SPIRIT OF JOPLIN AIR CAR
ENGINE CONSTRUCTION

Transcription of 3 hours of audiotape by the inventor, Terry Miller
6 tape sides of ½ hour each
recorded in about 1996
Terry Miller is now deceased

(side 1)

Our group in Joplin, Missouri is dedicated to running clean cars on compressed kinetic energy in the form of clean air, and we've used this kinetic air energy to power a fleet of cars.

If you're looking at drawing #3, I'm gonna go ahead and explain the different nomenclature and how these engines are put together. This engine is very, very simple in construction. People sometimes think it's complicated because they see the parts hanging out. Yes, the parts are hanging out, but the main thing is that there's very few other parts inside. This is very easy to work on.

The most prominent feature that catches your eye right off the bat is the large gear. It's a Martin 140-tooth gear, it's 8 diametral pitch teeth, and a 14-1/2° pitch angle on the teeth, if you'll notice on that big gear, it is not a flywheel because it doesn't turn fast enough to give you any flywheel action. You'll notice right down below the gear if you just figure if the gear was all wet with water and water was dripping off the gear, at the bottom of the gear where the water might drip off the gear, the round circle you see there is an oil-lite bushing. That oil-lite bushing is in a tube and pressed into the tube, and 2 of those bushings go all the way through the motor frame. Now that motor frame is 1/8" welded square steel tubing, 3" is the measurement, it's 3" square tubing. Anyway that oil-lite bushing is in a steel tube which is welded in the motor frame, and that oil-lite bushing is in a position to hold the gear and a 1" shaft which ties to the axle of the car.

Now the other fitting that you see sticking out to the left is one of several extra fittings that we welded onto the motor frame for instrumentation and different uses. And the bead welded at the bottom of the motor frame, on the picture roughly an inch and a half below the circle denoting the bronze bushing, you see a bead running at a 45° angle up and down about 2 inches long, this is a steel plate, 3/16" steel plate, little bigger than 1/8", which is welded to the bottom and it forms the end of the tank. The tank is in the shape of a T, if you'll trace on upwards now you can see on the lower left hand corner of the picture and the upper right hand corner, from one position to the other is another section of this 3" square tubing. Those 2 welded together with plates on each end make up an air tank to hold some of the air that's used in the engine.

Now probably the next most prominent feature after noticing the 140-tooth gear—which is by the way a cast iron gear—is the two cylinders. Now by cylinders we mean the part that at the lower left hand portion of the picture there seems to be a bolt attachment, a pivot point there, and those pivot points allow these cylinder to pivot from this end, so they're a rear pivot cylinder. And each of these cylinders, the one says "Bimba" on it, upside-down in the picture, who is the manufacturer and supplier of the cylinders that we use. Two cylinders, the lower one in the picture is a 3" bore cylinder meaning the piston in the cylinder in the inner bore is 3" in diameter, and the other one that appears to be gray-painted, and it is painted gray, is a 4" bore cylinder, and it's a double wall cylinder, and it's quite a bit larger than the 3" cylinder. Each of these two cylinders has a piston and a rod.

The piston is inside and attached to the piston is the rod, which you see coming out of the right hand side of the cylinders, and in the picture the stainless steel cylinder, the lower one, the 3" bore cylinder, the rod on it is at the center position, as far as being fully, we would say that would be at the top dead center of the stroke, that's what we call it, "top dead center," that rod is almost fully extended, and on the end of the cylinder rod is a standard rod end. If you'll look at the other cylinder, which has a piston inside and a rod, and you'll notice that the rod is larger, because that cylinder in the other uses could be expected to do more work and to have more force that it can put out because it is bigger, and you'll notice that there's a rod end on that shaft too. They're standard rod ends, available over-the-counter anywhere in the world.

Attached to the rod end coming up vertical about a 45° slant, is a piece of ½" steel tubing with a threaded nut welded on it, it's a 5/16" nut, and the combination of those three metallic pieces, the rod end, the short length of ½" welded steel tubing, and the mechanical nut, which has been welded on the end, and then the thread has been polished out a little bit to allow for sliding, we call that piece that's been welded onto the rod end, we call it the striker, and it strikes the set collars that are on each shaft as it moves up and down, we'll explain that later, but because it strikes the collar it comes up with its nomenclature as the striker, and we don't yet have a name for the rod end/striker combination, so we don't talk about the rod end/striker, we talk about the rod end and we talk about the striker.

Any engine that does cranking work, whether it's a steam engine, or this particular air engine, or a car engine, has to have a crank and also a crank pin to tie the end of the rod to so the engine can reciprocate and turn the reciprocating action into rotary action. In this case, if you'll refer back to the large 140-tooth cast iron gear, the rod end there has a code 9, high tensile strength bolt going through it, and the spoke on the gear has been threaded, drilled and tapped to receive the bolt. You'll notice that the opposite spoke on the other end also has a hole, both spokes were drilled and tapped and threaded, so if one ever messed up, the threads were stripped or wore out in any way, you could go ahead and change the crank pin which is your code 9 bolt, you could unscrew the bolt and put it down into the other spoke, and you'd have an extra crank pin and it wouldn't effect the operation of the engine any, you'd still function in a manner which is easily recognized right now.

We mentioned that the rod end was at the top dead center. If you'll look at the rod end on the upper gray-painted 4" larger double-acting cylinder, you'll notice that the rod end there is in a position which is neither bottom dead center, which would be fully withdrawn into the cylinder, or top dead center, as the 3" steel cylinder with the word "Bimba" on it, it is actually in the mid-stroke position where it is able to deliver the most force when there's air pressure in that 4" bore cylinder, that crank is what we call "out." Since we designed these engines and build these engines and they employ our sequential re-use of air to obtain energy efficiency, we can call the parts anything we want to, and where they're at we can say they're at anywhere we want them to be, so with the cylinder fully extended out, the rod all the way out, that's top dead center, that's all the way back, it brings the gear into a position in relation to the cylinder and the pivot pin at the back, which we call bottom dead center, and the position that the crank is on the 4" bore cylinder, we're able to deliver its maximum force, or 90° out, we call that being "out." The crank is "out," the crank is at top dead center, the crank is at bottom dead center. Now for every rotation of the 140-tooth gear, there'll be a position where the crank is at top dead center, there'll be only one position, there'll only be one position where the crank pin will be at bottom dead center, and in these positions, the cylinder is unable to produce any meaningful torque to apply it to the rotation principle of the engine, it would be able to supply force, but no torque, because you're at top dead center and at bottom dead center, and there's only one of each position. However the crank on the 4" bore cylinder, and the crank on the 3" bore cylinder, as it rotates, the crank is in the position we call "out" twice for each rotation of the gear, so when the crank on that 4" bore cylinder is pointing upward and to the left at a 45° angle, when it's down opposite, those two positions would be called for by saying that the crank is "out." So this engine in one rotation carries on through to the cranks being out four times, the crank pins being at top dead center or the cranks being at top dead center twice, and at bottom dead center twice, because we have two double-acting cylinders.

What we want to do now is go ahead and get back to the steel square tubing, it's 3" square tubing 1/8" thick that welds up to make the motor frame of the car. Now, not only does this provide an air tank for the re-use of air from one engine to the other and from one cylinder to the other, and also provides a means for a motor frame, it also, due to the fact that the rear pivot pin bolts, which are also heat-treated strong bolts, those are welded into the motor frame and they provide a very strong support for the rear pivot bronze oil-lite bushings on the cylinders that provide the rear pivot pin for these two to pivot around. Also where the crank for #4 cylinder is, and the crank for the 3" bore cylinder goes through, this provides your crankshaft bearing retaining structure to hold the crankshaft for the engine. And the bronze bushing that we mentioned pictured just below the large gear, that shows clearly that the motor frame also serves as a support for the driveshaft gear. Then at the upper right-hand part of the picture, the plate appears to be welded on not square with the tubing, and that's so that the engine can be positioned into the car. That steel plate bolts to the firewall of the car, the metal area separating the driving compartment from the engine compartment. So this engine is real easy to remove from the car, there's one bolt back by the pivot pin bolts that extends downward to a shock mount, that bolts to the cross-member of the car, and the other mounting point for the engine is ¼" bolts, three of them, which go into the firewall of the car. You disconnect your driveshaft, slide the set collar back, pull the nut off the bolt at the bottom of the engine at the front of the car where it goes into the carry-through, and you unbolt the three bolts that hold the front of the engine to the firewall, and you have to disconnect your air hose coming out of the #4 cylinder where it might be going into your tailpipe, and you disconnect the air hose going into the cylinder, and you can lift this whole engine out of the car in just about a minute very easily and put it back in just as quickly.

The other items that have yet to be mentioned are the washers that you see pictured most clearly on the rod end on the the 3" bore cylinder that is at what position? Top dead center. Those washers are various sizes and also they're bronze bushings, and they're made different sizes on purpose so that the bolt can be tightened up securely and torqued down into the spoke of the gear serving as your crank pin, but also the washers are so designed that the rod end and the bearing surface on the rod end is allowed to rotate in the direction of when the 140-tooth gear turns, but also the washers take up the space between the ball joint as you might say—I've always called rod ends "ball joints" but they're called rod ends, there's a space there between what would normally be the head of the bolt and the outer race of the ball joint or the rod end, now if there weren't any washers there, then the striker which is welded to the rod end, would be allowed to swing over and hit the gear with nothing to stop that rod end from slapping to the left or the right, or in other words, if the striker moves toward you away from the picture or back towards the motor frame, it would rotate far enough to get tangled up in the main gear or hit the motor frame or to misalign the rod that it supposed to actuate again. So we use different size washers and different size oil-lite bushings so the nut can be tightened up tight, and all the strikers, which are welded to the rod ends, when the rod end wants to slap a little bit back and forth, I would imagine that on one of our cars if you took ahold of the nut that's been welded to the ½" square welded steel tubing to make up the striker and if you pulled that left and right in the vehicle, not forward and back because it won't move that way, but if you moved it left and right your total travel would probably be somewhere in the neighborhood of ½" maximum, which is perfectly desirable and works out real good.

