfaces.) Install the dowel pins for bearings #1, #3 and #4 in the left case half. (The #3 main bearing saddle in the RIGHT case half may be drilled for a dowel pin. This is to accommodate the split-type #3 main bearing that is part of the ‘high latitude' package - engines destined for extremely cold climates. You may also encounter crankcases machined to accept a flanged thrust bearing on the #3 saddle. There are in fact dozens of such variations. Other than to note them in your documentation package, for the purpose of this article they may be ignored.)

Taking the offset of the dowel pin into account, trial fit the full-circle bearings (ie, #1, #3 & #4) into the left case half. Align them with their pins then use your thumbs on the inside of the bearings to press them firmly into the saddle.

The numbers, the metrology, tell us the bearings should fit their saddles. But there is a manufacturing tolerance in bearings and in crankcase bores, either new or rebuilt. The numbers say it should fit. It's up to you as the Mechanic-in-Charge to insure that is true. To do so you fall back upon your sensory tools. The bearing shells should be a tight fit in their saddles. Too tight and the shell will not seat to full depth, a problem clearly evident on inspection. Too loose and there will be a gap which is equally obvious; you can rock the shell back & forth. Either problem is good evidence you have the wrong bearings or the bores are not to spec. (The latter problem, woefully common in cases that have been align-bored by non-machinists using portable tools, should have been caught during blueprinting.)

Failure to achieve a proper fit is one of those ‘unimportant' details never addressed by the popular press. Yet it is these exceptions to the norm that cause so much grief for a novice engine builder. Since these exceptions are never mentioned by the popular press the novice usually assumes he has done something wrong. At that point the novice often hands the engine over to the local VW guru which in many cases simply compounds the problem, since the ‘guru' is liable to tackle a tight bearing shell with a hammer and a loose one with a slather of J.B.Weld.

YOU are your best mechanic.

To resolve a problem discovered while fitting your bearings you must first define the problem. Something obviously does not fit but the fix will depend on why.

Verify the dimension of the bearings. Yeah, I know... they say " +0.50mm " on the box but does their OD actually measure 65.50mm? (I'm assuming the usual metric tolerances here) The same applies to the crankcase. It may be stamped .020 on the boss near the #1 bearing but what is the actual dimension of it's bores? Torque it to spec and get in there with an inside mike or snap gauges and find out. And be sure to check ALL of the bores, not just the easy-to-get-at #1. Measure each bore at more than one point - with portable boring tools oval bores and tapered bores are not uncommon.

Once you've defined the problem in numerical terms the solution will be self-evident: the case must be re-machined or you have the wrong size bearings.

- - - - - - - - - -

There is a nice lesson in the above for people who accept the Conventional Wisdom that, while anyone is capable of assembling an engine, blueprinting and messing about with micrometers and such isn't really necessary. This fatally flawed perception is an artifact of the popular press. That flaw becomes painfully obvious the first time the novice engine builder encounter a problem. You can not resolve a problem until it is properly defined. In building an engine, definition hinges upon precision measurement.

Like all Conventional Wisdom the ‘Engines are Easy' philosophy is based on a kernel of truth. Threading Nut A onto Bolt B and torquing to spec is a no-brainer. But the reality of building a GOOD engine has to do with resolving the myriad of exceptions that crop up along the way. The Devil is always in the details, details the popular press blithely ignores

- - - - - - - - - -

Check the alignment then mark each of the bearing shells with an arrow pointing toward the clutch-end of the crankcase. Use a marking pen; paint is too thick. When you are sure the bearing shell is fully seated in its saddle, use your marking pin to scribe a thick line on both sides of the bearing at the point it enters the saddle. When you do the final assembly the arrow will remind you as to the proper orientation while the mark at the parting line will insure the shell is seated to the proper depth.

Except for #2, most main bearing sets are made of babbit. (#2 is babbit-coated steel.) Steel-backed full-circle bearings are used for special applications but are not commonly available. Regular full-circle bearing shells are quite soft. It is possible to torque the case closed with the bearings misaligned and have the engine run. Most such engines fail, often catastrophically, in less than twenty hours. If you accidentally crush a bearing shell against its dowel, buy a new set of bearings and start over.

TRIAL FIT THE MAIN BEARINGS TO THE CRANKSHAFT

Your crankshaft is CLEAN. It is standing on its nose or tail, plugged into a pulley or crankshaft and is covered by plastic bag.

- - - - - - - - - -

NOTE: The main hazard in contaminating your crankshaft is getting something in the oiling holes. With a new crank or one just received from the grind shop, cleaning of the oiling holes is done using a .22 caliber bronze gun barrel brush chucked into a drill motor and fed in & out of the drillings at low speed while flushing the brush with copious amounts of solvent. Once cleaned, the crankshaft is stood on its nose or tail and a final cleaning is done starting at the top and working down, using a coffee percolator pump brush and an oily solvent such as WD-40 or kerosene. The object here is to flush any debris down and off of the crankshaft. After using WD-40 or kerosene, wipe the crank dry using clean paper towels and cover with a plastic bag.

- - - - - - - - - -

Until now we've worked with the main bearing shells dry. Once parts are coated with oil or grease they must be handled and stored with extreme care to prevent picking up contaminants.

Working with one bearing shell at a time, squeeze a dab of moly-type CV grease onto your finger and work it in to the friction surface of the bearing shell. Don't just wipe it on, RUB IT IN. Wipe off any excess using clean paper towels. Do the same to the matching crankshaft journal then slide the bearing onto the journal, making sure you have the dowel pin hole properly oriented.

Factory spec for main bearing clearance is about .0015 to .004" That should be a smooth, sliding fit. At minimum clearance there should be no perceptible rock. If the fit feels too tight or too loose you will have to install the bearing shells into the crankcase, torque it to spec then mike the 'as-installed' ID.

Bearing shells are among the most accurately made of the parts you'll be handling. A poor fit is usually due to a crankcase or crankshaft of improper size. Overhauled crankshafts ground to minimum spec are a common problem due to the fact most American machine shops treat 1mm as equal to .040" when it's actually 0.03937" (approximately). This is one of those 'unimportant' details that becomes painfully important when trying to achieve proper clearance between a crankshaft (or crankcase) machined to inch standards and a set of bearings manufactured to metric standards.

Specified main bearing clearance is about 0.0015" to 0.0040" and your goal is to come up with a fit nearer the 0.0015" clearance than the .004". During your blueprinting you will have detected any gross mismatch and done something about it but there's little you can do about the stack-up of errors that occurs when the machinist treats 1mm as a full forty thou. There is always some small variation among main bearing sets and if you build a lot of engines you will have a shelf of bearings to chose from. But even then, the best you can hope for is to improve the fit by a few tenths.

If the fit feels especially tight or loose, and if on actual torqued-to-spec measurement you find the bearing will not provide the specified clearance, you will have to start over with a different crankshaft, ideally from a different shop. The reason is pretty simple. When the clearance reaches or exceeds seven thousandths of an inch, the engine is worn out and must be overhauled. The RATE of wear in a plain bearing is a function of its clearance; the wider the clearance the FASTER the wear. If your engine begins its life with a main bearing clearance of between .0012 and .0025 it will take up to 2,000 hours for that clearance to wear out of spec. But if you begin with a clearance of .004" the engine will wear out of spec in as little as 500 hours, if not less.

Install the #2 bearing shells into their respective saddles. Clean any grease from your hands and from the exterior of the bearing shells. (Make it a habit to keep your hands, tools and work area clean. Keep a pint of lacquer thinner or MEK beside you along with a roll of paper toweling.) Wipe down the bearing saddles in the crankcase and the parting line, paying particular attention to the places where the internal webs will make contact when the crankcase is closed.

Lay the crankshaft into the left hand case half. Starting with #1, rotate the bearing shell until it aligns with its dowel pin. Use the arrow and marks you made as an alignment guide. In a similar fashion, align #3 and #4.

Laying in the crankcase, supported by its bearings, the crankshaft should spin freely with light pressure of your hand.

(NOTE: The Volkswagen Factory Manual illustrates checking the run-out of a crankshaft by using the left-hand case half, without the center main bearing shell, as a holding fixture. This works fine as a field repair procedure at a dealership but fails the test of practicality for anyone trying to assemble an engine from one engine's worth of parts. Should the run-out exceed spec you are faced with the need to replace the crankshaft, which means you may need to buy a new set of bearings to match the new crank. A more cost-effective approach is to do the throw-length and run-out checks using vee-blocks. Once you have a known-good crank, buy bearings to match.)

SETTING THE END-FLOAT

Some type of thrust collar must be installed on the clutch-end of the crankshaft. It may be a magneto drive adapter, a dynamo adapter, a propeller flange or starter ring gear but whatever it is, now is the best time to set the end play.

Examine your end-play shims. If they have turned edges they must be stoned smooth. This is typically the case with after-market end-play shims. Shims from VW de Mexico are usually okay right out of the box. But check.

The end of the crankshaft must be perfectly square and clean. Degrease the surface then stone it lightly then inspect it visually, removing any high spots you discover. In a similar vein, whatever bolts to the end of the crankshaft must be perfectly flat. The squareness of these surfaces determines the squareness of the thrust collar.

If the O-ring is installed in the thrust collar, remove it and clean the groove. You'll find a new O-ring in your gasket set. For now, leave it off.

Bolt the thrust collar (whatever it is) to the crankshaft. You need torque it only tight enough to eliminate all play. (If the surfaces are true, torquing to spec can't move them any closer together. And if they aren't true, torquing to spec won't help :-)

Set up your dial indicator, push the crankshaft fore & aft and determine its maximum amount of travel. Subtract 0.0025 from that figure. The remainder is the required thickness of your shim stack. (Record these figures in your documentation package.)

The crank and the thrust collar rotate as a unit. The #1 main bearing and its thrust surface are fixed. If the thrust collar rotated against the bearing's thrust surface at crankshaft speed the soft babbit thrust surface would be worn away in a matter of hours.

The stack of three shims, never less, acts as kind of clutch, thanks to the film of oil between them. The shim nearest the thrust collar will rotate at nearly the same speed as the crankshaft, the middle shim will rotate much more slowly and the third shim, the one nearest the bearing, will hardly move at all. Wear is distributed across the stack of shims, limiting the amount of wear on the thrust surface of the #1 main bearing.

Thrust shims come in six thicknesses:
0.24mm (0.0094")
0.30mm (0.0119")
0.32mm (0.0125")
0.34mm (0.0133")
0.36mm (0.0141")
0.38mm (0.0149")

That is, STOCK VW shims come in those sizes. What you receive from an after-market supplier is liable to be any size at all.

Which doesn't really matter. The object is limit the amount of end-float using a stack of shims. You may never use less than 3 but you may use more.

So how thick are your shims? Use your tenths mike to check. (ie, use a mike that reads in ten-thousandths of an inch.) Sort your shims by thickness. Then do the paperwork. You want a stack of shims that will give you a clearance between .0025 and .004. (The wear limit for end float is .006")

Here's an example: Push the crankshaft as hard as you can into the case. I don't mean for you to slam it around, I mean for you to take out all of the slack. Do it a couple of times, pulling it out then pushing it back. With the crank firmly forward in the crankcase, rig your clock to the case and zero it against the thrust collar (whatever it is). Now pull the crankshaft back and read the amount of travel shown on the dial indicator. You may do this several times if you wish.

Once you know the total amount of end play, we do the rest of the job at the desk.

Let's say the total travel was forty-though - .040" Subtract your target clearance from the total travel. .040 - .0025 = .0375

Find your THICKEST shim and subtract it's thickness from .0375" For this example I'll use the stock shim thicknesses. That gives me .0375 - .0149 = .0226

Now find your THINNEST shim. Using the stock sizes that would be .0094" so I'll subtract that from .0226, giving me .0132" as the remaining gap to be filled by a shim.

From among your remaining shims, pick the CLOSEST MATCH and use that as your third shim. Using the stock thickness of shims the closest match would be .0133... and that's more than close enough.

Alas, life isn't a textbook example :-)

If your initial end play is too large to fill with four of your thickest shims and you can not obtain a thrust collar (whatever it is) that is thicker, you'll need to replace the #1 main bearing with one having a thicker thrust surface.