OK, now let's proceed on up. We're bypassing for just a little bit the spool valve and the operation of the spool valve, cause we haven't even gotten into the mechanical operation yet let's go ahead and cover the mechanical things that are important, but the gray part that looks like it has all the (?) in the end of the spool valve, all the ports and all, we're gonna bypass that for now and discuss this rod, you'll notice each one of the strikers has a rod going through it, now this rod also affixes to the timing of the spool valve to move the spool within the valve, but let's just say we're gonna push and pull on this rod, but what is gonna cause this to be able to do the pushing and the pulling. So here's the way we're gonna do it. As the 140-tooth gear rotates, and the crank pin goes from top center around to the out position and around to bottom dead center and on back up to the out position, on through the out position and back out and through the top dead center position and back into the out position, it will be obvious that as the rod end moves to the left and the right in the picture, at a 45° angle in the picture, and the rod end will be all the way down close to the double-acting cylinder, or as far away from it as it can get, if that rod does not move, and it has nothing acting on it to make it move, and the slack inside that striker is enough to allow it to strike on the rod, then that is exactly what will happen.

As the 140-tooth crankshaft gear turns, as the cylinder goes to push to pull acted upon by air, the piston's drawing the rod all the way out and all the way back in and the rod end will move back and forth and because the striker is welded to the rod end, it will come back and forth, and it will slide along this rod. Now the rod in this particular engine is ¼" diameter steel cab-plated rod, and the two set collars that look like set collars and that's exactly what they are, in the striker that we're looking at on the 3" bore cylinder, the one that's fixed to the rod end, that has the crank pin bolt going into the 140-tooth gear, that striker right now is probably maybe ¼" from hitting the set collar, and as that 140-tooth gear finishes its rotation clockwise like in this picture, that striker will hit that set collar and when it goes on around in a circular, completing a little bit of circular motion, it will hit the set collar and will pull the rod to the right, or up into the upper right-hand corner of the picture. Now when the crankshaft gear turns 180° and comes on back, the striker, being attached to the rod end, will come all the way back and it will hit the opposite set collar on shaft, and it will cause the shaft to move in the opposite direction, so every rotation of the crankshaft gear, and also every rotation of the crank, and every rotation of the crank pin, and every rotation of the opposite crank, which is only a crank, there's no crankshaft gear there, it has to be the opposite component of the crankshaft gear, we only need one crankshaft gear so on the opposite side all we need is a crank.

But for every rotation you will get two mechanical clicks as the engine rolls around one revolution and the striker hits the set collar and it'll rotate around 180° again and hit the other set collar, and in rotation as this engine rotates, if it rotates slowly and you can pick this up on a recording or something, every rotation will sound something like this (click, click, click, click), and another rotation will sound like (click, click, click, click), because the two cylinders are 90° out from each other, when one cylinder is at top or bottom dead center, and the other crank has to be where? It has to be out or out, one or the other. Now you won't hear timing clicks on these engines where the spacing isn't right, you won't hear anything like that all the clicks you'll hear will be right together. If you count these clicks and divide by four, you'll know how fast the engine is running. If you hear you clicks close together, you'll know the engine is running reasonably fast. Because the rpm at which this engine runs most efficiently appears to be from our experimenting and our working, you'll get the most energy efficiency from this engine at roughly 40 revolutions per minute, which is very, very slow.

All right, we'll get back to the strikers now. The rods are attached to the spool on the spool valve, and we'll basically review this a little bit, in that each spool valve, which covers the venting and the porting of the air, that is attached to each double-acting cylinder, they go in pairs, every double-acting cylinder needs a valve to vent and port the air to make the cylinder push and pull, so every double-acting cylinder will have a spool valve attached to it, they will all be rear pivot-mounted cylinders they'll all be double-acting cylinders, they'll all have a provision up front to attach a plate or some mechanical steel device to hold the spool valve, and the cylinder has a provision to be mounted at the front, and we take advantage of the cylinder's provisions to be mounted at the front, in order to have a place to attach the spool valve. OK, the 4" bore cylinder has four bolts up there that hold the cylinder together, and those four bolt holes also provide provisions for what in the Bimba catalog is called a plate mounting or a stationary bench mount type bracket if you will, it's available, where the cylinder can be bolted securely at the rear and the front, and where you wouldn't be using the pivot portion at the back. The 4" bore cylinder has a pivot bearing that bolts on at the back, and instead of a mounting a mounting plate at the front, we took a mounting plate and trimmed it to a smaller size, and instead of using it to mount the cylinders with, we took a piece of 3/16" X an appropriate length and width to mount the spool valve to, and we welded the steel plate to this mounting bracket, bolted the mounting bracket to the cylinder after drilling the holes to attach to the spool valve with 3/16" bolts. The spool valve that you see on this 4" bore cylinder is bolted on with four bolts and the bolts attach it to the steel plate, the steel plate is welded to the modified mounting bracket in the front, which provides a very secure position for the spool valve.

(side 2)

….timing arrangement for that spool valve. Before we get into the operation of the spool valve, let's get into the operation of the 3" bore cylinder, which has Bimba on the side of it on a decal upside-down, let's look at the cylinder there, if you'll look you'll see the outline of a large hex standard machine nut, and this particular cylinder where you can just stick it through a piece of plate steel, or stick it through an angle iron with a hole in it, and run the jam nut down against it, and when you purchase this cylinder you can actually purchase a front mount bracket with it, and modify the front mount bracket to hold the steel plate to weld to the mounting bracket to bolt the spool valve to by drilling holes in the plate and using bolts to bolt it to. The difference in the two is that this particular mounting bracket is a large threaded portion on the end of the cylinder, and the mounting bracket fits over that large threaded portion and that jam nut tightens it up. You have to be careful in this particular installation, in that when you tighten the jam nut, you need to hold the cylinder securely, and you need to have the spool valve positioned properly on the cylinder, so the air ports are out at approximately 90° so the cylinder can pivot up and down and you can still maintain your hose connections the way you want them, but you have to be careful that you don't tighten it up enough that the aluminum portion on the cylinder is not supported in a way that it might cause it to rotate within the stainless steel tubing. That's about the only way I know you could damage this cylinder tightening the nut is if you don't take the proper procedure in holding it when you tighten the nut.

So other cylinders by other manufacturers might have other types of mounting brackets at the front, we call the front of the cylinder, the portion of the cylinder where the rod comes out of, and we call the back of the cylinder where you either have a rear pivot point built into the cylinder, which is the lower left hand portion of this picture, you'll either have, in the case of the 3" bore cylinder, the rear end of this cylinder is aluminum, you can see the ring where it is swaged approximately an inch in at the front and the back of the cylinder, we call this the back of the cylinder, and we call it the rear pivot point. In the 4" bore cylinder, the rear pivot bracket bolts onto it, they're interchangeable with other, so there's possibly, I know Bimba, all 4" bore cylinder have different mounting provisions and different accessories. But this is a rear pivot bracket which is available from the manufacturer and other manufacturers, we're very partial to Bimba.

Now we get to the point here where we've pretty well covered the nomenclature, we're gonna go through it one more time. Each cylinder has a shaft, technically I believe they're called a rod. We call them shaft or rod sometimes, let's stick with rod. Then on the end of each rod is screwed a standard rod end, some people call them alignaballs because a lot of people buy the Alignaball brand of rod end, we're not partial to any rod end manufacturer because most of your manufacturers make rod ends and they all seem to be very useful. The cylinder walls or the curved tubing that makes up the tubing varies from manufacturer to manufacturer, the 3" bore cylinder in this case is stainless steel, I believe the cylinder inside the 4" bore is aluminum, this is a double wall cylinder that bolts together, they do the job very well.

The piston inside the cylinder has air seals, and these cylinders are called double-acting, because if you put air into the port at the end of the cylinder it will blow on the piston with kinetic energy and force that piston to the back of the cylinder, and since that piston is attached to the rod, it will bring the rod back with it and it will bring the cylinder back to the position in the engine that we call bottom dead center, then if we put air into a port between the back of the cylinder and the piston, we put air in a port and pressurize it there, then that will go ahead and force the piston toward the front of the cylinder, force the rod in the cylinder to extend outward, and rotate and drive the rod clear on out to the top dead center position, and I'll remind you at this time that on the way to the top dead center position it will have the crank out, as in the case in this picture, the 4" bore cylinder, the crank attached to the rod on that 4" bore cylinder is in the out position and the crankpin and crank for the 3" bore cylinder, the stainless steel Bimba cylinder, is in the top dead center position.

So each of the cylinders, the stainless steel cylinder, the 3" bore cylinder at the lower part of the picture, it also has a piston, now let's figure out where the pistons would be. In the stainless steel cylinder at the bottom of the drawing, the rod is all the way out, and we're at top dead center with the rod end and the crankpin bolt in the crankshaft gear, so the piston must be awfully close to the end of the cylinder. You see the two bolts that bolt the spool valve down to the plate, that's attached to the front mount bracket, those bolts are regular AN3 hex head bolts, and right about in there would be where the nut goes on that bolt would be where you would expect to find the piston. Now, if we look at the 4" bore cylinder and the crank is out, you would expect if you had x-ray vision and you could look into that cylinder, you could expect to find that piston halfway between the rear pivot point on the cylinder and the front of the cylinder, the front is what we call the portion where the shaft or cylinder rod comes out of the cylinder. So your piston position within the cylinder and what forces are acting upon the piston depends upon where that particular cylinder's rod end attached to its rod happens to be in the rotation or it happens to be in the clocking of the engine, whether it is out, halfway between out and top dead center, or halfway between out and bottom dead center or measuring from top dead center 10° of rotation, 20° of rotation, 30° degrees of rotation, 40° of rotation, all this will determine where the piston will be in the cylinder. And when we get into the theory of the sequential re-use of air, the position of the piston within the cylinder is very important.

It's also essential in the mechanical makeup of this engine, since it is comprised of two double-acting cylinder, that the cranks not be opposed. In other words, we wouldn't want to have both cranks to be at the center position, one at top dead center and one at bottom dead center at the same time. If we did, let's think about it a minute, if both cranks were out at top dead center at the same time, the engine would still function, if air were put to both the timing valves on the engine. If both the cranks were at bottom dead center at the same time, the engine would still function, but from a mechanical standpoint, and from a sequential re-use of air standpoint, making it work, you would still only have the benefit of one, as far as getting any advantage at that type of operation where both cranks were out, both cranks were at bottom dead center, at top dead center at the same time. You wouldn't get the mechanical advantage that you get with this engine, and you wouldn't be able to get into the sequential re-use of air. So for review, the cranks are 90° from each other. When you find one of the cranks at top or bottom dead center, the opposite crank will always be out.

This engine will run either direction. If the crankshaft gear you're looking at right now is turning clockwise, then the crank will also be turning clockwise as we're viewing it, along with the crankpin on the crankshaft gear. If you stop that engine and by some mechanical means you bleed the air pressure off of it, or if you simply manipulate the timing rod that it goes through the striker manually and manually manipulate the timing, you can reverse the engine. The engine will run forwards or backwards, because the cylinders are that way, the gearing is that way, the car will run forward or backward, and the other gear that goes into the crankshaft gear determines your gear ratio, then if you have a transmission that ties to this crankshaft gear, then you can have several speeds forward and one or two or whatever for reverse.

OK the mounting of the spool valves is unique in that of all the spool valves I know that are available, the Westinghouse Air Brake Valve, or the WABCO valve, which is obtainable from Rexroth International Pneumatics, is one where you can pull the bolts out of the different air segments on the valve, and you can literally clock the different segments of the valve. We're gonna take the time, we're gonna go slowly into this spool valve, and describe what you see in the picture, and then we'll do what we can to explain the function. The valve which we have right now, which shows all the ports at this time, is the spool valve which is located on top of the stainless steel cylinder, the 3" bore cylinder. Those are red plastic cups stuck into the tapped exhaust ports, not necessarily exhaust ports because that changes it, let's clarify the fact. There are five ports in this valve, and the ports all have cups in them when you receive it to keep dust and dirt out of the valve, but when a valve, in the nomenclature of the catalog, when the valve says it has tapped exhaust or tapped ports, they mean you can look for standard pipe thread where you can plumb in your pneumatic fittings and your pneumatic plumbing to get your air in and out of this valve to work the double-acting cylinder either in the push or pull position. If you'll notice the spool valve that's on the 3" bore cylinder on top of the picture, you'll notice that it only shows three ports, and the reason is that the other two ports or on the opposite side of the spool valve.

OK, back to the 3" bore cylinder and the spool valve sitting on top of it. If you'll notice at the rear of the spool valve, which we call the section closest to the rear of the double-acting cylinder, there are what appear to be three hex-head bolts showing, and there also appears to be three to four hex head bolts showing at the front of the spool valve. These are actually nuts, and there's a threaded rod that goes all the way through the spool valve, similar to the rods that go through electric motors, this spool valve bolts together the same way and it can be assembled very easily. You disconnect the four bolts that go through any of these Rexroth Wabco spool valves, and if you just slide the bolts out, even though this one section is bolted to this steel plate, any of these tapped ports can be rotated, there are segments that can be rotated.

So let's figure this out right now, let's go to the back of the spool valve, and we'll find the two bolts that bolt the spool valve down to the plate, that one plastic cup there covers a port, and there's a thin line that you may be able to see in the drawings where these sections bolt together, and there are o-ring seals and cup seals that provide air holding capacity between all these ports. Also the spool that slides back and forth in this valve housing is called a spool because it actually resembles a sewing machine spool. It actually has indentations in it that, as the spool moves left and right, it will allow different ports on this spool valve to be connected pneumatically with each other. OK, if you pull these bolts, any one of these ports that you see on the spool valve, let's take for instance the port at the rear of the spool valve, which is closest to the rear pivot point on the 3" bore cylinder, if you pull the rods on each end, that port can be rotated around to where the port on that cylinder can be lined up with the adjacent one, which is the next one over, then you go on over to the next one that appears to be on top of the spool valve, it is the center of the five. If all the bolts were removed, you could actually rotate it down. Then you can go to the one that's on top of the spool valve, at the front of the spool valve, closest to the crankshaft gear, where the timing rod attaches to it; all five of those ports can be pointing in one direction, or all five of the ports could be pointing up, or they could actually be rotated to point down, and if there wasn't anything above that steel plate, you could cut a hole in the steel plate to plumb your plumbing into that spool valve.

These spool valves are a dream, they're absolutely light to use, because it seems like every engine we put together and everything we do, we decide that we decide that we need to use the plumbing and the hoses in the cylinder a little different, and we'll get into that on another drawing, about the plumbing and the hoses.

Now, at the rear of the spool valve, there's a black, seems like a perfectly square cube, and I believe it's fiberglass-reinforced plastic. That's a detent kit. We use a detent, which is available from Rexroth Pneumatics. The detent kit just simply has an attachment that ties to the spool, which is a long stainless steel rod within the valve housing, with indentations in it which allow for the porting of air from one of these tapped ports to another. But to hold that spool valve in a particular postion, detent kits are available to hold the spool valve, it's subject to vibration, so it won't move on its own if you shake it or jar it. Detent kits are available to hold this spool valve in the center, or just to one end or just to the other end. The detent we use, obviously we use the detent to hold the spool valve where the spool is moved fully forward or fully backward, because in those two positions is where we're controlling the venting and the porting of air, and telling the cylinder whether to push or pull. So these detent kits simply have a spring and a ball, and the ball pushes into a groove on the detent, and the spool valve has this tendency, if you listen with a mike pickup and you move the spool valve back and forth, you can hear the little ball drop down into the detent, click, click, click, click. You can't hear it with the engine running, but if you put a microphone on it and work the rod by hand you can hear it. This detent kit is needed for one reason. Just look at the spool valve and picture a spool in there with detents in it that allows for the porting of air, and then the end of that spool is attached to the timing rod, and the nomenclature and what we call this is the timing rod.

So we have the striker made up of the ½" steel tubing with a nut welded on the end, we have the timing rod which is ¼" cab-plate steel, and then the set collars you can identify real easy, well you can't identify them real easy but they are set collars and there's a set screw adjustment for timing, and once we get the timing set where we want it, which is real easy to do, we'll tack weld it, and this particular method of timing has proven to be very, very reliable. It's a little noisy, and we don't mind that, and actually if you wanted to put a little rubber washer on the timing rod so that the nut on the striker, when it hits the set collar, it will actually be hitting this small rubber washer first, that will probably get your noise down to practically nothing. So as this engine goes around, if it's rotating at say 8, 9, 10 revolutions per minute, you'll hear the striker hit the set collar. Of course at 40 rpm or 50 rpm or 60 rpm, it's faster than you can count it; you could record the clicks and then run your tape player slower to count your rpm, but when you're running faster all we need to do is to count the exhaust, and divide by 2 to get engine rpm, or to have a muffler on one exhaust and no muffler on the other, and then we just count the loudest exhaust noise, and the number of exhausts that you hear in a period of time will give you the rpm.

Now, the spool valves we've explained that the tapped exhaust ports can be clocked in any position, and a real good way to explain that is, at the three ports that you see on the spool valve closest to you on the stainless steel 3" bore cylinder, in the cluster of the three ports, the one in the center on the top of the spool valveis the one that you would supply air pressure to. Then, the two ports that are pointing out sideways from the spool valve, those two ports we would call the pressure ports, and the other two ports which are at the extreme forward and aft portion of the spool valve on top, we call them the exhaust ports, and that's their function. If we take the two threaded ports on the spool valve which are pointing out and not up, on the spool valve, and run a hose from that tapped port down to the inlet port at the front of the cylinder, which you can see it, it shows up black in the picture, then we run a hose from there to there then we run a hose from the other threaded port which is pointing out, to the rear pivot portion of the cylinder where the black hole is that you can see, it's just black, that port is also threaded, so we hook up a hose there and there, we put pressure in the center, so when the spool valve is pulled all the way out, or all the way back, or the spool is moved to the front or the back, the pressure entering that center port will be directed to either one of the other two ports adjacent to it and pointing out. They will never be supplying air to both ports at the same time.

Now, the other two ports on the spool valve are simply used to collect the exhaust from this operation, and we save that exhaust via a manifold which we call manifold 16. It's the pressure equalization transfer, mid-stroke venting, pumped pressure transfer manifold; we'll get into its operation later. But this spool valve, again, if you're ordering one from Rexroth International, is a 4-way spool valve with tapped ports, closed center position, and you can order one with a detent kit, and the plumbing ports on these spool valves are ¼" pipe thread. The 4" bore cylinder is large enough that the hose going into the spool valve mounted on top of it, you can only see three ports because the other two ports are pointing out, and they're on the opposite side of the spool valve from the pressure port that you can see, and those two ports we plumb to the push and the pull of the cylinder—I'm sorry I made a mistake, they're the two ports that you see in the drawing, pointing up; they haven't been clocked yet in this arrangement. We'll pull the bolts out of that spool valve and those two ports will eventually be pointing out so that the hose can go from there, around, make a u-turn and come back into the cylinder, and the exhaust portion will be on that side, and they'll leave and go down and under the car and out the tailpipe, and the pressure port we'll probably rotate up, we'll check it when we see the drawing. So that's the nice thing about these spool valves, you can clock the ports any way you want to. Now the reason the five ports on the spool valve on the 3" bore stainless cylinder at the bottom, the reason you can see all five of those ports is real simple. As this crankshaft gear goes around and the crankpin goes to the out position either at the top or the bottom down there of the picture, if you had any plumbing coming out of the side next to the motor frame, the up and down action of the cylinder would just wipe the plumbing right off, because the motor frame would hit it.