Going the other way, if the initial end play is less than the minimum clearance plus the thickness of your three thinnest shims you must move the thrust collar farther away from the thrust face of the #1 main bearing or reduce the thickness of the bearing's thrust face. Each overhaul gasket set contains a metal shim 0.24mm thick that fits the end of the crankshaft. The maximum you can safely machine off the thrust face is about .010" Combined, that gives you about .020" of additional play.

Once you've set the end play, mark and bag the shims and put them in that Special Place. We won't need them until we do the final pre-assembly.

CHECKING THE MAIN BEARING CRUSH

Do a final check to insure the main bearings are properly seated in their saddles then install the right-hand half of the crankcase.

Locate the six nuts and washers for the main case studs. Install them finger tight then use your torque wrench to run them up to 15 lb-ft starting with the middle-lower stud, then the upper-outer then the middle-upper and finally the lower outer.

As you tighten each stud, periodically rotate the crankshaft. It should turn easily.

With the studs torqued to 15 lb-ft, go over them again torquing them to 20 lb-ft, this time starting with the upper-outer and using the same vee-pattern to finish with the upper middle.

The crankshaft may be difficult to start turning but once free it should move smoothly with only moderate drag. If at any point the crankshaft fails to spin freely, STOP. Dismantle. Inspect.

Finally, torque the six nuts to 25 lb-ft. Do the middle upper/lower pair first, then the clutch-end pair and finally the pulley-end pair. The crank should continue to rotate freely throughout the tightening sequence. Indeed, the crank should spin more freely when the crankcase is fully torqued since doing so should cause the bearing shells to form perfect circles.

If the crankshaft should bind, dismantle the case, remove the crank and inspect the bearings. Odds are, you've gotten one misaligned. If so, you'll have to obtain another set of bearings and try again.

This pre-assembly has confirmed the fit and crush of your main bearings and determined the APPROXIMATE shim stack for your end-float. Dismantle the crankcase and remove the crankshaft. Bag them both. Update your documentation package.

VW Engines - Part VIII - More Preassembly
by [Robert S Hoover]() Robert S Hoover

RAP ON RODS

Over the years Volkswagen used three types of connecting rod in their Type I. Tom Wilson does a nice job explaining their differences in his book "How to Rebuild Your Volkswagen Air-Cooled Engine," a copy of which should be in your library.

Hopefully you'll be using 311-105-411B's which was the stock rod in the 1600cc engine. The 1500 used -411A. The main difference between the -A and the -B is that the later rod secures the cap with a self-aligning threw-bolt while the early rods (all of them) use a cap screw that is not self-aligning.

As part of the inspection procedure you should have dismantled your rods, driven out the thru-bolts (which are a force fit in the rod cap) and had everything magnafluxed or dye-checked for cracks. If you are using rebuilt rods, always replace the thru-bolts and nuts. (If using the older rods, replace the cap screws with new items.) Rod nuts and cap screws should be a one-time use item. Use old nuts during pre-assembly, replacing them with new nuts for the final torquing and straking. Once a nut or cap screw has been straked it should not be reused in an aircraft engine. If you have trouble finding new thru-bolts and nuts call Lou or Nancy at OVW in Escondido, CA (760-743-7587) and order a set. (You may use my name if you wish... but it won't help :-)

FITTING THE CONNECTING RODS

Preassembly of your rods is not to see if the parts fit, blueprinting has told us they will. The purpose of pre-assembly has to do with the Quality Factor, with how well the parts fit together. Unfortunately, with but one engine's worth of parts to work with there isn't much we can do to improve the fit. But we can verify the tolerance stack-up and human factors of assembly have not pushed us out of spec.

The spec for the rod-to-journal clearance is .0008" to .0027" with a wear limit of .006". The purpose of this pre-assembly is to confirm our rods fall within that .0019"-wide window of acceptability. To do this we will use Plastigage.

Plastigage (brand name) is made by Perfect Circle, the piston ring and bearing people. It is an extruded wax rod not much larger in diameter than a coarse hair. When Plastigage is crushed its width is proportional to its thickness and that thickness is the clearance in the bearing. The edge of the package is printed with a scale to measure the width of the crushed rod, inches on one side of the package, millimeters on the other. Plastigage comes in a wide range of sizes allowing you to measure from a one thousandth of an inch to about thirty thousandths. The different ranges are color-coded and their packages are printed in that color. The smaller sizes, red, blue and green, are most often used for automotive work. Blue can measure a gap up to .009", red up to .006" and green up to .003". The color is incorporated in the nomenclature. 'Type PG-1' translates as 'Plastigage, green, one foot.'

All real auto-parts houses carry Plastigage. Green Plastigage has a crush-range of .001" to .003", so so ask the clerk for some green Plastigage. Expect to pay about a dollar.

Unfortunately, most franchise auto parts stores won't have any idea what you're talking about. If the clerk has to look it up in his computer, give him the full nomenclature - Type PG-1. If that doesn't work, try the manufacturer's name (Perfect Circle). Almost everyone carries Plastigage but it's often stuffed into a corner with the piston rings.

J.C.Whitney used to carry Plastigage and still does, if you talk to the right person, but it is no longer listed in their catalog.

I'm giving you this background because you can't do proper work without proper tools and Plastigage, which typically costs less than a dollar per length, is the best tool for checking your con rod bearing clearance. But it is sometimes very difficult to obtain and this is one of those cases when the Internet isn't much help. Perfect Circle is now part of the Dana Corporation and like most billion dollar corporations the purpose of their website is mostly an Ego Page, having more to do with enhancing the corporate image than providing information to potential customers, especially those looking for a dollar's worth of Plastigage.

- - - - - - - - - - - -

Okay, you've got some green Plastigage, your rods are laid out in the proper order, wiped clean and dry, and the con rod journals on the crankshaft are wiped clean of oil. Everything is clean, you have your notebook and pencils and you won't be disturbed for at least half an hour.

The ground edges of the rods should have already been deburred and you've already checked the cheeks of the rod for any shop-rash, the tiny nicks and burrs that occur when steel parts are carelessly stacked together. (If you find evidence of such, stone it out with an Arkansas stone or burnish it with #600 silicone carbide paper and then clean the rod -- but also, see below.)

FEELING UP YOUR RODS

This is going to sound a little crazy so bear with me.

Lay a piece of paper on a flat surface; on a desk or table. Smooth it down against the surface; get all the air out from under it.

Now shut your eyes and FEEL the edge of the paper. Not just the textural difference between the paper and the surface it's laying upon, I want you to find the edge and track it using only your sense of touch.

Most typing paper, common #20 bond, is about three-thousandths of an inch thick. The paper is THICKER than the clearances we must achieve if we want to produce a durable engine.

When you check your rod bearing clearance you're going to be shooting for a clearance of between one- and two-thousandths of an inch. The interesting point here is that clearance is DIVIDED around the circumference of the journal. Make sense? Let's say we measure a clearance of .002". That means one side of the bearing is touching, metal-to-metal, and there is two-thousandths of an inch of clearance on the other side. When the engine is running there will be a film of oil between the journal and the bearing and the average clearance with only .001" at any point on the journal.

Can you feel something as small as one-thousandths of an inch? YES! In fact, you can FEEL things you can't see, imperfections so small they go unnoticed by the rest of the world. When building an engine you must apply all of your senses to the task. Precision instruments give you numbers and we always start with that but a really good engine is more than numbers, it is a sense of harmony, for want of a better word. The mechanics of numbers and gages and fit or not-fit addresses only the grossest details of your engine. The harmony exists below that mechanical horizon. Touch the parts. Learn to trust your senses. The harmony is an undefinable link between you and the engine.

Okay, second exercise. Have you got a beam-type caliper? Open the jaws about an inch and FEEL their edges. The edges of the jaws have been machined square and then dressed. The corner is sharp but not too sharp. There is no feather-edge of metal; you can't cut yourself. That's what a dressed edge feels like.

Now go feel up your connecting rods. You're interested in their cheeks. New or rebuilt, the cheeks are usually NOT dressed. Under a 7X glass you can probably catch the glint of feather-edges of metal and, if your fingers are sensitive enough, you can feel those sharp edges.

Get rid of them. A light wipe with #600 wet & dry carbide paper is all it takes. Once the edge is dressed, clean the rod; get rid of any residue.

The books give us two reasons for going this. The first is because those feather edges of metal will end up in your oil and if you don't have an oil filter they will be recirculated through your engine over and over and over again, until you change the oil. Such microscopic contaminants in your oil are the main cause of bearing wear.

The second reason has to do with stress. Any nick, scratch or thin section of metal liable to fracture, such as those feather edges, is a potential stress riser. In building your airframe you've been cautioned again and again about this problem but the problem isn't restricted to airframes, it applies to engines as well. So dress those edges.

And there is a third reason. Properly dressed, the rods simply feel better; the harmony thing, which you won't find in any book on engine building.

End of lecture. Go back to work :-)

- - - - - - - - - - -

Are the shells installed in the rods? If not, install them now. Note how the tangs on the shells must align with the notches machined into the rod. After giving the rod and shells a final wipe down with MEK, press the shells firmly into place with your thumbs. Insure the tang-edges are flush with the rod. Work with just one rod at a time so you won't get the caps mixed up.

Put a length of Plastigage across the crank journal you want to measure, install the connecting rod, torque to spec, remove the rod and measure the crushed width of the Plastigage using the scale on the package. Anything under a thou is too tight. Anything on the high side of two, too loose.

- - - - - - - - - - -

That's about all you get on rod fitting from the popular press. And while the above is accurate and valid, for a newbie it's about as useless as mammaries on a male swine.

First off, as with any tool, you need to know HOW to use Plastigage before you can get any good from it. You can't allow the connecting rod to move while being tightened. If it moves, it will smear the Plastigage. Since the rod caps are torqued to 32 foot pounds you must begin with the crankshaft held solidly in position which, because of the task, should be horizontal. Unfortunately, there's no way to do this without using some form of fixture to hold the crank. Such fixtures are available but they aren't cheap. A flywheel secured in a vise makes a good fixture but few people have a vise of suitable size or a stack of old flywheels under the bench. You can also make a fixture. I'll put a drawing of such a fixture in the graphics archive when we get it to accept .dxf format.

Lack of a suitable fixture to hold the crankshaft will see most of you doing the Plastigage check with the crank standing either on its nose or tail, plugged in to either a pulley or a crankshaft. It will work but you're going to have to be extremely careful not to move the rod while tightening the cap. Even a small amount of movement can smear the Plastigage enough to give you an incorrect reading.

But the real question here is what to do if the clearance is not within the .0019" window allowed by the specifications

The initial blueprinting should have detected a crank that was under spec, just as it should have detected a rod with a big-end that was over. But if your tools are only good to a thou or if your surface place isn't true to within a couple of tenths, you're liable to get too tight a fit from simple stack-up error. That is, the journal was on the low end of spec (according to your tools) while the rod was on the high end.

Too small a clearance isn't much of a problem. Simply haul the crank back to the grinder, tell him the reading you got with the Plastigage and ask him to polish a few tenths off the rod journals.

But too much clearance is a royal pain in the ass.

With just one engine's worth of parts there's no simple answer for this type of problem, which isn't that uncommon. The most logical fix is to have the crank reground to the next undersize, buy a new set of rod bearings and try again. Of course, if the problem is due to poor quality workmanship on the part of the crank grinder, you could spend a fortune chasing spec and never get there.

The best cure for this type of problem is to not let it happen. I know how trite that must sound if this is your first engine or if you think it will be your last. The truth is, the time and money spent on blueprinting has a worth at least ten times greater than its cost. You'll discover this for yourself the first time you get a problem engine, one of those Monday Morning Specials with odd-ball dimensions.

The reality of the situation is that when they get a bearing that's a bit too loose, most first-time engine builders simply bolt the thing together, fill it with 40-

weight and run it. And yes, it will run. But the useful life of a journal that is already out of spec is going to be measured in hours rather than years. Your decision. You're the Mechanic-in-Charge.

- - - - - - - - - - - -

I keep both red and green Plastigage in my toolbox but I rarely use it. Having accurately blueprinted the components I KNOW they are going to fit. Plastigage is a handy confirmation of that fact and a very useful tool when you can't blueprint the parts, as is often the case when doing a REPAIR on an engine.

INSTALLING THE CONNECTING RODS

At this point you've confirmed the fit of the rods; they have the proper clearance, both radial (ie, bearing clearance) and axial (ie cheek-to-crank gap). Now you're going to assemble them onto the crankshaft.

(Typing the above, I realized I'd failed to mention connecting rod axial clearance, which should be .004" to .016" with a wear limit of .027" (!) Although I prefer to build my engines ‘tight - with minimum bearing clearance – for axial clearance on the rods I've found it best to shoot for .006 to .010.)

Clean you hands and use your fingers to wipe a dab of moly-type CV joint grease into the bear shells. As with the crankshaft bearings, I want you to really rub this stuff in, not just smear it on. Wipe off any excess.

The cheeks of the rod are also a bearing surface. Smear a film of moly-type CV joint grease onto the cheeks.

Ideally, the crank is positioned horizontally. Check your documentation package to insure you mate the proper rod to the correct journal. Orient the rod so that the forging mark will up on the upper side when the crank is installed in the crankcase.

DON'T put any Loctite on the rods at this time. We're going to take them apart again. DO use old hardware. We'll save the good stuff for the final assembly.

CHECK THE FORGING MARK (Yeah, I know - we just did that. Humor me :-)

Torque all four rods to 12 ft-lb. FEEL each rod. I want you to rotate it around its journal one full circle. A SLIGHT bind is okay if it is SMOOTH. What you're feeling for is any sign of grit or debris. I'm sorry I can't describe this process any better - if you feel any thing suspicious, remove the rod, clean it and do it over.

All of the rods should move freely.

Reset your clicker and torque to 20 ft-lb. Repeat the check for free movement and grit. Reset the clicker for 28 ft-lb and repeat the procedure.

Finally, reset for 32 ft-lb and do it again.

Rod bearing shells are not truly round until they are torqued to spec and even then, there may be some binding at the parting line. If you have a rod that hesitates in the rotation test it is probably due to this slight out of roundness. Holding the rod horizontal, use a small hammer to deliver a single LIGHT tap to the joining line on each side of the rod. This tends to equalize the stresses produced by torquing the rod to spec, just as torquing them in stages introduces an element of time that serves the same purpose.

The rods are torqued to the crankshaft and move freely. Using both hands, raise all four rods to the horizontal then let them go at the same time. They should all swing down at the same RATE. A slow rod will be tight, fast rod loose. Too tight? Too loose? It's a judgment call. And you are the Mechanic in Charge.
Leaving the rods installed on the crankshaft, cover the crankshaft and stand it on the bench or leave it in its fixture until called for in the next step.

VW Engines - Part IX - Even MORE Preassembly
by Robert S Hoover

TRIAL FIT CYLINDERS TO CRANKCASE

Your clean, ready to assemble crankcase is on the bench or in your engine holding fixture.. The cylinder studs are NOT installed.

Go find your jugs.

You know the height of your jugs from the deck lip to the chamber sealing surface but you don't know if they are the same height all the way ‘round. To know that, you would have to measure the height of the lip every ten degrees or so of its circumference, which isn't very practical. Besides, there's an easier way.

Examine the spigot bores in the crankcase. The deck on the case and the lip on the cylinder must form an oil tight seal. To do so, they need to be as flat as we can get them. So let's find out how flat they are - how well they fit.

Find the small whetstone you used to deburr the valve stem keeper grooves. Press it flat against the deck surface on the crankcase and rub it around the spigot bore a couple of times. Wipe the surface with MEK first, and make sure the whetstone is not clogged with oil or sharpening particles. (If it is, soak it overnight in MEK then pack it in whiting compound or diatomatious earth and bake it in a low oven for about four hours. The combination of solvent & heat will drive most of the oil out of the stone, where it will be absorbed by the diatomatious earth.) When you stone a non-ferrous surface, what you're looking for is evidence of any dings or scratches.

Use the same stone or a tab of #600 wet & dry paper to dress the machined edge of the lip on the cylinder. Don't try flatting the lip, just dress its edge. The fine sandpaper is a better choice here than the whetstone because of the indentations in the edge caused by the head stud reliefs.

Wipe down both surfaces with MEK.

Now go buy yourself a tube of lipstick.

Okay, stop yelling. Use Prussian Blue if you've got it. But if you don't got it, try the lipstick trick. (I use Purple Passion Parfait. Got it on sale at the local drugstore; fifty-nine cents for about a hundred engine's worth of spotting compound.)

Using the lipstick, make eight evenly spaced marks on the deck of the crankcase for the jug you're working with. Ignore the stud bolt holes, you can't use them for laying-out the marks because they aren't placed symmetrically around the spigot bore. Go on; make a mark about an eighth of an inch wide at noon, three, six and nine o'clock. Then go back and make a mark in between each of the first marks. That's 2:30, 4:30, 7:30 and 10:30.

Slide the cylinder into the spigot bore, press it firmly against the decking surface and TWIST it... for about an hour and a half across the face of that clock you just drew. Or forty-five degrees. One of those.

Lift it out of the bore and place it upside down on the bench.

There should be a perfect, continuous line of Purple Passion Parfait completely around BOTH the decking surface and the lip.

Repeat the procedure for all four jugs & spigots.

When inspecting the line, take your time. That smear of lipstick may seem like a joke but it contains a lot of valuable data. Don't be afraid to use a glass and some extra light.

A continuous line of color means the surfaces are flat enough for our purposes. A few gaps or streaks in the line of color says you need to find out what caused them but odds are, we can make it work. What you DON'T want to see a dashed line or color, or big gaps in the line. That sez one - or both - of the surfaces is not true.

The initial stoning of the case should have revealed any dings or gouges that might cause an interrupted line of color. If that's what you've got and the interruption is a single isolated gap, don't worry about it. You need to wash off the lipstick and flat the case a little better but we can make it seal okay and there is obviously enough support for the jug.

The worse-cast is chatter marks on the machined lip on the cylinder or a canted deck surface on the case. The chatter marks will prevent the jug from sealing properly, offer a poor load platform and does not present a uniform height. If you see either of these problems it means another trip to the machine shop. The case needs to be decked properly and you'll have to get ten-thou turned off ALL of your cylinders, plus buying a set of .010" spacers to make up for the loss... plus any loss of the deck height(!)

(When you've finished inspecting the color line, remove it. Use MEK or other solvent and be sure to remove every trace of lipstick. Not only does lipstick contain organic oils and coloring agents that can prevent sealants from bonding to the metal, a dab of lipstick in the wrong place can lead all sorts of domestic problems.)

CYLINDER SHIMS

… come in any size you want... for about $40 a set. But they are available in standard sizes - .010, .020, .030 and .060 - for about eight bucks a set.

If you are using a crankcase that has been decked ,you should have been told the size of shim you need to bring the deck height back to spec. In a similar vein, if you've had to true-up your jugs by shaving the lower lip, you must use a shim equal to the thickness you've removed from the cylinder. If BOTH the case and cylinder has been machined, try to combine the required height in ONE shim. Each shim adds another sealing surface to the stack and the fewer sealing surfaces, the better.

NOTE ON CYLINDER SHIMS

Why do you need them? Decking the case reduces its width. Trimming the cylinders reduce their (installed) height. Each causes the cylinder heads to move closer to the center-line of the crankshaft but the crank throw, rod length and piston height remain UNCHANGED. This can cause the piston to extend BEYOND the cylinder... which it isn't allowed to do because it will hit the cylinder head, at which time your life becomes very interesting :-)

In fact, in this engine the piston doesn't even have to touch the head to cause the engine to self-destruct

In this series of articles I am describing the construction of an AIRCRAFT engine assembled from Volkswagen components. It is NOT a car engine. It is a chugger - a low rpm, high torque engine. Because its volumetric efficiency will be quite high the compression ratio of 7.8:1 will result in a brake mean effective pressure (BMEP) that is higher than anything you'll ever see in a VW-powered vehicle. So forget all the cute hotrod tricks, such as dialing in zero deck height. In this engine the top of the piston must NEVER get closer than about .055 to the top of the cylinder and for best operation, it should be about .060.

Why? It has to do with the process of combustion. The Volkswagen engine uses a wedge-type combustion chamber. The combustion chamber is designed with two flat areas, parallel to the crown of the piston. These flat areas are the secret to the excellent combustion properties of wedge-type chambers. As the piston rises on the compression stroke the flat part of the head, called the 'squish' area, acts as a turbulence generator, causing the fuel/air mixture to be thrown toward the top & bottom of the combustion chamber (remember, it's laying on its side) which is canted away from the piston. The wedge shape of the combustion chamber causes the fuel/air mixture to rotate in a fashion similar to the boil at the base of a waterfall. But being a gas rather than a liquid (although both are 'fluids' as defined by the fluid dynamics that apply here), the rapid rotation of the fuel/air mixture causes it's core to be compressed more than its edges. And it is that core of rotation which is closest to the spark plug at the time of ignition. Once ignited, the turbulence produced by the squish areas tends to push the fuel/air charge into the fire, so to speak. (Remember, ignition is initiated long before the piston reaches Top Dead Center.) The bottom line is that we get near perfect combustion... if everything is working as it should. And one of those factors is the thickness of the 'squish' area, which we will try to nail down at sixty-thousandths of an inch. According to Ricardo that amount of squish area should provide the optimum degree of turbulence needed for uniform ignition. As a point of interest, the VW spec for the 'squish' height is .055" to .065". (Ricardo was a 1930's British automotive engineer who literally wrote the book on what we now modern engines.)

NOTE ON CYLINDER 'SPACERS'

What's the difference between a spacer and a shim? None. Spacers are just thicker shims. And I mean THICKer - up to half an inch.

Why do you need such thick shims? You don't, on a stock engine. But you do on strokers. When you install a stroker crankshaft the added length of the throw is liable to shove the piston beyond the cylinder. Stock stroke is 69mm - 2.717" inches. An 82mm stroker crank has a throw of 3.228". That's more than half an inch difference. So you have to lengthen the cylinder by half the length of the new stroke. The principle is the same as for adding shims after decking the case, only the magnitude changes.

(Why only half? Because the increased stoke refers to the diameter of the throw-circle, whereas the piston travels only on the radius. That is, the 13mm difference between the stock 69mm crankshaft and an 82mm crankshaft is achieved by moving the center of the rod journal 6.5mm farther from the centerline of the crankshaft. The piston now travels an additional 6.5mm up the cylinder... and an additional 6.5mm down as well.)

There are special pistons (called 'B-type') for use with strokers in which the gudgeon pin is installed nearer the head of the piston. Unfortunately, you can't move the wrist pin very far or you'll have to redesign the piston to use narrower rings (such pistons are available). But the real problem is the rods. On any stroke longer than 73.8mm, with the stock rods, the side loads on the piston increase exponentially as the crank throw increases. Bottom line is that with increased rod angularity, wear rate goes up dramatically. The solution is to reduce rod angularity through the use a longer connecting rod. Stock VW rods are about 5.4" (137mm) in length, center-to-center. According to the Ricardo Rule for side loading and rod angularity, you'll need a rod having a length of about 5.7" (145mm), common stuff in Porsche or Chevy engines. Of course, use of a 145mm rod means you'll need to use an 8mm spacer under the cylinder.

There's no such thing as a free lunch :-)

Egged on by the magazines and other commercially oriented 'experts,' kiddies continue to build strokers using stock rods. Such engines seldom last more than a year or so, giving rise to the Conventional Wisdom that strokers just don't hold up. Which is kinda odd when you think about it because the world is filled with reliable, long-lived engines having the same bore & stroke as those unreliable VW strokers. All a vast mystery to the kiddies, of course :-)

Properly built, a big-bore stroker ends up at least an inch wider than a stock engine, which means the blower housing must be sectioned and all of the shrouding modified, a labor intensive operation. The typical price tag for such an engine is about five grand. (Despite their high cost there is a small but steady demand for quality-built, cool running big-bore strokers from replicar owners.)

Cheaply built big-bore strokers destined for the kiddie market use stock length rods and zero deck height so the stock width blower housing won't leave too wide a gap. But to keep the compression ratio within reason they are forced to hog out a huge hole in the top of the combustion chamber, weakening the head and guaranteeing poor combustion efficiency. To convince the kiddies this is a good idea they call it a 'semi-hemi.' Such engines are of course wildly popular among the kiddie crowd despite their dismal reliability. (Note: 'Kiddies' are technologically naive individuals. The term has nothing to do with age.)