(side 3)

The detent kit which in the drawing is the black square shape portion at the rear of each spool valve is an accessory available from Rexroth Pneumatics to go with their WABCO Westinghouse Air Brake valves. These detent kits are probably one of the best devices in this engine to minimize timing problems. As the striker moves up and down the timing rod, there's a little metal to metal friction there, and we have added a little bit of oil on occasion where the rod was dragging a little bit, and that oil collected dust, and then in cold weather—a lot of times, everybody knows that, like on a racing engine sometimes you can be using 20 weight or 30 weight oil, and if you'll put 10-weight oil in the engine, the engine will wind up faste—what it boils down to is the timing rod has to remain dry, but also you don't want any bumps in the road or anything else telling this spool valve, "I'm gonna make the cylinder push," when the spool valve is telling the cylinder, "Oh no you're gonna pull instead of push," you got problems there. There don't appear to be any gremlins in the timing. It is so simple and so straightforward, and I have yet to be able to figure out a more positive and quicker way of timing unless we were to go to electrical solenoid operated spool valve which we could, but if you had a loose connection, a dirty connection, a broken wire or something, then you'd be out of the timing business. This has proved to be very reliable so far, and you don't oil the push rod because it collects a little dust which causes a drag, and in cold weather too, the dust and the oil combination could cause the spool valve to be pushed into the wrong position. So essentially your push rods remain rods, your detent kits are great, they are available, we have used spool valves without detent kits, but if you're planning on building an engine, the detent kit is not all that expensive, and it will sure make up for a multitude of errors, cause if your timing rod gets a little oil or a little dust on it, the detent kit will hold it in position even on bumpy roads, so it's well worth your time to explore it.

OK, I'm thinking about the things that need to be covered on the particular engine, and we're still on drawing #3, the cylinders can be obtained by contacting Bimba Cylinder Manufacturing Company in Monee, Illinois, they're just out of Chicago up there. The crank that shows in the picture attached to the crankshaft and on the opposite side of the motor frame from the crankshaft gear, is made out of steel, it's approximately ¾ of an inch thick and wide enough to be strong enough, you could put a ruler on these drawings and do a lot of scale up and figuring dimensions on your own. But the thing about the cranks, and the thing about the crankshaft gears is that we have a lot of brute force, when you figure that you have a cylinder capable of putting several hundred pounds of force on a crank, you determine that this crank had better be tied to the crankshaft securely. Now, in our more advanced engineering that we're doing, we have a firm here that's a sponsor, and they helped us early on with our Pneumatic Urban Commuter Club projects, they have machined a crankshaft that goes through the flywheel gear, and the shaft is machined with a head on it, and the head presses in to the crankshaft gear which is machined to accept this head, and also there's a set keyway, and this is all a press fit, so there's just no way in the world that crankshaft can get off of the gear, or the gear separate itself from the crankshaft—from the flywheel gear which serves as a crankshaft.

Now on the 4" bore cylinder—let's get back to the crank that goes onto the crankshaft—that particular crank in this engine was machined to a few thousandths tight fit, and it was pressed onto the crankshaft, and the crankshaft was 1" diameter, but it was pressed through the crank, about ¼" through the crank and then welded around. And we found that you have more holding power if you do not countersink the crank and weld down into the countersunk area, that in some ways only gives you maybe ¾" of the diameter circumference given area of the shaft to hold onto the weld, but if you press the crankshaft through the crank a little bit and weld all the way around then you're extending out on the 1" circumferential area that you get because of the 1" diameter shaft, you get more holding power on the crankshaft. If you want to build an engine with a minimum of machining, you can put one of these engines together and order all the parts and have it all put together in four weeks or less. If you want to use a steel gear for your flywheel gear, you can press the shaft through the steel gear, press fit several thousandths tight fit and weld it, and you can weld your cranks on, and then if you want to disassemble the engine you can take a grinder to your crank to disassemble it, however you can always weld the shaft to the crank and then put the crankshaft gear on, keyway to press fit with a nut to hold it, if you're gonna go to a cast iron gear.

The whole motor frame of this car, and the tubing is welded together. You want to keep the tubing clean inside, wash your tubing with soap and water, and don't have any oil on it at the time when you do the welding, and the fittings that you need for air, the fittings that we use are just simply standard tapered pipe thread couplers cut in two, and the couplers are welded into the motor frames in different places after drilling a hole for air passage, now before you weld the plates on all the ends of all the motor frame, which also serves as the re-use tank, you can clean and blow out any metal particles and oil and debris from the tank, and then weld the plates on the end. Then what we do is fill the whole motor frame, not the whole motor frame, but put about a half a quart of oil in the motor frame and slosh it all around and then pull one of the drain plugs and let the oil drain out, and this coats the inside of the tank with a film of, I suggest you use 10 weight non-detergent oil, that's what we used in our motor frames, cause a little bit of oil in there is pretty good for protecting the inside of the tank. However it's advisable to never weld on this motor frame once you've put oil in it, and don't use any solvents at all that might be explosive, and never weld on this motor frame, and before you put the oil into the motor frame, after it's all welded together and put together, pressurize this motor frame up to the pressure that you would expect the motor frame to have, and we'll get into the pressures, also it would be a good idea if you had a safety valve on each one of the motor frames that relieves it at a considerable pressure below the point at which it would start to turn into a football instead of a square shape.

We've just about covered this motor, you can call it the pneumatic engine, you can call it the air motor, we don't care what you call it, we're just tickled to death that you're interested in reviewing it and looking at the pictures and hearing how it works.

The bolts we used on the rear for the pivot pins are code 9 heat-treated bolts, they go through the motor frames and are welded on each end where they go through the motor frames, and when you're getting ready to install these cylinders in your motor frames, you want to purchase your rod ends and put them on the cylinders, on the rod, and put them on the gears, and put them on the cranks, and actually check your top dead center and bottom dead center position to find out exactly, according to your dimensions of your rod end, where you want your pivot pin to be located. We have had instances where, to get everything to turn out right, we had to take your standard rod end that your striker is welded to, and grind a little material off that rod end, so that when you screw the rod end onto the cylinder rod, that it would change the dimensions a little bit, and sometimes after the pivot location and the code 9 bolt was welded to the motor frame, we might have to grind a little bit off the rod end to get your dimensions right, because you don't want the cylinder to bottom out either top dead center or bottom dead center, that's hard on your seals on your pistons, another thing is when you weld up your tank, and you think, well now, I'm ready to put it to use, do not hesitate to put 10, 20, 30 pounds of pressure on the tank and soap check, mix soap and water or dishwashing liquid in water, and make a bubbly mixture, and put plugs in all your ports that you have welded into your re-use tanks, we have several extra ports that will show up in our photographs, and these ports were in case the threads on one port go bad you could put a plug in there and use another port, and we also put extra ¼" pipe thread ports for instrumentation so we can take hoses off for pressure, but welders often, whoever's doing your welding for you, find someone that's a good MIG welder and caution them that when they go around and weld the plates on the tanks, that they don't just come up to the weld that's already there and stop, have them come up there and build a little heat and overlap the weld, and be sure that they build a lot of heat before they stop.

Same way with welding your air fittings on your tanks. You want to weld those pipe fittings, the pipe couplers that you cut in half and weld on the tank, be sure when they're welded on that your weld overlaps and that there's a lot of heat so you'll have the minimum of leaks. If you can weld this whole motor frame up, and then pressurize it, and not find more than three or four leaks, you'll be pretty lucky. I would say that your first motor frame that you put together, considering the fact that the steel tubing going through the motor frame, to hold your bronze bushings, plus all your fittings and your end caps, you'll be lucky if you can get this put together without having six or eight leaks, but the leaks are easy to fix, and then after you weld over an area that might be leaking, then pressure check it again, because if your motor frame leaks air, then you're gonna have air that you're not gonna be able to use in the engine. Now in the motor frame pictures of construction, we'll have another description of how the motor frame's welded together. Just real briefly, it's obvious that this whole thing is gonna be used as a tank, the 3" square tubing that you use at the bottom of this, and you weld onto the longest piece of motor frame, where that 3" tubing welds onto the side of the other 3" square tubing, you need to take a hole saw and drill at least a 1" hole through there so that the whole motor frame can be used to hold air.

The front plate on this engine that bolts to the firewall, that's pictured at the upper right hand side of this drawing, also has a piece of 1/8" thick rubber glued to it, and we also found that the area underneath the motor frame where the pivot bolts are for your rear pivot on your cylinders, that bolt that goes down through your carry-through on one of your front wheel drive vehicles needs to have a shock-mount on there where you've got rubber insulating the engine from the car frame. This is just to minimize noise. This engine has practically no vibration whatsoever, and the noise you hear is air, the timing unless you have a rubber washer where your striker hits the set collar, and then your gear noise. If you run the exhaust back to the tailpipe of the car, you know, into a tailpipe and out to the back of the car, when you're driving in the car the loudest noise you'll hear will be the gear noise. You'll hear the gear whirling along and we have audio tapes of the car driving where you hear a lot of exhaust noise and not so much gear noise, and we also have tapes of driving the car where we plumb the exhaust clear out the back of the car out through a tail pipe, and you hear very muted exhaust air noise, but you hear your gear noise. It's interesting the sounds of the pneumatic urban commuter, and they're unique.

But I do want to repeat, this engine can be built in four weeks with the information we have. You can vary the sizes and the stroke lengths and the gear ratio on the engine, but when we get into the theory of operation, you'll understand why it's essential to build the engine with your cranks being 90°out from each other, your crankpin locations, the one on your crankshaft gear and your crank. You'll understand why we have such a large crankshaft gear, it's because for every revolution of the crankshaft you want to get several feet down the road. The Spirit of Joplin Chevrolet has this engine in it, and the gear that is hooked up to this gear, and the oil-lite bushings at the bottom of this motor frame, is a 20-tooth gear, which gives you a gear ratio of one crankshaft gives you 7 on your constant velocity CV joint to your wheel, and your wheel is 5' 4" in circumference. Every time the air operating one of these cylinders, and it goes "choo-choo" as you count for every choo, you're going half of 38-1/2 feet down the road. And for every "choo-choo" you're going 38-1/2 feet down the road.