ALL ABOUT COMPRESSION

Compression ratio refers to the change in volume from when the piston is at bottom dead center and the volume to when it is at top dead center. This is a purely mechanical computation. Unfortunately, the computed compression ratio does not reflect the actual compression ratio of the fuel/air charge. For that, we must include volumetric efficiency in the equation. For example, if our volumetric efficiency is 0.5, meaning the fuel/air charge fills only half the cylinder by the time the intake valve closes, our effective compression ratio becomes one-half of the calculated compression ratio.

What effects our volumetric efficiency? EVERYTHING! The temperature of the air and of the engine, the amount of moisture in the air, the smoothness of the walls in the intake runners, how well our carburetor meters the fuel, the size &

shape of the intake valve... dozens of factors. Automotive articles seldom mention these factors because there are so many that a truly comprehensive article on the subject would take up an entire book. Instead, such articles make a host of unmentioned assumptions and blithely describe some quick & easy way to get 500hp out of a 1600cc Volkswagen engine :-)

Reality is a bit more harsh. With an un-supercharged, carburetted engine it is impossible to achieve 100% volumetric efficiency at a useful rpm. So we do the best we can. But to do so, we must understand the relationship between volumetric efficiency, compression ratio and rpm.

Review the definition of ‘effective compression ratio' then tackle this problem: What is the effective compression ratio of a normally aspirated racing engine with a CR of 10:1 when it's turning 8000 rpm?

I don't know either :-) But it's probably around 6:1.

The fuel/air charge has mass and mass has inertia. In a normally aspirated engine, as the rpm goes up the volumetric efficiency goes down, mostly due to the inertial effects displayed by the fuel/air charge. At higher rpm, with less time to fill the cylinder, the amount of fuel/air mixture that ends up in the cylinder is less than for lower rpms. When ignited, the smaller charge produces less energy and the engine begins to slow down. To offset that effect we can use a larger intake valve, leave the intake valve open for a longer amount of time or increase the compression ratio. High speed racing engines use all of these methods (and more). Such engines use compression ratios of 10:1 or even higher and their valve timing is such that, while they run fine at high rpm, they may not run at all at any speed below 1500 rpm.

The interesting point here is that the effective compression ratio of such engines may be as little as 6:1 when running at maximum rpm.

So what is the ideal compression ratio for OUR engine?

I don't know that either. In theory, the ideal compression ratio for the engine I am describing in these articles should be about 8.3:1. But that is based on a host of assumptions, such as an rpm of 2850, Standard Atmosphere (ie, 59 degrees Fahrenheit at an atmospheric pressure of 29.92" of mercury), perfect fuel and so on. Design an engine for those conditions and it will only run well when all of those conditions are met. At anything less, you'll see less power. But if the conditions exceed the designed norms you will probably destroy the engine.

The wiser course is to address the Reliability Factor first - to design an engine that will provide the widest possible range of RELIABLE performance. With that in mind I am going to set the compression ratio of the engine described herein at 7.8:1. For a displacement of 1584cc (about 96.6 cubic inches) that compression ratio should give about 34.5bhp at the prop. That happens to be about the same power you'd get from a stock VW engine but on the engine described here the power is going to be available at a lower rpm allowing the use of a longer, more efficient prop. The specific fuel consumption should also be lower.

WHAT IS 'COMPRESSION RATIO'?

Compression ratio is defined as the sum of V1, V2 and V3 divided by the sum of V2 and V3.

V1 is the volume of the cylinder swept by the piston and is often called 'cylinder volume' or 'swept volume.' It is found by squaring the diameter of the cylinder (that is, to multiply the diameter by itself) multiplied by the length of the stroke and to then multiply the product of the two by 0.785.

V2 is the volume of the 'squish' area, usually called the deck height of the cylinder or the deck clearance. It is found in exactly the same way as V1 except we use the deck height instead of stroke length.

V3 is the volume of the combustion chamber, which you have already measured and recorded.

V1 and V3 are not a problem. We have measured V3 directly and know its exact value. V1 is not a problem because it is easily computed.

V2 – the Chamber Deck Height or squish area - is as yet undetermined.

SEARCH FOR THE MISSING V2

V2 or Chamber Deck Height is the distance from the top of the piston at TDC to the top of the cylinder.

The easy way to find V2 is to install the pistons (without their rings) onto the rods, slide the cylinders over them, put a Deck Plate atop the cylinder, torque everything to spec, locate TDC then measure V2 directly.

So let's do that.

But before we do that let's consider that Deck Plate. Ideally, your deck plate should be a piece of steel or aluminum, half an inch thick and accurately flat on both surfaces. Odds are, you don't happen to have one handy.

You can buy a deck plate but most of them cover only ONE cylinder. To do a proper job of it you need one that covers BOTH cylinders. A full width deck plate is the only way to emulate the clamping pressure of the head. Using a plate that covers only one jug allows small errors to creep in. They may not be significant... but then again, they might. Your decision; you are the Mechanic in Charge.

The most common source of accurately flat steel is cold-rolled mild steel which is usually accurate to better than a thou for the distances involved here. You'll need a piece at least 10" long by five inches wide. Those dimensions are not carved in stone but that's the size that will work for cylinders of all sizes. Metal suppliers commonly carry cold rolled steel (CRS) in half-inch thicknesses and four to six inch widths. They'll typically charge you for the cut plus the length of the stock to the next-nearest foot.

Cast iron will work, if you can find an accurately machined cast iron plate. So will aluminum. Aluminum tooling plate commonly comes in half- and three-quarter inch thicknesses, has a zero temperature coefficient and is flat to better than a thou in 12".

Once you have your plate you must mark it for drilling then drill the holes for the studs. To mark it, use a cylinder head as your pattern and a transfer punch of suitable size to dot the plate. Clamp the head to the plate so it won't wander around while marking.

Once the plate is marked, scribe diagonals across each cylinder space and mark the center. Drill the bolt holes to 3/8" and the center hole to one-half or three-quarters. The center hole is where you'll take your measurements using a depth mike or a beam type caliper with a depth-foot attachment. (If you don't have a depth mike, order a depth-foot attachment for your caliper.)

You will need spacers for the head studs. I made mine on the lathe so they would be square on each end but you can do well enough by cutting up some electrical conduit (EMT) or similar mild steel tubing and grinding the ends flat. Use washers on both ends of the spacers so as not to mar your deck plate and to provide a surface for the nut.

(I can't tell you the length of the spacers for a stock engine. Most of the engines I build are quite a bit wider. I have a bread-pan full of spacers of various lengths, plus a lot of USS washers. I make up whatever height is required, torque to spec, wait a bit then come back and re-torque. Seems to work okay. My deck plate is cast aluminum tooling plate, half an inch thick.)

HEAD STUDS

Go find them. They should be freshly painted and the paint should have been baked. If the threads are fouled with paint, clamp the stud in wooden blocks in the vise and chase the threads with a die. Do not put anything on the threads at this time. I'll assume you've already checked the threaded bores in the crankcase halves. If you haven't, and if it's a used crankcase, chase the threads with a tap, flush out all the swarf with MEK and blow the bores dry. If it's a new case, flush the bores with MEK, blow dry and use one of the head studs to verify that the bore will accept the full depth of thread. (On new cases, be sure to get all the preservative out of the threads. This often requires a bronze bore brush and lots of solvent.)

This is getting a bit long so I'll break it here. In the next step we're going to pre-assembly the crankcase including the crankshaft with rods, then add the pistons to the rods, thread the head studs into the case and slide the appropriate cylinder down over its matching piston. Working on one side of the engine at a time we will install the deck plate, torque to spec, find TDC for each cylinder then measure the Cylinder Deck Height, which is our missing V2.

VW Engines - Part X - STILL More Preassembly
by Robert S Hoover Robert S Hoover

VW Engines - Part 10 - STILL More Preassembly

Install the crankshaft, complete with rods, into the left half of the crankcase. Insure the bearings are properly seated on their pins then install the right half of the crankcase and torque to spec using the six main bearing saddle studs. You've already done this when you did the initial check of the crankshaft's bearings. Refer to those instructions and torque to the same value.

PREPARE YOUR SHIMS

If your crankcase has been decked you should have obtained shims equal in thickness to the amount of material removed during the decking process.

If you've refaced either the deck or sealing surface of your cylinders and the amount of metal removed was more than .050, you must provide a shim equal in thickness to the amount removed. When the cylinder needs only a clean-up cut of .010 or less AND the case has not been decked, you may be able to accommodate the shorter barrel-length when you adjust the deck height. If you've shortened the barrels between .010 and .050 the need for a shim will be determined by the stack-up error and will vary from engine to engine.

If your crankcase has been decked AND your barrels turned by ANY amount, you must provide a shim equal to the COMBINED thickness of the metal removed.

Shims for stock cylinders are available in .010 increments up to about .090. To keep from having to order shims ground to your requirements, you may use the next larger thickness. For example, if you need a .054 shim, use .060.

Inspect your shims to insure they are truly flat. Stone any turned edges. With the cylinders standing upside down on the bench, wipe the deck lip and the shim with MEK and place the shim onto the cylinder. As this is a pre-assembly, do not use any sealant or adhesive at this time.

INSTALL THE PISTONS

Once your cylinders & pistons are mated with a particular rod, journal and spigot bore, they acquire a Cylinder Number identity in addition to the Work Number we assigned earlier. From this point on we will refer to them by their Cylinder Number. Refer to your documentation package to insure you have the correct piston & cylinder (P&C) set for cylinder #1. Heat the piston if required and install on #1. Rotate the crankshaft to extend the #2 rod, locate the #2 piston and install. At this time it would be a good idea to mark the pistons as to their cylinder number. Write it on the crown of the piston with a Magic Marker.

INSTALL THE HEAD STUDS

Install the eight head studs for that side of the crankcase. They should thread full depth using only finger pressure.

INSTALL THE CYLINDERS

Once the studs are installed, identify the matching cylinders and install them by sliding them down the studs, taking care to insure the shim (if any) is aligned with the studs and is installed flat.

At this time it would be a good idea to mark the cylinders as to their cylinder number. Using white or silvery fingernail enamel, mark the cylinder by painting its Arabic numeral at the 12 o'clock position (when looking into the cylinder) on the cylinder's upper most fin.

Install two spacers and nuts as temporary hold-downs on each cylinder. DO NOT TIGHTEN THE NUTS. The spacers will bear against the cast iron fins. Cast iron is brittle. You can break the fins with hand pressure alone.

With the #1 & #2 cylinders installed, loosen the clamp of the fixture and slowly rotate the engine to bring the left side uppermost. Repeat the installation and marking procedure above for the #3 & #4 pistons & cylinders.

SHORT CYLINDER CHECK

Using a pulley temporarily installed on the nose of the crankshaft, rotate the crankshaft and check that the piston does not extend beyond the cylinder. Check each cylinder. (‘Short cylinder check' is just a handy name for this procedure. We aren't really looking for a ‘short' cylinder. We already know the length of our cylinder barrels.)

When assembling an engine from used/overhauled components it is possible to arrive at this point and discover the pistons extend beyond their cylinders by some small amount (typically less than .010). When this condition exists it means we must lengthen ALL of the cylinder barrels through the use of a shim. The thickness of the shim should be equal to the LEAST amount of piston extension plus .060. This assumes the piston extends no more than .020 and the difference between the maximum and minimum extension is no more than .010.

IF your pistons extend beyond their cylinders by more than .020 it is good evidence of an error in the blueprinting process or that the case was decked more than you were told. Whatever the cause, you will have to install shims thick enough to prevent the pistons from protruding from the barrels before you can continue with the deck height check. You may use a thicker shim than needed for this purpose. Called a 'blueprint' shim or 'set-up' shim, its purpose is to allow you to proceed with the pre-assembly measurements so you can determine the actual size of the shims you will ultimately need. If you must use set-up shims be sure to keep track of that fact :-)

IF the deviation between the maximum and minimum extension is greater than about .060 it indicates a gross error at some point in the blueprinting process. You may actually have a short cylinder. You could also have a long rod or a 'fat' piston but the bottom line is that the combination of parts you are working with is not suitable for use in the same engine. There is no simple fix for this problem, which should have been detected when blueprinting the components. Identify the exact nature of the problem, obtain replacements of more suitable size and begin again.

USING THE DECK PLATE

Install your deck plate and torque to spec in two passes.

There are eight studs arranged in two rows of four. Use the following tightening sequence, in which 6/7 is nearest the pulley, 8/5 nearest the clutch-end of the crankshaft.