So we're in the process of coming up with multi-speed transmissions and we're really getting into the states now with international publicity on what we're doing, and we're handing out and disseminating information as quickly as possible, my name is Terry Miller, I live in Joplin, Missouri, and I can be contacted if you're in the midst of working on something. The reason we've come up with these descriptions of the engine and how to put them together and how to get the parts is that I'm 60 years old and I'm not as fast as I used to be, and I forget things once in a while, and I'm sitting here right now at home looking at this photograph #3, which was a series of step by step building photographs taken during the construction of these two engines, and it's somewhat of a trouble to stop what you're doing, say in the afternoon when you have the right kind of sunlight to take pictures, get your camera loaded up and get all the tools and extemporaneous material and notes and clutter out of the way and try and find a place to set the engine and select an angle at which you can take some pictures, knowing that a year or two or three years in the future these photographs that you took will be perhaps a valuable aid to other people and to engineers and to other people in other countries to learn how this engine works. While even I look at this picture and I wonder if I've told you everything I can tell you that will be of a benefit to you, if I tell you everything I know of that could be of benefit to you in putting this engine together, I do also hope that I don't neglect to tell you anything that might be a problem. It's really very simple, once you get started on it, and you can put two of these engines together, the smaller engine, and this is the larger engine, in four weeks' time, that's even getting started on it and getting your double-acting cylinders ordered from Bimba, and your WABCO spool valves ordered, and then when you get your cylinders in you'll know, even with your brochures, you can contact these people and get your brochures in within a week, and start on your motor frames and have these things put together in short order, and it's not all that expensive, and when you find the prices and you get into figuring the price for your air and your fuel and everything, you'll understand why we're very much enthused about it.

Let's go over things again, OK, the motor frame holds air, right? It has pipe couplers welded on at different strategic locations so you can put air into the tank and take air out of the tank which is also a motor frame, it's called a motor frame because it holds the tubing which holds the oil-lite bushings or the roller bearings if you will, for your crankshaft and also for your drive shaft, it's called a motor frame because it holds the code 9 heat treated bolts which serve as your rear pivot pin locations for your double-acting cylinders. Your cylinders are double-acting pneumatic cylinders, your spool valves again are 4-way spool valves with tapped exhaust, even though they're not all exhaust, I think they call them tapped exhaust, or tapped ports, with a closed center position, and your center port is your supply port, the parts are easy to name and find in the picture by now, there's your set collars or your collars that are used on the timing rods to adjust your timing and change your timing when your crankpin location and your extension and retraction of your double-acting cylinders is either at top dead center or bottom dead center, your striker is real simple and straightforward, there's your rod end, your crankpins are simply code 9 bolts, and we'll review the fact that the washers on either side of your rod ends are to keep your rod ends from rotating and allowing your striker to get tangled up in your gears or something else.

Your timing rods: this is something I forgot, and we're gonna talk about this right now. Once you get your spool rods from the supplier, and you want to figure out how to tie a ¼" rod to the end of the spool valve, you'll find out that you can go to the auto supply store and buy the cheaper sockets, regular mechanic's sockets like you put on a ratchet to tighten bolts, don't buy the very best heat-treated sockets because you're gonna need to drill a hole in them, but you can buy a socket of the right dimensions regardless of what country you live in, even if you're not using a ¼" rod for your timing rod, you could still find a socket and you could still find set collars and timing rods in whatever country you live in, and you could find a socket that will be a ¼" drive in this case, but it might be a metric drive in your case, which can be slipped on where it snaps onto a ratchet for turning the socket, you can slip the socket over the end of that rod and be sure it's lined up straight and weld it to the rod, and the end of the spool on each end of the spool valve has a hole drilled in each end of the shaft for the spool valve for a clevis pin and a cotter key. A clevis pin looks like a nail, and at the end of the clevis pin opposite where the head is, there's a hole drilled there for a cotter key. So if you slip this onto the end of the spool valve and you drill a hole clear through the socket that's welded to the rod that you're gonna use for a timing rod or push rod, you'll be able to use the clevis pin that came with the spool valve or have Rexroth send you extra clevis pins and cotter keys, you'll be able to slip the cotter key into the hole in the socket which is welded to the timing rod, onto the hole that's already drilled in the end of the spool valve shaft, on out through the other end of the socket, and then put a cotter key on there, and you'll have it all tied together so that your spool valve is bolted on your double-acting cylinder, the end of the spool is tied to the regular socket wrench, your socket wrench is welded to your timing rod, and so when the striker hits either one of the set collars since the two are fixed together, when it hits that set collar it will immediately move the spool valve. The spool valve that you're looking at right now requires only 5/8" travel to change the ports and the venting from push to pull in this case.

If you want to put a safety relief valve like they have on air compressor tanks on your motor frames, you can weld fittings underneath so your safety valve can be underneath and out of sight and not cluttering up the place. These rod ends are available from several different manufacturers, and as I said before, you don't want to just go ahead—the major mistake you could make would be to go ahead and take the dimensions from the brochures and just assume that the dimensions on your rod ends are all alike and assume that every double-acting cylinder from every manufacturer is the same dimensions and just lay this all out and make you a drawing and go ahead and weld your rear pivot bolts without physically checking them first, could prove to be a very costly mistake.

(side 4)

And you want to do this before you determine the actual location that you want to use for your rear pivot pin or rear pivot bolt location. Another critical dimension which will vary according to your engineering and whatever country you're located in, but to give you an example, this engine that is pictured here is an engine that uses double-acting cylinders, and the stroke length of our cylinders is 10" in length meaning that the rod end will travel 10" if you allow the cylinder to go as far as it will go. The cylinder manufacturer gives you a little leeway there, because they don't want you bottoming your pistons out against the end of the cylinder and possibly ruining the seals, but to eliminate this problem is very easy, whatever the length is of your stroke, if you have say an 8" stroke cylinder, then that would mean that normally from the center line of the crankshaft to the centerline of the crankpin bolt would be 4 linear inches from centerline to centerline. A 10" stroke cylinder like this, if you wanted your piston attached to the piston rod to go all the way to the front and all the way to the back of the cylinder, then if your stroke length is 10", then you would want your crank from the centerline of the crankshaft to the centerline of the crankpin bolt to be 5", however in the engine that you see here it has a10" stroke length on each cylinder, but the crank that you see on the 4" bore cylinder at the top of the picture, and actually the distance from the centerline on the crankshaft, from the center of the crankshaft on the crankshaft gear, out to where the bolt screws in to make the crankpin, that distance is 4-7/8", which means that when you reach top dead center, your actuating cylinder, the rod will be all the way extended out of the actuating cylinder except you'll have 1/8" of safety there to be sure that no way mechanically, unless something breaks, can your rubber seals within your double-acting cylinder bottom out.

Now you may have a cylinder where if you actually set it up, it would be a good idea when you take the cylinder out of the box, to actually set it up and push the piston gently all the way to the back and all the way to the front and actually measure the linear distance of your stroke length, because you may find a cylinder manufacturer whose 10" stroke cylinder is actually 10-1/8" or 10-1/4", which gets you back to the same point I mentioned before: the most costly or most delaying mistake I can see in coming up with your dimensions and putting it together would be to just go ahead and put your without actually checking the operation of your double-acting cylinder with a rod end screwed on tight and with the crank bolt screwed into your crankshaft gear or your crank. You want to do this and you want to feel it out and check it, and then very carefully centerpunch the location you want. You can actually stick a bolt through the bronze bushing at the rear of the cylinder, and when you get the cylinder where you want it and you hold it there, and you turn the crankshaft over a time or two and let the cylinder go ahead an suck in a little air through the ports, but go ahead and turn it slowly, and double check and find out that it's not bottoming out on either end, and then scribe line around your bolt or actually put a bolt through there that's machined to centerpunch, and precisely locate that rear pivot pin location so that when the double-acting cylinder operates, there' no way that you can take up more piston than you need to take up. This would be comparable to the thought of putting pistons with a dome inside a car, or pistons in a car engine that aren't designed for that engine, and having the piston hit the top of the cylinder head, or another similarity would be to screw the spark plugs down into the engine that were extra hot spark plugs, and screw them in so far that when the piston come up, the piston would hit the spark plug, you'd have a collision there. It would almost be as bad as having an excess of water in your cylinder when your cylinder when your cylinder was driven home, there's no place for the water to go. This is bad news and this is one think that's got to be right and it's easy to get right if you do it the first time. If you make a little mistake you can grind a little bit off your rod end that's on your rod, so it would screw on a little farther, or you can put a washer on it to make it a little bit longer, your linear distance between your pivot pin and your crank pin. That's what it all boils down to: it's the linear distance between your rear pivot pin centerline and your crankpin location on your gear or on your crank, and that linear distance, if it's right, and you double-check it at both top dead center and bottom dead center, then you have probably done the most important thing in putting this engine together, other than being sure it doesn't have any leaks and other you're your machinist does the machine work for your bushings and your tapping and threading that needs to be done.

In regards to the bearings that are used to hold the crank shaft and the drive shaft, we found steel tubing which was pretty close to the right dimensions to use the oil-lite bushings in it. That's the bronze bushings that are pressed together out of powdered metal by different processes, and they hold oil very well, and considering the engine rotation is anywhere from 0-50 rpm, you don't have any problem with the bearings heating up, and you press your bushing in, we used 1/8" wall thickness oil-lite bushings, and we used the oil-lite bushings that have a flange on one end of the bushing so that the gear and the crank can lay right up against the flange, and take a lot of slop out of it. We have motor frames we're putting together right now with roller bearings in them, and from what our engineers tell us, the roller bearings on the crank shaft and needle bearings on your rod end or even on your rear pivot pin location for your cylinder, your rear pivot bolt, could help; the general consensus of opinion is that at this low of an rpm, chances are that replacing your oil-lite bronze bushings for your crankshaft and your driveshaft would probably help more for the resulting power that the engine would put out. But we've all been amazed at how well the regular oil-lite bushings function and how well they're holding up. You think you hear a little slop in these bushings and all, so you disconnect from them, and you disconnect the driveshaft coupling from the driveshaft gear and the shaft, and you wiggle it in the oil, and you think you're gonna be able to wiggle that shaft in that oil-lite bushing, and then you find out that you can't wiggle it in that oil-lite bushing. So you find out that they're really wearing quite well.

This concludes the major discussion of drawing #3.