6-4-2-8
7-1-3-5

On your first pass, torque all eight head studs to 12 ft-lb. After torquing to 12 ft-lb take a moment to check that your spacers are square to the plate, the plate is square to the cylinders, the cylinders are square to the spigot bores and that the nut hasn't bottomed out on the threads. On the second pass, torque to 18 ft-lb if you have 8mm studs, 25 ft-lb if you have 10mm.

To find TDC, observe the piston through the center hole in the deck plate, raising the piston by rotating the crankshaft until the piston is at the top of its stroke. At that point, install a dial indicator through the center hole so as to bear upon the crown of the piston. Rock the crankshaft until you identify TDC precisely. With the piston at TDC, use a depth mike to measure the distance from the crown of the piston to the top of your deck plate. Subtract the thickness of the deck plate from your reading and record that distance.

Repeat this procedure for the adjacent cylinder then transfer the deck plate to the opposite bank, being sure to replace the temporary hold-downs before you flip the engine.

- - - - - - - - - - - -

NOTE ON TDC:

You should never use the notch in the stock pulley nor an after-market pulley printed with degree markings as a means of locating TDC. Many stock pulleys do not have a notch at TDC and some which do have it off by as much as three degrees. In a similar vein, the markings on cheap after-market pulleys are applied by silk-screen printing and are often wildly in error. There are accurately made degree wheels, their markings either machine engraved or laser-printed but their price starts at about fifty bucks and goes up.

In either case, the accuracy of the pulley with regard to TDC depends entirely upon the accuracy of the Woodruff key and its associated keyways in both the crank and pulley hub. While the stock crank is usually quite accurate (if it has not been reground), the pulley hub is not, especially so with regard to inexpensive after-market products, in that the keyway is seldom exactly 90% from the zero mark on the pulley.

Using a dial indicator and rocking the crank to determine the piston's maximum point of travel allows you to locate TDC within a fraction of one degree.

- - - - - - - - - - - - - - - - -

DECK HEIGHT CK

Whatever you call it, piston clearance, squish space, chamber deck height, etc., your measurements should fall between zero and .080 with a variation across all four cylinder of .020 or less. (Example: The deck heights of a stock engine I recently assembled .058, .060, .059, .063, for cylinders 1,2,3 & 4 respectively.)

If your deck height is significantly more than .080 there's a chance you're using the wrong pistons, the wrong rods or even the wrong crankshaft. Which doesn't mean you can't come up with a useful engine.

We want a deck height of about .060. When our measured deck height is greater than that amount it means we must SHORTEN the cylinders. If your cylinders are already shimmed the odds are the shims are of the wrong thickness. You may be able to get the proper deck height simply by using different shims. But if there are no shims involved and the deck height is greater than .060 then you must shorten the cylinders by the appropriate amount and repeat the deck height procedure. But before making any adjustment to your deck height, read the following procedure.

DOING THE PAPERWORK

Once you've measured & recorded deck height you may retire to your desk and work on the 'paper' engine :-)

Our goal is to achieve a compression ratio of 7.8:1 AND a deck height of .060. Odds are, we can't have both but let's see how close we can come.

Using .060 as your deck height, compute V2 using the formula in the preceding article. The easiest way to do this is to convert your deck height dimension into millimeters by dividing the inch-measure by .0394.

Using a stock 85.5mm cylinder (for example) you would have .785 (the pi constant) times 85.5 squared (7310.25) times 1.50 (the deck height in millimeters) gives us 10965.375. Since we're working in cubic centimeters, divide the result by 1000 to get 10.96cc, which I'll round to 11 for V2

Refer to your documentation package. Use the SMALLEST chamber volume to compute compression ratio using the formula in the preceding article.

I'll use a stock 85.5mm cylinder and stock 69mm crank for this example and 53cc for V3 (ie, chamber volume).

V1 is then equal to .785 x (85.5 x 85.5) x 69...
...0.785 x (7310.25) x 69 = 395959.691

To convert that to cubic centimeters we divide by 1000 and round to 396.

V1 = 396
V2 = 11
V3 = 53

V1 + V2 + V3 = 460
V2 + V3 = 64

So our compression ratio is 460 divided by 64 or 7.2:1 (rounded). Which is a bit lower than I'd like to see. Now the trick is how to adjust that figure.

The three factors in compression ratio are V1, V2 and V3. V1, the swept volume, is determined by the bore & stroke and as such, there isn't much we can do to change it at this stage.

V2 is most easily adjusted factor in the compression equation. Reducing the deck height to .040 will bring the compression ratio up to about 7.6:1 but that's about as far as we can reduce the squish area without incurring an unacceptable penalty in combustion efficiency.

(Could you live with 7.6:1 and a squish height of .040? Yes. In fact, the attention you have shown toward achieving proper volumetric balance means your 7.6:1 will probably outperform improperly built engines having higher CR's by a wide margin.)

V3 is the volume of the combustion chamber, which we can decrease rather easily by flycutting a few thousands from the chamber's sealing surface. This is the most common method of nailing down your compression ratio once you've worked out your deck height. And while it's a simple matter to flycut a head the trick is in knowing how much metal to remove.

\- - - - - - - - - - - -

NOTE: Earlier in this series of articles I mentioned the remarkable effect small changes in chamber volume could have on the power output of an engine. In this regard, please note how a change of only twenty thousandths of an inch (about half a millimeter) in your deck height wrought a significant change in your compression ratio.

\- - - - - - - - - - -

FLYCUTTING THE HEADS

Work out the compression ratio for your engine. If the calculation says you need to reduce your chamber volume use an iterative process to determine what that new, smaller volume should be. (That is, reduce V3 by one or two cc's and do the calculations over. As you home in on the ideal volume, go to .5cc steps and finally to .1cc steps until you get the volume nailed down with an accuracy of +/- 0.1cc) Once you know the required chamber volume it's easy to find how much the head must be flycut.

Working with your SMALLEST chamber, begin by leveling the head, chambers up. This is the same procedure you used when measuring the volume of the chambers but you will need to be as precise as possible in the leveling procedure. Be sure to check for level on both the z and y axis of the head (ie, end-to-end and side-to-side).

With the head level, use a depth mike and a parallel or other known-accurate bar to measure from the flat reference pads on the head (or from its re-machined surface if you've machined the pads away) to the sealing lip inside the chamber.

Using a syringe or burette accurate to 0.1cc, fill the chamber liquid having the same volume you are trying to achieve. Do this by filling the syringe or burette with the right amount of liquid then draining it into the chamber. Better shops use mercury here but colored water will also work.

Using a depth mike and the known-accurate bar you used to measure the height of the sealing surface, SLOWLY extend the depth mike until it touches the surface of the liquid. This is a rather tricky operation so do it several times and average your results. (At the moment of contact the liquid will appear to jump toward the anvil of the depth mike. With a strong light shining on the surface of the liquid at a shallow angle this 'jump' is clearly evident. Read the mike at that point.)

The difference between the height of the liquid and the height of the sealing lip is the amount that must be flycut from the heads.

As with the original cc-ing procedure, you should repeat this step several times to insure you come up with the right numbers.

If you have to send the work out, spec +000, -.002 for the tolerance of the cut, making sure the machinist understands that while the cut may be slightly less than specified you don't want it any deeper at all.

After flycutting your heads, repeat the CC-ing procedure and go back through the compression ratio calculations using the new, smaller chamber volume.

- - - - - - - - - - - - - - - - -

NOTE ON 'STOCK' COMPRESSION RATIO:

Volkswagen engines, vehicle and industrial, used compression ratios ranging from about 5:1 for those running on kerosene to over 10:1 for those fueled with alcohol or natural gas. The term 'stock compression ratio' is meaningless unless you specify the engine, its fuel and its application. Volkswagen of America, which is nothing more than a sales agency, only imported about a dozen of the more than 130 different types of vehicles manufactured by Volkswagen of Germany. To most American VW 'experts' stock compression means something between 6.6 and 8.5 to one. But when buying after-market pistons & cylinders, all of which are manufactured in other countries, you're liable to end up with pistons having dished crowns or different compression heights than what you expect.

In a similar vein, I've seen after-market and overhauled heads having chamber volumes from about 42cc to over 65cc.

The point here is that the typical American VW 'expert' is probably only qualified on one or two types of VW vehicles and engines - and may not even be aware of the many variations. When it comes to veedubs, YOU are your best mechanic. Take nothing for granted. When buying parts the wiser course is to inspect and measure before plunking down your money.

SHAVING THE PISTONS

At this point in the pre-assembly your deck heights should be less than .060 and all four cylinders within a few thousandths of each other. What you want is a deck height of .060 and a deviation across all four of no more than .001. To achieve that goal we will trim our pistons. On a low compression engine such as we are building here you may safely trim as much as .060 from the crown of the pistons.

To make the final adjustment to your deck height, identify the cylinder having the greatest deck height. This piston becomes your standard. Next, determine how much metal must be shaved from the other three pistons to make their deck height equal to that of your standard. Finally, having determined how much each of the three 'fat' pistons must be trimmed, write that amount on the crown of the piston and send them out to be machined. Hold the best possible tolerance here. (Working with a rather shaky old 12" lathe I have no trouble holding +/-.0005.)

As the Mechanic-in-Charge cost becomes a consideration when you must send work out. If your deck heights were equal to within .005 and somewhere between .050 and .070, I would probably be happy with that.

You must constantly keep the Harmony Factor in mind. Within the acceptable range of dimension and tolerance, achieving uniformity across all four cylinders is far more important than achieving a precise dimension. Back in the good old days, whenever that was, mechanics believed minor imbalances and dimensional differences were not important, that such things tended to balance each other out. That happens to be true but modern methods have shown that 'balancing-out' can absorb up to ten percent of the engine's output and reduce its useful life by as much as fifty percent. Simply by paying attention to these 'unimportant' details can give you two engine's worth of service for the price of one.

BALANCING

We put off balancing until the pistons are trimmed to their final height. If you have to send your work out, it's best to use a machine shop that has a balancing facility since many offer a package price for shaving the pistons and balancing them. Your connecting rods and crankshaft must also be balanced and here again, the price is usually less if you have all of the work done at the same time. Be sure the shop understands the parts are for a Volkswagen engine. The balancing procedure for vee-type engines is different from that for horizontally opposed engines. Some balance shops charge a premium for balancing to what they call 'Racing' specs, which is bullshit. But if they are the only facility available you'll have to pay what they ask. Make it clear that you'd like to see zero difference across the set of rods & pistons. And it wouldn't hurt to track down a gram-scale and check their work. Machine shops are only as good as they have to be, especially if they are the only shop in town. If they know you can tell the difference between quality workmanship and the other kind, you'll generally get the best they can do. But in many cases the best automotive quality workmanship simply isn't up to aviation engine standards.

Pistons and rods are mass-balanced, ideally to .1gm or better. Your rods should also be balanced so as to have the same center of mass, meaning they would all balance within .001 of the same point. This is commonly called 'Big-end, little-end' balancing and if your shop tells you it isn't necessary, take your work to a better shop, even if you have to ship the stuff.

When you buy rods or pistons the seller will often say they are balanced. In some cases they are but rarely to modern standards. Volkswagen balance specs are crude by modern standards.

You can check the gross balance of your pistons and rods on a laboratory scale capable of measuring to .1gm (with a total of about 600gm). It pays to check. I've seen a variation of 10gms across a set of four 'balanced' pistons and 30grams across four 'balanced' rods. That's THREE HUNDRED times worse than modern specs for the rods alone.

Balancing a crankshaft is the final step in its manufacture but here again the real question has to do with the spec and that balance speaks only to the crankshaft itself. As soon as you add a prop hub, magneto drive, ring gear or what-have-you the crankshaft is no longer in balance. To insure your crankshaft is properly balanced the work must be done with its prop hub, magneto drive, etc., attached.

I don't know of any convenient method to check the dynamic balance of a crankshaft. The only way to insure your crankshaft is properly balanced is to have the work done by a competent shop.

When the balance shop sees that prop hub, the cat will be out of the bag - they will know the crank is going into a flying machine. At that point, many shops will show you the door, afraid of being sued should you kill yourself in your dream machine. Their fear is justified. Since the mid-1970's many American attorneys have devoted their entire career to filing frivolous law suits. Once you have been served with the papers they then offer to 'negotiate,' meaning they will remove your name from the law suit if you pay them a suitable bribe.

If your balance shop will not work on your crank, remove the prop hub and have it balanced separately. Or refer to the prop hub as a 'drive flange.' Or find a shop that works on real aircraft engines. Do whatever you have to do to get the thing balanced. A properly balanced engine is not only more efficient, it is more powerful and much more durable..

VW Engines - Part XI - Cam Stuff

VW Engine - Part XI - Cam Stuff

CAM - YOU NEED ONE

Got yer cam? Stock Volkswagen cam works pretty good... in stock Volkswagens :-) Actually, the stock cam doesn't do all that badly in an airplane engine but the torque peak occurs at about 2000 rpm, too low to produce much power (ie, about 27hp). Like most small automotive engines the VW cam causes the torque to come in early so the engine will have enough oomph to let the vehicle get underway smoothly from a standing stop. And because cars need variable speed engines, Volkswagen made the power band as wide as possible, peaking rpm up around 4000. Trading torque for rpm works fine if you've got a box of gears to play with but it doesn't work for spit when you're spinning a prop.

When you want to swing a prop mounted directly on the crankshaft the best cam is one that produces maximum torque across a narrow power band that peaks at a fairly low rpm. This allows you to take advantage of the aerodynamic realities of converting torque into thrust via a propeller. Such cams are available for the Volkswagen engine and I'll describe a couple of them later in this series. But our first task is to make sure whatever cam we use fits our engine.

VW CAMS COME IN TWO FLAVORS (and so do cases & oil pumps)

You've got your flat faced, three-rivet cams and you've got dish-faced four-rivet jobbies. Either one will work - the cam is the same for all 1300, 1500 and 1600cc VW engines. But the oil pump, which is driven by a tang that mates with a slot in the flange on the gear-end of the cam, must match the cam. And oil pumps themselves come in two flavors, the early types with the small inlet port and later models with the large port.

I've already touched on this subject earlier in this series of articles but the emphasis was on a stock engine, pointing out the need to use an oil pump that matches your crankcase and a cam that matches your oil pump. The need to match these three components leads to some confusion when we get to non-stock after-market cams because all such cams are based on the early flat-faced design which on the surface, says they can't be used with a later-model crankcase because the pump that matches the early style flat-faced cam does not match the later-style big-hole crankcase.

Which is true... sorta... if you're speaking of stock components. But when you elect to use a non-stock part such as an after-market cam in an early-style crankcase, you simply shop around for an after-market oil pump that has the big hole... but will mate with the early-style cam.

I prefer to use the stock Bilstein oil pump whenever possible because its quality is generally better than that of after-market pumps. But after-market pumps do work and can usually be made to work better if given a bit of attention.

If you're using a stock cam then a lot of this particular article will NOT apply. This article is mainly addressed to those who elect to use an after-market cam.

STOCK CAM vs ...SOMETHING OTHER THAN STOCK

I have two partially assembled engines out in the shop built specifically for the purpose of providing you (and me) with information about a couple of different cams and TBC's. I don't have a dyno but I do have a couple of different props (and the ability to carve more) which allows me to guesstimate the engine's performance based on static rpm. Unfortunately, for the reason stated below, I've no data to offer here.

When I began posting this Powerplant Epistle I thought I would have at least one engine running on the test stand by now (January 2001). My plan was to include some comparative test data between the stock VW cam and two after-market cams (the Schneider 248-F for solid lifters and the Schneider 254-H for juicers) plus some data for a set of heads using thermal barrier coatings versus an un-coated set. But it simply didn't happen and I'd like to tell you why.

By any standard my income is quite small. Even so, I'm quite happy with my situation, probably more so than most. My income was adequate for my needs and with careful management, provided a small surplus for personal projects such as the engine and airplane I'm building. But the recent energy scam has wiped out that surplus.

They can talk conservation until they're blue in the face - there is a finite limit to how much you can conserve. We are now heating with wood and have cut our electrical usage by 80% compared to the same billing period last year. But our hot water heater uses gas, as does our stove in the kitchen. And the refrigerator runs on electricity. Even without using any gas for space heating and using only a couple of fluorescent fixtures for light, our utility bill for December was HIGHER than the year before. For us, any further reduction in energy usage will not be conservation but deprivation.

Under the new regime of legalized theft I've no idea what next month's utility bill will be. I'm afraid to do any welding or even run the lights in the shop, to say nothing of the tools. Time that would have been devoted to steel or aluminum is now spent hewing and hauling wood. Time that could have been spent writing is now devoted to washing dishes by hand so we don't have to run the dishwasher, or hanging out clothes to dry rather than use the dryer. (My wife still has a regular job. Since I'm ‘retired' it seems only fair that I take on such chores. Add the woodcutting, ash hauling and so forth and there's little time left for engines.)

The bottom line is that outside events have caused this series of articles to be delayed and less complete than I'd hoped. I will try to include the cam and TBC data in an addendum. In the meantime, let's move on with the assembly of the ‘paper' engine.

AFTER-MARKET CAMS

Volkswagen used two styles of cam, the so-called ‘flat faced' cam thru the 1970 model year and the ‘dished face' cam thereafter. After-market cams are usually of the flat faced variety. After-market cams typically come tapped for three caps screws. The cap screws and washers are normally provided with the cam but sets of cap screws and washers are available separately. The trouble is, there is no standard for the threaded fasteners. Some will come threaded for 1/4-28 others for 8mm.

(Note: A cap screw is a bolt that does NOT go into a nut. When you say ‘bolt' you imply the presence of a matching nut, washer and so forth. Say ‘cap screw' and the mechanic knows it goes into a threaded hole. Non-mechanics place no distinction in such nicety of detail but a bolt is normally only threaded on the lower portion of the shank and is sized according to ‘grip length' - the un-threaded portion of the shank. A cap screw is designed to bear its load in compression whereas a bolt is meant to take a load in shear, hence the importance of the un-threaded shank.)

RE-GROUND CAMS

As a general rule, don't use them.

The problem isn't the regrinding it's the regrinder – the people doing the work. A properly ground cam is accurately made with polished journals and a fine dense finish on the nitrided lobes. Most products on the Volkswagen after-market are aimed squarely at the Kiddie Market, technologically naive consumers who tend to be immature (no matter what their age) and shop only by price. The quality of cams reground for the kiddie trade is embarrassingly bad.

Good shops don't regrind old cams, they start with a new blank. And the lobes are always hardened so as to be compatible with stock VW lifters.

LIFTERS

Always use new lifters. The problem with reground lifters is even worse than for reground cams.

New lifters, VW p/n 113.109.309c, manufactured by Mahle, are available from a variety of sources for less than twenty-five dollars for a set of eight.

CAM GEAR

Don't use STEEL after-market gears. Such gears are the cat's pajamas on the drag strip where it may take 50hp (!!) to actuate the valve train but they serve no purpose in a flying Volkswagen. Not only are they heavier than the stock aluminum gear, they are typically 60-tooth spur cut gears having excessive lash. They do fine if the engine is constantly accelerating but at a steady speed they are noisy and wear quite rapidly. And besides, they cost four times as much as the stock gearing.

(The stock VW aluminum cam gear with its fifty helical-cut teeth is designed to run at near-zero lash. It is light in weight, reliable and comes in eleven (!) sizes, allowing you to set the lash with excellent precision.)

GEARING THE CAM

So you buy an after-market cam. Now you need to find it a gear. After-market cam gears of stock pitch are available as a bubble-packed item for about twenty bucks. It may come drilled to accept an 8mm capscrew (ie, hole dia of about .315") and counter-bored to 19mm which is tad shy of .75". Or it may not. Some are drilled to accept a quarter-inch capscrew and counterbored to .750"

This is one of those little Gotchas! that isn't a problem... until it happens to you. So don't let it happen. If you use an after-market cam, make sure you have the matching capscrews. Now all you have to do is find a suitable cam gear and as I mentioned above, they are a commonly available bubble-packed item.

Unfortunately, after-market cam gears only come in one size and their finish is generally very poor. Yeah I know - they're pretty as hell to the untrained eye. But if you want to see what a properly made gear should look like all you have to do is compare the bubble-packed crap to the real thing. A German-made replacement cam gear is so accurately machined that the teeth shine like mirrors, without the slightest trace of tool marks.

The other problem with bubble-wrapped hanging-on-the-wall after-market cam gears is that they only come in one size (!). Volkswagen provided at least NINE sizes of cam gear (some sources list ELEVEN). German-made after-market cam gears come in three sizes, plus (ie, .01mm oversize), zero (ie, stock spec) and minus (ie, .01mm undersize).

Yeah, the bubble-wrapped after-market crappy gear will work. But it isn't as well made as the Good Stuff and with just one size (generally about a -3), your odds of getting a perfect mesh are slim. The bottom line is you're paying a lot of money for a poorly made gear that will be too loose in about 95% of all engines and too tight in about 2% of them. (Why not 77% and 11%? Because the nine sizes are not uniformly distributed. About 66.6% of all VW engines will use a +1, 0, or a -1 cam gear. The remaining six sizes fall on the ends of the Standard Distribution Curve.)

The obvious choice is to use a German-made gear. Alas, German replacement cam gears are not only rare as lips on a chicken, they come drilled for the stock 6mm RIVET. If you can find one (OVW still has some) and if you intend to use it on an after-market cam having threaded fasteners, you'll need to open up the 6mm holes to match your fasteners and counterbore the thing so the heads of the capscrews won't interfere with your oil pump.

Or you can do what I do. Use old cam gears, salvaged from used cams.

Wear enjoys an inverse square relationship with rpm. Running at one-half the speed of the crankshaft, the cam gear wears at a very slow rate. Picking through the bin of used cams at a junk yard you'll see that while the cam may be worn all to hell about a quarter of the GEARS are still usable. Now all you gotta do is get the thing otta there. (Or mebbe not. See 'USED CAMS AS GAUGES' below.)

RIVETS vs BOLTS

The stock cam gear is riveted to the camshaft using three 6mm mild STEEL rivets. Because the cam gear is aluminum the rivets should NOT be removed in the usual way (ie, drilling off the head) but should be center-drilled for about a quarter of an inch using a 3/16" drill bit. The head may then be removed by counterboring with an A-size drill (or 15/64" in a pinch) and then reversing the drill bit in the drilled hole and using it as a lever to 'wobble' the rivet head until it breaks free. The rivet may then be driven out in the usual way. I've never had any luck grinding off the head on the cam side of the gear and punching the things out. The rivet appears to upset within the bore of the aluminum gear making them very difficult to drive out unless they are first cored.

\DRILLING & COUNTERBORING

Once you have a usable gear in hand it may need to be drilled and counterbored to accept the threaded fasteners used by the after-market cam. This is a relatively straight forward operation made troublesome only by the difficulty of finding metric-sized counterbores and pilots from American sources. One option is to stick with inch-sizes, opening up the hole to 5/16" and using a 3/4" spot facer and a 5/16" pilot. Or you can use the closest inch-sized drill to open up the 6mm rivet hole, and turn a matching pilot on the lathe. Making such a pilot is a ten minute job, assuming you have the stock on hand. The pilot for a 3/4" aircraft-type spot-facer uses a 3/16" shank so there's nothing fragile about the turning. Just be sure to make the shank long enough to be engaged by the spot facer's grub screw. Aircraft-type spot facers cost $15 to $25; their pilots are about $3.

BOLTING THE GEAR TO THE CAM

Got the cam gear there in front of you? Okay, make sure it is face up (ie, the flat side with the three recessed bolt holes). Now find the alignment dot. It will be directly above one of the three holes.

Got the cam there in front of you? Look at its mounting flange. See how the slot in the middle of the flange aligns with one of the threaded holes? Install the cam so its flange fits into the recess on the REAR of the gear with the hole that aligns with the slot matched up with the hole directly under the alignment dot.

Nothing to it.

As a double check, with the gear installed on the cam and the cam gear staring at your belly, with the alignment dot at high noon, look at the last lobe out on the opposite end of the cam. That's the exhaust lobe for cylinders #1 & #3. When the alignment dot is at high noon the #1 exhaust lobe should be at about 6 o'clock.

IS IT TRUE?

Probably not. There's always a little slop in a bolted fitting, plus the fit between the cam's flange and the recess in the gear has to have some play to allow the one to fit into the other.

The real question isn't if it's true but by how much it is NOT. You should find that. You can do so by setting up the cam in vee blocks and checking the runout, both axial and radial, against an angle plate or with a dial indicator. Rotate the cam through several revolutions. With the fasteners snug but not torqued, find the high spot and give it a GENTLE tap with a plastic mallet. You should be able to reduce the radial runout to less than a thou. (No vee blocks? Then try using the crankcase as a support fixture.)