See if you can find drawing #4, and before we leave drawing #3 completely, if we can let's look at both of them at the same time, and there'll be one thing that's obvious when we look at them. If both of these engines say bolt to the firewall of the car, then the crankshaft is on the wrong or opposite side of one engine compared to the other engine, and the crank is on the wrong side—oh! Now we know what—we've got a left engine and a right engine. One drives the left wheel and one drives the right, let's figure out which. Let me see, if in drawing #3. We've discussed where the oil-lite bushing is down at the bottom of the gear, so we take a 1" shaft and we weld it onto a 20-tooth gear, 8 diametral pitch, 14-1/2° pitch angle, we press it through the gear and weld around the outside after we've pressed it through ¼" to be sure it stays on there, we oil it up and slip it through the oil-lite bushings, and then we're gonna want to tie the CV joint of a wheel to it, and if we put this engine in a car and run it out that way, and the plate on the engine bolts to the firewall, and the pivot pin location bolts to the carry-through at the front, then this engine, I mean the one in #3 drawing, is gonna be driving the right wheel. So therefore, it would appear that the engine in drawing #4, you can see the bronze bushing at the bottom, it's right down below the crankshaft if you measured it dimensionwise, in this engine if we welded up a 1" shaft to a 20-tooth gear, 8 pitch, 14-1/2° pressure angle on the gear teeth, and we slipped it through there with a gear on this side, it wouldn't work if we slipped it through from this side in drawing #4. So we'll have to put it around on the other side, and what'll be sticking out on this side toward us on the bottom right hand side of the picture or the motor frame portion that has an oil-lite bushing in it, when we slip the shaft in back toward us, and we take this engine then with the shaft sticking toward us and we bolt it onto the firewall and we put the back of the cylinders out toward the front of the car and we close the hood, the only thing we can tie to this shaft then will be the CV joint from the left wheel.

So drawing #4 has the engine, which is the left engine, and it drives the left wheel. Drawing #3 is the right engine, and it drives the right wheel. The reason we went after drawing #3 first in explaining all the parts and the nomenclature, is that drawing #3 is a little bit more complicated. It has hoses and other things added that you'll be able to understand now that we've been through the spool valves and the operation, we've been through all the nomenclature, so now's the time to set #3 drawing aside but maybe where you can glance at it, so let's discuss #4 drawing which depicts the engine which is set up to drive the left wheel. Boy we got a good view of the crank, in the lower right hand quarter of the drawing is the crank, and it's welded to the crankshaft. The machinist put a little indent in that crank, which is mild steel, with his cutting tool, to make it look a little neater. You can see the code 9 bolt very clearly screwed into the crank, which forms the crankpin, and there's a perfect picture there of the rod end with the striker attached, and the spool valve that you see on this cylinder, which is at the bottom of the picture, is the same size spool valve, a ½" spool valve with ½" pipe tapped ports. It has a detent kit on it and so does the other spool valve on the opposite side, except the spool at the top of the picture has ¼" taper pipe tapped ports instead of ½", and that's because the other cylinder uses a higher pressure, and we'll get into that real soon. So this engine is just the opposite, as far as left and right goes, as the other engine, except that there's some other things that are obvious if you look at them.

This drawing #4 shows smaller cylinders, which is necessary for the sequential re-use of air. The cylinder at the top of the picture is a 2" bore cylinder, and the power factor then is less than the cylinder at the bottom of the page that says Bimba on the decal which is upside down. When this cylinder is in the car, when you look down on the cylinder, you read Bimba a lot more clearly than you do in the picture; we did it that way on purpose. OK, the cylinder on the bottom of the page, the one with what looks like white hoses on it, they're actually yellow hoses, that cylinder is actually a 2-1/2" bore cylinder. And the one on the left, I said before, is a 2" bore cylinder, this one's 2-1/2" bore cylinder. Then you see your crankshaft gear, and if you go to the right hand side of the picture you'll see the plate, and you'll notice it's not put on there square, it's put on so it will fit the firewall, and this engine sits in at an angle and it's also cocked, so that the driveshaft going through the oil-lite bushing at the bottom of the picture will line up with your CV joints.

Now there's your plate, you can even see a couple of the bolts sticking through the plate which go into the firewall on the car. Now also you can see some air fittings along the top of the motor frame, right back from the plate on the right hand side of the picture about an inch back from the plate is an air fitting, 2" from that air fitting is another air fitting, and if you'll notice between those two fittings you'll see the nut on the crankpin, in other words, you have your crankshaft and this spoke on that gear ends up being your crank, and your crankpin is that bolt, and what you see is a nut on that bolt, so after we screw the bolt in through the washers which keep it from rotating too much, and through the spoke, then we put a jam nut on the back to cinch it up. If you'll notice too, considering the bolt going through the flywheel gear also serves as your crank, you get two for one, you get the flywheel gear and the crank in one unit, if you'll notice, it is 90° out as far as clocking, you'll notice that your cranks are 90° out in degrees of rotation or in clocking, so that when one cylinder on this engine also is at top dead center, then the other cylinder will be out, and when that cylinder is at bottom dead center, the other cylinder will be out, or vice-versa.

Both these cylinders are single-wall, stainless steel, Bimba cylinders, and a very good picture now at the bottom of the picture, go to the center bottom of the picture, come up about 2" and there is a very good view of the jam nut, which is a large hex nut, screwed onto the thread of the front mount bracket. The front mount bracket is what looks like a piece of angle iron sawed off, but it's the front mount bracket modified and made to fit for this application, then there's the 3/16" steel plate that's welded onto the front mount bracket, and that jam nut tightens it up and holds that plate and the spool valve bolts to the plate, we've been through that. Look right above the jam nut, on up above the motor frame, and in the very center of picture #4, and you can see the mount bracket and just a little bit of the jam nut. Now the jam nut and the mounting bracket are smaller because the cylinder is a ½" smaller in diameter, and the spool valve's linear dimensions for length and width and height and all is less because it's a smaller valve, it's ¼" pipe threads, and we selected that in the Spirit of Joplin car because often we call upon this cylinder to accommodate and handle higher pressure, up to 500 psi pressure we use occasionally in this cylinder.

You're beginning to wonder surely by now, different cylinder sizes, and most of you by now interested enough to go this far into studying the engine, will know by now what we're doing. What we're doing with these two engines is we're compounding air, just like a compound steam engine, but air does not have the continually expanding nature of steam, however we have figured out that if we run this engine slow enough, at an ideal rpm of 40, we have the time to save and re-use the air. So the cylinder at the top of these two cylinders in picture #4 is the first to use air, then it goes into the motor frame, which is an air tank, the air that exhausts from the spool valve after being used to either push or pull that cylinder goes into the motor frame, then the air is allowed to come out of this motor frame and into the pressure port on this 2" bore cylinder at the bottom in this picture. You see a black hose, and you can see a fitting on the motor frame, and the black hose goes up at the left hand side of the picture, makes a u-turn and comes right back down into the pressure port on the cylinder. Then once the spool valve moves, whichever position the spool valve's in for push or pull, allows the two hoses that come out next to the black hose fitting on that spool valve on the cylinder closest to us, you'll see the hose comes out of the tapped pipe ports on the spool valve and goes down and into your port on the cylinder, and the other one, you can't see it go into the port of the cylinder, but where the jam nut is that holds the mounting bracket on this 2-1/2" cylinder at the bottom of the picture, you can see clearly the hose going from the air port on the cylinder and on into the spool valve, that only leaves two other ports on this spool valve, and you can see the hose is coming out, tying together in a "T", and this is where you save the exhaust air coming out of the cylinder that is plumbed and ported and vented out of the cylinder, through this spool valve, and out and into this “T.” And this air coming out of this “T,” having been used in the first cylinder at the top, the 2” bore, and then the exhaust collected and put in this motor frame tank, and then the air coming out of the motor frame tank and into the spool valve on the 2-1/2” bore cylinder at the bottom of the picture, and being used here, then the air after being used here comes out into these hoses and you see the “T” at the lower left hand of the picture, and that goes into the motor frame of the right hand engine driving the right hand wheel, and it goes into the motor frame that you see in drawing #3.

Then the air comes out of that motor frame and it goes into the spool valve you see pictured, and we’re gonna get into a breakdown of that a little farther when we get into the full engine drawing, but I hope you have drawing #3 where you can look at it, and the air goes from this 2-1/2” cylinder in drawing #4, out through the spool valve and goes into the motor frame in drawing #3, and is used the same way: the hoses aren’t on the cylinder in this drawing, but the spool valve controls the venting and porting of the air, and the air comes out of this motor frame, and is used in this 3” bore cylinder, then the exhaust air goes to another tank that goes crossways underneath the engine from wheel well to wheel well, and that air is allowed to come out of that tank and into the spool valve for the #4” cylinder, which is the last to use the air, and then that air is vented to the atmosphere. Drawing #4: if you’ll notice that the upper cylinder in the drawing, as I said the jam nut that holds the bracket is approximately in the center of the drawing, the plumbing on that particular spool valve, the manifolding that saves and collects the exhaust air is made of brake line material and steel tubing, and it’s smaller and higher pressure, and this will show up real good in our engine drawing that we’ll get to pretty soon, but your exhaust out of #1 cylinder spool valve, this is the only drawing that you have before you that shows how the two exhaust ports are plumbed together. That plus looking at the spool valve on the cylinder at the bottom of the picture shows how the exhaust ports here are plumbed together with hose, and the 2” bore cylinder spool valves are plumbed together with steel tubing, it’s just smaller and it was just easier to do that way. It’s readily apparent that we save and re-use the exhaust air from one cylinder, and re-use it in the next cylinder, and then re-use it in the next cylinder, and use it in the next cylinder.

It is this sequential re-use of air that allows us to get the maximum benefit, and to get the most of the kinetic energy of the air. These cylinders are progressively larger. The top cylinder in drawing #4 is 2” in diameter, the bottom cylinder is 2-1/2” in diameter, the cylinders in drawing #3 are 3” in diameter and 4” in diameter. So the pressure drops as we use the air, and as the air comes out of one cylinder and goes into your motor frames which are also re-use tanks, the pressure drops. So in order to get the same force or close to the same force on the cranks, we have to go to the next larger size bore cylinder The total Pneumacom project is proceeding along smoothly. We’re into flow bench operations select the optimum cylinder bore and stroke lengths to get the maximum of the kinetic energy out of the air and the air receivers on-board the car. We hope to have production prototype engines available no later than January in the first of this year 1995. There'll be an engine that can be fitted into several different front-wheel drive vehicles. There'll be a left and a right engine and a person can purchase one engine set up specifically to be theory engine to explain how the sequential re-use of air works. By selectively alternating the sizes of cylinders in a theory engine, a lot can be learned, and then the engine can also be used with another engine to drive both the left and right wheels.