Axial runout will appear as 'wobble' on the face of the face of the cam gear. It should be no more than a couple of tenths with a properly made gear. It it's more than a thou, take the thing apart, clean the mating surfaces and try again – odds are the wobble is due to a trapped bit of debris between the cam's flange and the recess in the gear.

But if that doesn't fix it, find out why. If it's a used cam gear it could be bent. Or the mounting flange of the cam may not be perpendicular to axis of the cam (VERY rare). Or the surface of the recess on the rear face of the cam gear is not perpendicular to the axis of the gear (VERY rare with German gears, happens occasionally with bubble-packed crap.)

USED CAMS AS GAUGES

Normal manufacturing tolerances cause the distance between the axis of the crankshaft and the axis of the camshaft to vary slightly. If you used only one size of cam gearing that slight difference would cause the mesh of the gearing to vary. If you don't care about efficiency or durability you could make all of your cam gears undersize by enough to accommodate the widest possible variation in crankcase tolerance. That's what Henry did with the Model T.

Volkswagen manufactured the cam's gear in nine different sizes in order to provide the best possible mesh, according to the different distance between the cam and crank. The manuals list the sizes as +4, +3, +2, +1, 0, -1, -2, -3, and -4. Some authorities refer to +5-size gears but I've never seen one nor do I recall more than five part numbers for replacement cams, although that was half a century ago.

The different sizes reflect a change of .01mm change in radius of the diametrical pitch of the gear, which is point about half way up the flank of an involute gear. To achieve perfect mesh of an involute gear you try for zero lash at the moment of contact. The closer you get to perfect, the less power is lost in the gear train, the longer it will last and the quieter it will run.

Volkswagen obviously had access to gauges and fixtures we don't have. So how can we determine the best fit?

The old fashioned method is to paint the gear teeth with spotting compound, rotate them together for a full revolution of the driven gear and inspect the resulting mark. If you had a lot of experience setting up gear trains you could tell at a glance if the mesh was too deep or too shallow. You then take everything apart, try a smaller (or larger) gear and do it all over again. Which is okay by me, since I've been doing it since Jonah was a Seaman Deuce. Of course, it took me a couple of years to learn how to do it right.

A method that works almost as well is to acquire some extra VW cams. Get yourself a zero - that always works as a starting point - but also try to track down a +2 and a -2. Here's why.

In the procedure outlined in the next installment of this series I tell you how to determine the lash of your cam gear. But when you have three gears of known size to use as gauges you can do the whole job by inspection alone - no dial indicators or special tools. What you do is install the zero-gear and determine if it is too tight or too lose. Based on that evaluation you install one of the other gears and do it over again. After just two tests you will know which SEVEN of the nine gears will give the best fit. It isn't perfect but so long as you don't jam a gear it's one hell of a lot better than the 'One size fits all' bullshit you're stuck with when using one of those bubble-packed gears.

VW Engines - Part XII - Fitting the Cam Gear

by Robert S Hoover

WV Engines - Part XII - Cam Gear Lash

The tasks of determining your cam gear mesh and clearance, covered in this article, and verification of valve timing which is covered in Part XIII, may be done any time after verification of the fit of the main bearings to the crankshaft and crankcase. I normally do these things early in the engine assembly process as part of the basic blueprinting. The procedure takes only a few minutes but describing the procedure without benefit of illustrations has taken up more than twenty pages. Had I including this information earlier I suspect a lot of folks would have thrown in the towel, convinced the proper assembly of an engine was beyond their means. But if you've stuck with me this far I hope you will have seen that proper assembly is nothing more than attention to detail. When broken down into digestible bites tasks that seem impossibly complex when viewed as a whole are in fact quite easy to do.

INSTALL GEARS ON CRANKSHAFT

There are actually two cam gears, the driver-gear mounted on the crankshaft and the driven-gear riveted or bolted to the camshaft. Before we can determine if we have the proper gear lash or clearance the gears must be mounted on their respective shafts. In the preceding article I described attaching the cam's gear to the camshaft. Now it's time to install the cam's driver-gear onto the crankshaft.

The driver-gear is a shrink fit onto the crankshaft. Putting the gear onto the crank is easy, getting it off is hard. You'll need to be able to do both if you want to build a proper engine. It takes an hydraulic press or a well made puller to remove the driver-gear. A standard knife-edge gear-press plate (a common hydraulic press tool) will work but it isn't a very good fit and will occasionally round a tooth. I've provided drawings for a screw type puller as well as a turned press plate that matches the size of the gear. (You'll need access to a lathe to fabricate these tools. A 7x10 mini-lathe is large enough to do the job.)

The driver gears, so called because they drive other gears, are installed on the crankshaft, aligned by a Woodruff key. Clean the keyway in the crankshaft paying particular attention to the corners. Don't use a scriber or other steel tool to clean the corners. A scratch here can turn into a crack. Use a Q-tip or sharpened wooden scraper. Do the same to the keyway in the gear. Clean the Woodruff key and test its fit, which should be tight, first in the driver-gear then in the crankshaft. The Woodruff key is made of mild steel and is quite soft. It is supposed to be a tight fit in its keyway and may not seat to full depth with hand pressure alone. Use a brass or copper drift to seat the key, being careful to keep its top surface of the key parallel with the axis of the crankshaft otherwise, it will cause the gear to bind when you slid it on.

To install the driver-gear it must be heated to about 350 degrees. Make sure the gear is perfectly clean then place it on a clean piece of aluminum (foil will do) atop a metal plate and slide it into an oven. Set the oven to 350 and allow the gear to heat-soak for about an hour. The bronze scroll gear for the distributor must also be heated. (Follow the procedure above.) The distributor's driver-gear also serves as a spacer. It must be installed on the crankshaft even if you are not using a distributor.

The #3 main bearing is trapped on the crankshaft by the cam's driver-gear. Make sure the bearing is in place and properly oriented, ie, dowel pin hole toward the clutch-end of the crankshaft. After positioning the #3 main bearing, wipe the nose of the crankshaft with MEK or similar – you want the heat-shrunk gears to go on dry.

There is also a spacer and a snap ring associated with the crankshaft gearing. Have these parts immediately at hand, clean and ready to install, along with the proper tools.

With the bearing on the crankshaft and the Woodruff key installed, bring the heated gears to the workbench. I heat these parts on a heavy metal plate and cover them with a little tent of aluminum foil when carrying them from the oven to the workbench. The heavy metal plate insures they stay hot and of a uniform temperature.

One side of the cam driver-gear is beveled, the other side has two alignment dots. The bevel goes toward the clutch-end of the crankshaft, the dots toward the pulley.

Using insulated welder's gloves, slide the hot gear onto the nose of the crankshaft. (Oven mitts will also work but their lack of fingers doesn't give you much control.) Immediately install the spacer then the bronze distributor gear, which may be oriented either way. Install the snap ring.

Once the gears have cooled they should be perfectly secure to the crank. Twist them with your hand, as if trying to unscrew them. If you detect any motion, remove the gears and start over using gears having a smaller ID.

INSTALL CAM BEARING SHELLS

Go find them. Dress their edges and wipe them with MEK. Wipe their saddles with MEK. Lube the bearing shells using moly-type CV joint grease and install them in the crankcase.

In the stock set of cam bearing shells one half of the #3 shell serves as a thrust bearing. I buy two sets of bearings so as to provide a full circle thrust flange. Cam bearing sets having two thrust shells are available. For a low speed engine this is a minor point; the engine works well enough with a single sided thrust flange.

CHECK CAMSHAFT END PLAY

The left-hand crankcase half is in the fixture, cam bearings installed. Lubricate the cam's journals and lay it into the bearing shells. Use feeler gauges or a dial indicator to measure the end play. A one-thou feeler gauge should go, a four thou should not. Spec is .0016" to .005". I shoot for about two thou.

If it's too tight, I dress the thrust surface of the bearing shell(s) by rubbing them on a sheet of #600 wet & dry, flooded with kerosene, atop your surface plate or other flat surface. Use the pseudo-random motion method described elsewhere in this series of articles. Be cautious! Carbide paper cuts fast.

If the fit is too loose I try a different sets of thrust shells. If it's way the hell too loose... but the cam is otherwise within spec I'd probably knurl the thrust face then dress it flat. Knurling is the term used for creating a linear pattern in metal by displacement. To knurl the thrust face of the cam bearing you take a round nosed scriber - the nose about as sharp as a pencil - and simply scribe a regular series of radial lines across the thrust face. Then you mike it. Still too thin? Then go over your lines again, using a little more pressure. Keep doing that until your mike sez the thing is about half a thou too thick... then flat it back to the size you need.

In knurling you don't remove any metal you simply plow furrows into it, displacing the metal to either side. The displaced metal effectively increases the thickness of the part since you are now measuring from the height of the furrow, which you then flat back to a uniform surface.

Knurling isn't a cure-all. You would never use it on a main bearing, for example. But the camshaft runs at such a slow speed and the thrust loads are so low that it is valid to use the procedure here.

CHECK OIL PUMP INTERFERENCE

The cam with its gear attached is laying in the left half of the crankcase. Find the oil pump, install the gears and slide it into position, inserting the drive-tang into the slot in the face of the camshaft. Rotate the camshaft through a full revolution, checking for interference with the pump.

The back of the oil pump is pretty well concealed from view here, inset within the cam gear. If there is any interference it is going to be between the cam gear fasteners and the boss supporting the LOWER shaft in the pump.

If the cam gear is riveted, there is usually no interference unless you have a strangely made after-market oil pump. But when the cam gear is attached with bolts, interference is common even with a stock pump. You must resolve the interference.

There are two common methods of dealing with interference between the oil pump and the cam gear fasteners. One is to reduce the thickness of the fasteners, the other is to grind away part of the pump. In special cases you'll probably use a combination of the two, grinding down the head of the bolts as much as possible plus filing away the interfering corner of the boss on the pump.

The interference problem is one reason I prefer to use rivets instead of bolts but bolts are the standard with most American made after-market cams. When I have an interfering bolt I may deepen the counter bore, so long as I still have at least .120" of metal after doing so. Otherwise, I chuck the bolts into the lathe and face off their heads to about half their original thickness. This always solves the interference problem but doesn't leave much metal on the head for drilling, assuming you want to safety wire the bolts. (You could also reduce the bolt head thickness by grinding, milling or filing.)

If you're using a bolted cam gear and you can't safety wire the thing, get it perfectly clean of all oil, degrease the bolts, washers & cam gear, then assemble using high strength Loctite, torquing the bolts in steps to about 10 ft-lb. Be damn sure you don't over torque these bolts – remember, the normal operating temperature for the cam gear is on the order of 180 degrees Fahrenheit. If you torque the bolts too tight, expansion of the aluminum cam gear at running temps can be enough to pop the head off the bolt.

Over on the oil pump, interference is sometimes due to projection of the lower gear SHAFT, the one that is supposed to be fixed in place. If the lower shaft is loose enough to have moved out of position don't try to press it back into place, look for another pump. If for some reason you have to use the pump, remove the shaft, knurl the bore, freeze the shaft, heat the pump body and press them together hot. Hopefully, you'll achieve a shrink fit. In the worse case, grind away the offending projection of the steel shaft.

If the interference is only with the corner of the aluminum boss around the pump's lower shaft, you may be able to file away as much as a quarter-inch

(6mm) of the CORNER (not all around, just on the lower part where the interference occurs. And if it sounds like I'm guessing here, I am. There are a lot of different oil pumps out there. Some of them won't cause any interference while others may require extensive filing & grinding to keep from fouling the cam gear fasteners. I've found the stock Bilstein oil pumps offer the best fit and finish. You can make after-market stuff work. Indeed, for some combinations of crankcase and cam your only option will be to use an after-market pump. But it takes a bit of work (see the section of oil pumps in Bill Fisher's 'How to Hotrod Volkswagen Engines'). You begin higher up the curve when you start with a Bilstein pump.

Once you've checked the cam against the oil pump and resolved any problems, bag the pump and put it away until needed then remove the cam from the crankcase.

NOTE ABOUT THE OIL PUMP

You are working with the left-hand case half here so there is no opportunity to check the alignment of the pump's inlet to the hole in the crankcase. This is a basic check when blueprinting the pump/crankcase fit and I'll assume it has already been done.