(side 5)

I'm Terry Miller, I'm a resident of Joplin, Missouri, and the president of Pneumacom Corporation. Toby Butterfield, also of Joplin, is the vice-president of Pneumacom Corporation. We also have a club here in Joplin called the International Pneumatic Commuter Club, the Joplin chapter, and we've been teaching school this summer. We have a school named the Joplin International Autopneumatics Institute. It is our goal, and we seem to be succeeding at it, to teach our pneumatic commuter technology around the world, and we're very fortunate to have a fairly detailed description of our sequential re-use of air technology published in several trade magazines that are distributed all around the world, hence we're getting a lot of phone calls and a lot of letters. Our address for all our endeavors, both the club, the corporation (Pneumacom Inc.) is 511 Main, Joplin, Missouri, 64801, and our corporate office phone number, available five days a week, is 417-624-5585.

This presentation that I'm making is the wrap-up of the presentation on some pictures—I'd like to bring out the fact now that when you take a beautiful glossy color print of parts of the pneumatic engine and they are photographs, they are really pictures, and then when you make a Xerox copy of it, and the quality of the endeavor is somewhat diminished, even though the detail is there, somehow in my mind I look at them and I call them drawings, once we make a copy of something, then the machine "drew" this picture, I'm 60 years old, I call them drawings, I'll probably call them drawings the rest of my life, but other than that we'll try to get the details correct for you.

If you are in receipt of an engine drawing showing the front end of a Chevrolet Sprint with the two engines that we have talked about, on drawing #4, drawing #3, and drawing #5, the engine drawing I'm not going to number, and the reason is, we may updated drawing to go with this text, maybe a little different dimensions or something, maybe in a Ford Festiva or a Ford Aspire vehicle that we hope to be working on soon. If you have a copy of any of these engines drawings of the engine in the car, the description explaining how the air goes through the engine and how the air is re-used, the particular drawing that you have will suffice. If you'll look at the left engine, in the vehicle, if you're sitting in the driver's seat, the left engine will be the one that's in the uppermost part of the sheet of paper that you're holding. The engine has one large gear on it with multi-teeth that we've talked about before, and the right engine also has a large multi-tooth gear. A lot of people call it the flywheel gear, which is all right, however at 40-50 rpm, you can easily see that there's no such thing as a flywheel action here.

Along the top of the motor frame, you'll notice there's a dark hose in this black-and-white drawing, that comes out of the firewall, and there's a bolt at the top of the firewall, and there's a hose clamp holding the hose, and the hose goes up slightly off the motor frame and is tied back down to the motor frame, and it's visible between the spokes of the left hand engine, there's a hose clamp there that clamps the hose down against the motor frame. Then roller-coaster style, the hose comes on down over the top of the motor frame and goes up and loops down and comes into the spool valve, and this might throw you a little bit, because I'm gonna tell you that it goes into the spool valve for the #1 cylinder. Now if the right engine's cylinder is 3" in diameter, and the next one is 4" in diameter, and I tell you that the #1 cylinder is 2" in diameter, and the #2 cylinder is 2-1/2" in diameter, then you might be concerned or wonder about the placement.

The placement of these cylinders has to do with their dimensions. The 2" bore cylinder, which I've just described the black hose going up roller coaster style and curving down to the center port of the spool valve located on the top of the #1 cylinder, which is the 2" bore cylinder, the reason for that is that particular cylinder is a longer cylinder in its body, even though it is a 10" stroke it is longer in its body, and therefore we had reason to put it there because we needed to clear the brake's master cylinder for the hydraulic brakes for the vehicle, and it just so happened that we needed an extra 3/4" that the 2-1/2" cylinder, or second cylinder, would give us. Otherwise, if it hadn't been for the constraint of space, the first cylinder to use air, the 2" or #1 cylinder, would have been the farthest to the left and the closest to the left front wheel and the wheel well of the vehicle. So here we go. We have the cylinder, which is a double-acting cylinder with the spool valve mounted on top, as we have discussed and explained in drawing #5 and drawing #3 and drawing #4. This particular spool valve has ¼" tapped pipe thread ports, and the cylinder in more detail is shown in the other drawings, however, this engine drawing in the car for the left engine shows you a lot more of the hoses hooked up.

Now the spool valve besides having that one particular hose that's hooked up to the center port of the spool valve comes directly from a regulator, a welding-type regulator sold by Victor. It is a regulator capable of cranking up to 1500 psi, and it will handle a manifold pressure of 4000 psi. It is simply a welding-type regulator, and when you screw the T-handle of a regulator in like a faucet, instead of turning off the water or the gas like your manifold valves on your tanks do, or the faucet in your wash basin at home that has a screw-in process, when you screw in the screw thread on a regulator, you actually increase the pressure. So a regulator, as far as the rotation of the T-handle or the handle, works just the opposite of a faucet. So we have the regulator between the seats of the car. It's mounted where either the passenger or the driver can reach the t handle. You can reach the manifold valves usually while still sitting in your seat, unless the tank is mounted on the roof of the car, in which case you have to turn them on and off while you're outside the car.

So here we are, we can discuss air tanks in the car later, let's go through how the air goes through the engine, and what happens after it goes through this engine. All right, the air going into this spool valve, shown in a dark color which happens to be a black hose, goes into the spool valve and according to the striker, however it hits the set collars on the timing rod, which is tied to the spool in the spool valve. The spool valve is set up direct and allows the double-acting cylinder to either push or pull, so once the air is ported into the push or the pull port on the cylinder, then the next thing it does when it changes and reverses the flow, so that one port on the cylinder for a while becomes the pressure port for driving the rod and giving you the force to turn the crank, and in the next instant once the spool valve shifts, the pressure port in the cylinder becomes an exhaust port, and the air backs out of the hose, first it went in under pressure, and now it reverses and goes back out of the hose. Because the spool valve has shifted over, it goes out one of the exhaust ports on the spool valve.

As shown in drawing #4, the exhaust ports in the spool valve are tied together and teed together so both exhaust ports comes into one hose, and that particular hose comes around and goes into the check valve that's located, and you can find it, the Chevrolet insignia on the center of the grill of the car, and the black hose where the intake port is on the spool valve, on the top of the motor frame you'll see the piece sticking up there in the fitting, and that is a one-way check valve, so the manifolded exhaust of the air that has been already been used to push and pull the double-acting cylinder or #1 cylinder, and once it exhausts out of the cylinder at the time that it's being used as an exhaust port, and back through the spool valve, and collected in that manifold, or your re-use manifold, then the hose from there, you can't see all the hose, but you can see the black hose looping up again and down and into that check valve, and that check valve is affixed to and screwed into one of the pipe couplers which was cut in two welded to the motor frame.

We have discussed previously that the motor frame serves as a re-use tank to hold pressurized air, so we have operated this double-acting cylinder, the first cylinder to use air, and as the ports on the double-acting cylinder automatically alternate between pressure and exhaust, and the exhaust air, once the hose changes from a hose supplying pressure to one supplying pressure in exhaust, and through the spool valve and out through the manifold and into the re-use tank, then the air in the re-use tank, which is also the left-hand engine motor frame, once it's into the re-use tank, then it can be drawn out of that tank and used again somewhere, and we'll do that. But first, before we take the air out of the left hand re-use tank, we're gonna consider a few things. Since the air is stored in the car, in aluminum tanks that are carbon-fiber wrapped to be lightweight and hold a whole lot of pressure, or this kinetic energy in these tanks is manifolded together and comes to the regulator and is regulated, and the first cylinder to use this air determines how much air the car uses as it goes down the road when you figure in some other factors.

The particular vehicle that was the real successful vehicle, called the Spirit of Joplin, has two pneumatic engines in it: one drives the left wheel and one drives the right wheel. The engine that drives the right wheel, or the right engine, has nothing to do with the initial use of air. What has to do with the initial use of air is the initial cylinder to use the air, and that is the #1 cylinder, pictured on the right hand side of this left-hand engine motor frame, it's the 2" bore cylinder, 10" stroke. Now, every time that cylinder goes choo-choo back and forth, and every time the striker hits the set collars on the spool valve timing rod, and it hits the set collars, and you've made one complete revolution of the crankshaft gear. Depending on the gearing, and in the Spirit of Joplin car, the Chevrolet Sprint, it is geared with a 140-tooth gear driving a 20-tooth gear, so every time the crankshaft goes around, I believe we have mentioned this in the tape preceding this one, the car actually goes 38-1/2 feet down the road. So, if the cylinder is gonna go choo-choo, and the hoses supplying the pressure are gonna change from pressure hoses supplying kinetic energy to push the piston to give you force on the cylinder rod, and that force to the crank, which gives you a turning action, or torque, and that torque is transmitted from the crankshaft gear to the driveshaft gear, and it's all tied together, then there's a certain amount of volume that this #1 cylinder is allowed to take in every time you go 38-1/2' down the road. It would also take in a certain volume of air every time you went a mile down the road, or every time you went ten miles down the road.

So let's stop and think what would be the other factor that would determine how much air this vehicle is going to use. For all practical purposes you can take the 2nd cylinder, and the 3rd cylinder, and the 4th cylinder, and the 5th cylinder, and the 8th double-acting cylinder, how many cylinders happen to be in different engines driving this car? If all the cylinders down the line are gonna use the same air that we just got through putting into the first cylinder, and they're gonna use the same air with the desire or the assumption that they're gonna be able to go to a larger size in diameter and increase their power factor and still be able to deliver a sufficient amount of force on the crank, which is turned into a rotary action on the crankshaft gear, there's got to be another factor that's gonna determine how many cubic feet of air at atmospheric pressure like you and I are breathing right now, how many cubic feet of air is gonna be eaten up every time this car goes 38-1/2' down the road, or how many cubic feet of air per mile. Or how many cubic feet of air to come up with a vehicle that will go 50 miles at say 30 mph. The other factor that determines how much air this car will take in with this gear ratio using a 10" stroke cylinder with a 2" bore is simply the pressure of the air that's going in that black hose that we described that goes underneath the hose clamp tied to the motor frame, into the center tapped port, or the pressure port, on #1 cylinder.