The problem is that the inlet port of many after-market pumps does not properly align with the oil inlet port in the crankcase. The misalignment can be subtle – just a tiny bit off for some pumps – but that's all it takes for the pump to suck air. And air is a very poor lubricant.

I've mentioned this problem here for those of you who are doing these procedures out of sequence. If your oil pump interferes with the cam gear fasteners, before doing any work to make it fit, make sure the pump is USABLE. If the inlet port does not form a perfect seal with the crankcase oil port you'll need to find a new pump and start over since there's no fix for this particular problem. (Actually, there is a fix. Just as there is a fix for ANY problem, from hang nails to dishonest politicians. But repairing a mismatched pump involves building up the pump body with TIG then machining it back to size. Since a new German-built oil pump costs less than $40 millennium dollarettes, the required repair fails the test of practicality.)

PLACE CRANKSHAFT INTO CRANKCASE

At this point I'll assume the cam's driver gear is installed on the crankshaft. Now we need to check the mesh of the two cam gears.

With the left half of the crankcase installed in the fixture, lubricate the #1 main bearing with CV joint grease and slide it onto the crankshaft. Install the crankshaft into the crankcase and insure it seats fully in the bearing saddles. The crankshaft should spin freely with hand pressure alone.

Insure the crankshaft bearings are fully seated in the case. This is critical. Use a rubber mallet to tap the crankshaft at several points. Using a pulley or assembly crank (ie, a lever & handle welded to a pulley hub), rotate the crankshaft several times, tapping it with the mallet as you go.

(Why is it so critical? We are attempting to determine the proper fit of a gear train that is bolted inside the crankcase during normal operation. With the cam and crank simply laying in the case half, the normal as-installed conditions are NOT being met. Using a rubber mallet to insure the crank is fully bedded in it bearing shells is a crude but effective means of EMULATING its as-installed position.)

MATE CAM TO CRANK

Rotate the crankshaft until you can see the two alignment dots on the cam driver gear. Position the cam driven gear so as to mesh with the driver gear, with the marked tooth on the cam gear going between the TWO marked teeth on the driver gear.

The gears will not drop into place, you need to ROLL them into mesh, as you lower the cam into its bearing saddles.

With the gears meshed, take a marking pen and draw two bisecting lines on the face of your cam gear. That is, one line up & down, aligned with the slot in the cam, and one line from side to side, bisecting the first line. The object is to divide the cam gear into four identifiable zones. You may mark them 1 thru 4 if you wish but the geometry of the part - the relationship between the cam and the locating dot on the cam gear - is already distinctive.

CHECKING THE CAM GEAR LASH

The gears are kept dry for this test. Do not use any lubricant at all on the gear's teeth.

Place the palm of your hand on the cam gear and using a LIGHT amount of pressure, try to rock the gear back & forth along its axis of rotation.

If there is SOME gear lash you should feel SOME motion. This is okay. We can work with it. (See Case #3)

If there is NO CLEARANCE the thing will feel solid, as if your hand were trying to move the entire mass of case, crankshaft and fixture. (See Case #2)

If there is a LOT of lash you'll feel a lot of motion and you'll HEAR the thing going 'thunk-thunk' as you rock it back & forth. (See Case #1)

ROTATE THE CRANKSHAFT CLOCKWISE half a turn and repeat the test. DO THE TEST FOUR TIMES, rotating the crankshaft half a turn each time. (The clockwise rotation is critical to this test. I'll tell you why in a minute.) Ideally, whatever the fit of the gears, it will be UNIFORM.

If you are using a stock VW cam & gear there is usually never a problem with the uniformity of the fit between the cam and crank. The purpose of this test is to discover tight or loose spots... which means we've got a problem with our cam gear, usually due to misalignment with the fasteners. Dividing the cam gear into quadrants will give you some idea as to the location of those tight or loose spots and will help you figure out which way the gear needs to be moved to make it run true.

Did that come across?

We've just meshed our cam gears. They may be too tight or too loose or just right... but we aren't interesting in that right now. What we need to know is if the fit, whatever it happens to be, is EVEN.

If you're using an after-market cam or gear, and if you can feel any lack of uniformity in the mesh of the teeth, go back to Part XI where I've described how to attach the cam gear and try to resolve the problem.

What you DON'T want to do is buy into the conventional wisdom that sez it's okay to assemble the engine with the cam gear a bit too tight because it will 'wear itself in.' That's the kind of bullshit you hear from mechanics too lazy or incompetent to do the job right. The reason it's bullshit has to do with thermal expansion. A jammed aluminum gear does in fact wear itself down when running against the steel gear. But when you start out with the gears actually jammed together, the resulting friction produces exceptionally high temperatures – much higher than the gear set will ever see in normal operation. And when metal gets hot, it expands. So it 'wears itself in'... and because the hotter gears are physically LARGER, within a few minutes it quite literally wears itself OUT as well. By the time it finishes 'wearing itself in' it will be grossly undersized - it starts out too tight and ends up too loose.

The cam gear train is one case in the VW engine where the components move farther apart as the engine reaches its normal operating temperature. That is why it's okay to set up the gear train with zero lash. But if we start off with too little lash in our gear train - with the gears jammed together - sure as babies shit green, we'll end up with a sloppy, clacking fit that will result in a radical change to your valve timing and a resulting loss of power. (To put the frosting on the cake, guess what happens to all the metal that gets worn off the gears while they're ‵wearing themselves in'?)

- -

Actually, you CAN run two gears together for the purpose of improving their fit. But you do it slowly in order to keep the gears from heating up, initially making only a light contact. And you use a fragmiable abrasive, softer than the metal being hobbed. For an aluminum gear you might use cerium oxide mixed with diatomatious earth. (You can't use hard abrasives for such work. The pressure at the point of contact causes the abrasive material to become embedded in the metal.)

UNEVEN FIT OF STOCK CAM GEAR

This is an exceptional case and I probably can't do anything to help you resolve the problem.

The first thing I think you should do is to try another cam&gear. Since all stock cams have the same grind, if the second cam fits okay, red-tag the first cam and get on with building your engine. Substituting another cam & gear is the quickest way to discover if the FIRST gear is damaged in some subtle way. It's pretty easy to overlook a bent or scored tooth. Either can give you a tight spot.

But if a second (and subsequent) test with a different cam yields the same results, odds are the cam & gear is not at fault. Here's some other possibilities:

The nose of the crankshaft is bent. You should have caught this during blueprinting but if you focused only on the mains and rods you may have overlooked a bent nose.

The driver gear is improperly cut (try another one) or improperly installed. I've seen cases where the driver gear was installed cold using an hydraulic press. If the Woodruff key becomes displaced you can end up with a bulged gear. Or a bent nose. I've also seen cranks where there were hammer marks on the driver gear & crank. I place such parts gently in the trash, where they belong.

If the case has been align-bored, the axis of the rebore is not always parallel with the axis of the cam. This can also occur if you have the cam bearings align-bored. (Early VW crankcases didn't use bearing shells for the cam.) This situation

MAY show up as a lack of uniformity in the mesh of the cam gear. But not always. If the axis of the bores are parallel but end up too close together the fit will be uniform but so tight you probably won't be able to find a cam gear small enough to provide adequate lash. Same sort of problem when the bores are moved too far apart, although you could probably end up with a running engine in the by using a +5 gear and just letting the thing clack. The worst type of misaligned align-bore is to have the axis of the crankshaft bored at a slight angle to the axis of the cam shaft. This may not show up as either tight or loose but it displays a characteristic contact pattern, runs very noisily and results in asymmetric wear of the cam gear teeth.

In my experience the most common cause of uneven cam gear lash was due to improper installation of the gear on reground cams. Most regrinder shops start by removing the aluminum cam gear. After the cam shaft is reground it is usually hardened by nitriding, during which the cast iron cam shaft is raised to a temperature that would destroy the edges of the gear teeth, which is why the thing is removed. After the cam is hardened the gear is reinstalled using rivets.

Misalignment usually occurs when the regrinder rivets the gear back onto the shaft. A bit of debris gets trapped between the gear and the face of the cam shaft. Once riveted in place, the gear is canted at a slight angle. This built in wobble gives the tight/loose symptom during trial fit. If you run an engine like this you'll get more noise and faster wear on the cam gear. (The wobble is clearly evident during blueprinting. You don't see this on factory assembled cams because during the riveting process the aluminum gear is pressed onto the flange of cast iron shaft with sufficient force to embed any debris into the softer aluminum.)

THE REASON FOR THIS MEETING IS...

At this point we've resolved any problems of uneven or non-uniform mesh between the cam gears. From here on our purpose is to achieve the proper mesh.

We have arrived at this point along one of the following paths:

1. - We felt SOME motion when we rocked the cam gear with our hand.

2. - We felt absolutely no motion at all.

3. - The thing was loose as a goose, clacking back & forth.

CASE #3 - TOO LOOSE

This one's a no-brainer. It's too loose. You need a gear that is a better fit. If you're using stock VW gears, look at the size, go find a larger one.

With a loose gear your Worse-Case scenario is to discover that fact when testing with a +5 size gear, meaning you're already using the largest gear available, at least from stock-gear sources. You may be able to find a larger gear from an after-market supplier but you need a surface plate and some tools to determine that fact. With gears, simply measuring the OD isn't sufficient because the mesh involves the diametrical pitch, a point located about half way down the height of the gear tooth. Two gears of identical diameter can have a different diametrical pitch.

You can also try to find a driver gear having a smaller diametrical pitch but here again, you need the proper precision instruments to determine the gear's exact size, unless you install the thing on the crankshaft and do a trial fit.

In most cases, when the gear train is too loose, it stays that way unless you can afford to replace the crankcase. Excessive clearance in your valve gear train upsets your valve time and costs you power. How much? It depends on how much slop there is in the gear train. A worse problem is that excessive lash leads to accelerated wear and here again, the bigger the gap, the faster the rate of rate. A loose fit of your cam gear also means the engine is going be noisier than it should.

CASE #2 - TOO TIGHT... MAYBE?

When you can't feel any lash at all it does NOT automatically mean the thing is too tight. You could have lucked out and gotten a cam gear that is a perfect fit. Here's how to find out.

Press lightly on the #2 bearing of the camshaft while rotating the crankshaft COUNTER-clockwise. If the gears are jammed the reverse rotation of the crankshaft will lift the cam shaft up, right out of its bearings. Be careful here. There will be some lift even with a loose fit which is why we put finger pressure on the center bearing. But if the thing is truly jammed the effect is unmistakable. It will toss the cam right out of there.

So... is it too tight? You're the Mechanic in Charge. It's your decision. If you need more data, go ahead and try the next smaller size of gear. Now repeat the counter-clockwise test. You should feel some lift. Compare it to the amount of lift you felt with the first gear. This should give you enough information to decide if the first gear was really too tight.

CASE #1 - YOU FELT SOME LASH

How much did you feel?

The sensitivity and precision of our sense of touch varies from person to person. All we know at this point is that the gears were not jammed AND they were not loose enough to make a clacking noise as we rocked them back and forth.

To find out how much lash you're dealing with you'll need to set up your dial indicator. You want to measure the lash directly opposite the point where the cam's gear engages the driver gear, that is, over near the bottom of the crankcase. Rig your clock with a pointed pallet so as to make contact with the middle of one of the gear teeth. You need to take the angle of the helical cut into account when you mount the dial indicator; just cant it at an angle so as to be perpendicular to the plane of the tooth.

When you've got your clock set up, rocking the gear with finger pressure should give you a repeatable indication on the scale. Anything up to four thou (.004) is pure gold. Anything over .006 sez you can do better by trying the next larger size.

THAT'S IT?

Well.... sorta. The manuals tell you the spec for cam gear fit is .000 to .002. What I've tried to do here is tell you HOW to achieve such a fit. But in telling you how, I worry that I've made it sound too complicated. The truth is, I don't spend very much time fitting the cam gear. I've got three cams I use as gauges. Starting with the zero-gear I know if I'm too tight or too loose. If the zero feels tight I reach for the -2 gear. If that feels too loose I KNOW a -1 gear is going to be close enough. But if the -2 gear is tight I know it's going to take a smaller gear and guesstimate which - a -3 or -4 accord to how loose it feels... and go looking for that size gear in the drawer. Once I know what size cam gear is needed I confirm the mesh using spotting compound.