So if we just simply disconnected the fitting on the top of that spool valve, and rolled the car down the street, and we rolled the car very slowly, say maybe just a mile an hour, and we disconnected this hose, and we allow this cylinder with the rod end and the striker operating the spool valve, so that as you push this car slowly down the road, the spool valve sitting on top of that #1 cylinder with the hose disconnected, could go in and suck air in every time for push and pull, and allow the exhausting of the spool valve, to go ahead and let the exhaust go into the #1 engine re-use tank, and we pull the plug, one of those plugs right on top of that #1 engine re-use tank, the one the high pressure hose goes into from the regulator, there's one plug there, we could just pull that plug, so as we went down the road the cylinder's drawn back just like a pump, like a tire pump, when that cylinder actuated it would cause a vacuum and the air would come in at the top of that spool valve where we had the hose disconnected, and once it went through the cylinder and went through the spool valve, it would go into the motor frame which is the re-use tank for the left engine, and the air would exhaust out there, and we're pushing the car very slowly.

Now, in this particular instance, with no pressure on the air, just enough to suck it in there and blow it back out the exhaust and on through, if you had some way of measuring this, you could get very accurate data on how many cubic feet of air at atmospheric pressure you would take in every time you went 38-1/2' down the road. This can also be done mathematically, you can figure out how much air your hoses carry, because from each spool valve to the cylinder, you have to have a hose or on this particular one a steel tubing plumbed from the two pressure ports on the spool valve down to each port on the cylinder, and those ports as I said before are alternately the pressure and exhaust hoses, but you could figure out the capacity of those, knowing that when the spool valve changes over, the air that's in that will be lost, it won't go on into the cylinder, it will stop where it's at and go back out into exhaust, and you could figure out the internal volume of the double-acting cylinder and come up with a pretty good equation as to how much air this cylinder would take in and exhaust due to the volume of the cylinder, measured in cubic inches or whatever depending on what country you're in. This would be pretty easy to compute. It's rather insignificant, though, because this car, and this particular cylinder, and the one's we're going to build in the future, operate on air pressure, or the kinetic energy of the air.

So it stands to reason that the black hose that comes out of the firewall and through that a-dell(?) clamp that has a bolt through it, and clamped to the motor frame with a hose clamp, and goes roller-coaster up and down and into that spool valve, that particular hose right there, if you had the regulator set at 500 pounds of pressure, that hose would have 500 pounds of pressure in it, and none of that air would be used until the car started to roll, and then the porting and the venting of the spool within the spool valve on top of #1 cylinder would tell the cylinder and would deliver to the cylinder either pressurized air on the pull stroke, while allowing the air that had already been used to push, to exhaust, and be constantly changing that, hence that's the name that the spool valve has, it's a 4-way spool valve, 4-way meaning you've got one hose that ends up being alternative pressure and exhaust, and another one that ends up being alternative pressure and exhaust, you've got a 4-way action there. But if you had 250 pounds of pressure in the hose, you would have air that had been condensed, or compressed, and confined in a smaller area, and the molecules in that air are trying to do work and they're trying to escape, and they're bombarding the sides of the hoses trying to get out and back to mother nature. If that hose had 500 psi in it, chances are that hose would contain in every linear inch of hose would probably contain twice as many cubic inches or cubic feet or cubic whatever depending on the country you reside in. But the point I'm wanting to make is that the other factor then that determines how much air you use when you roll down the road, it wouldn't make any difference if you had a tractor on the front of this car, and that cylinder say wouldn't have enough power to drive the car, but you would like to know how much air it would take at say 250 psi, you could hook a tractor and a chain onto that car and you could pull it slowly down the road at 5 mph or 10 mph or 2 mph and if you had the same pressure on that cylinder, whether it was 200, 250, 300, 500, the pressure would be the other factor that would determine how many cubic inches, cubic feet, or whatever it's called in your country, how much air could be used in that first cylinder if it went choo-choo every time you went 38-1/2 feet down the road.

So, the gear ratio of the car, meaning how many feet it's geared to go every time the cylinder actuates one time completely, push and pull, the volume of the cylinder is how much air it would hold at different pressures, and the pressure of the air you're using at the time, it stands to reason that if you used 200 psi and you drove the car on this one cylinder alone at 200 psi, and believe me, the car will roll, this vehicle will roll with only that one 2" bore cylinder hooked up. It will drive on that one cylinder only. And if you're driving that car on that one cylinder only and you're making it roll, it will use a certain amount of air at 100 psi, it will use probably twice as much air at 200 psi, 3 times as much air at 300 psi, 4 times as much air at 400 psi, and probably 5 times as much air at 500 psi. All right, now don't hold me to this, but this is by way of explaining that the amount of air pressure your air is at, at the time it is run through this first cylinder, is one of the determining factors that determines how much air you will use.

(side 6)

Go ahead and take this first air from the regulator, and put it in the 4" bore cylinder, which cylinder is gonna use more air at 100 psi? They'll both drive the car at 150-200 psi. But let's put 200 psi on this 4" bore cylinder, it will drive the car, and it will drive the car with more force, and more speed, and have better hill-climbing ability and everything else, because it will have a power factor three times what the 2" cylinder will have. Because as cylinder, say from 2" to 4", you think the 4" diameter cylinder will be twice the power factor of the 2" diameter cylinder. This is not so. When you figure up the square inches of surface area that the air has to push against, on the piston in the 4" bore cylinder, that 4" bore cylinder at 200 psi is able to deliver much more force at the crank than the 2" bore cylinder is able to deliver.

So let's just figure we'll drive the car for a mile with only the 4" bore cylinder on the right hand engine connected, and it's using the air for the first time. It's obvious that the car will have a little more power, and it will go farther, no it won't go farther, it'll go less if you use the same amount of air, let's just say it will have more power and will move a little faster because you'll have a cylinder able to deliver more power. Let's say we're using 200 psi. Well the 2" bore cylinder #1 located on the right hand side of the number one motor frame or the 4" bore cylinder on the right hand side of the right hand engine, they'll both be able to drive the car, but the 4" bore cylinder because it is larger, the only factor then we're changing in the equation, the gear ratio is the same, right? 140-tooth gear driving a 20-tooth gear driving the wheel. The stroke lengths are the same, the distance we'll go down the road is the same, the only thing that's gonna change the amount of air that we use is the size of the cylinder. If we wanted to use two cylinders and they were both 4" bores, and we tried the air in one cylinder one time and tried the air in the other cylinder the other time, and let each single cylinder drive the car, then we would use less air—and this requires a little bit of thought now—if we had two 4" bore cylinders, one on the left engine, one on the right engine, and had all the other cylinders laying on the bench not being used, and we had a 4" bore cylinder tied to the crank of the right hand engine, and a 4" bore cylinder tied to the crank on the left hand engine, and we put 100 psi on both cylinders, both cylinders would use the same amount of air to drive the car a certain distance at a certain pressure.

But if we change the pressure, and we drove the car on the 4" bore cylinder at a certain pressure, say 100 psi, and then we drove the car on the other cylinder, say at 200 psi, we would not get as far down the road with the cylinder that was using the air at 200 psi, because every foot down the road, every inch down the road, we would be eating up more air. We would be going faster, granted, because we'd have twice the force on the shaft, pushing on the crank, turning the crank, turning this force into torque to transmit from the flywheel gear, or the transmission gear, the crankshaft gear to the driveshaft gear and out to the wheels of the car. So we get right back to it, it takes a little thought, the 2" bore cylinder is the first cylinder to use the air, and it's the first cylinder to use the air for a reason. We use the air at up to 500 psi. And we have a lot of kinetic energy in the air. We don't want that cylinder to be big, because if it's big, we'll use up all the air the first shot, and there won't be any way to use it again. So we use the small 2" bore cylinder the first time, and whatever air pressure we use, about half of that air pressure is saved in the left hand re-use tank, which is the motor frame for the left hand engine, now that motor frame for the left hand engine therefore supplies compressed air at roughly half the pressure that we were putting into the #1 cylinder.

We see the check valve there, just behind the Chevrolet emblem, and the fitting going down into the motor frame, in this particular instance we don't see a hose coming out of the left hand motor frame going to the #2 cylinder spool valve, but there is a hose going in there, we can see just behind the Chevrolet emblem, just about an inch up on the drawing, on the Chevrolet emblem on the grille, about one inch up we can see the hose looping and and going down into the center port. It's a black hose, we can see the light shining on the black hose as it loops up by the left headlight and comes right down into the top of that spool valve, and it is a wire-braided high pressure hose, which is the last high pressure hose to be used in this engine system, because we drop down to lower pressure hoses, which are more flexible. So there is the hose that's taking air out of the left engine re-use tank, the motor frame, and putting it into the spool valve for #2 cylinder, and in that place, that spool valve sitting astride that double-acting cylinder like a saddle on a horse, it being timed by the striker that's welded to the rod end and the striker sliding up and down the timing rod, hitting the set collars, bumping against the set collars, and the timing rod being affixed to the spool valve shaft, that moves the spool valve back and forth and changes the venting and the porting of the air to cause that cylinder to go choo-choo, and to go push-pull, just like the #1 cylinder did. However, this cylinder is a 2-1/2" bore cylinder, so it is enabled to deliver a considerable amount of force to the crank because the power factor of this cylinder is larger.

So we have taken the air that's used in the first cylinder, 2" bore, put it into the left hand motor frame, stored it there under pressure, let the air come out of the left hand motor frame via the hose, down into the pressure port, the center tapped port of the spool valve on top of #2 cylinder, be used to drive that cylinder push-pull, by venting and porting the air, then we save the exhaust air that comes out of the two exhaust ports on the spool valve—now that's a good time to mention that the spool valve does have two exhaust ports on it, and they are the two ports farthest away from the center pressure port where you supply pressure to the spool valve. And the spool valve selects two other ports, to allow this pressure to pass over to them, through the indentation in the spool, and these other two pressure ports supply air pressure via the hose to the port at the front of the double-acting cylinder and at the back of the double-acting cylinder.

Then when the spool valve changes over and tells the cylinder no, the hose that was supplying pressure to the pipe-tapped port at the front of the cylinder, we just got through supplying pressure, and we've pushed the piston to the back, and we've been on the pull stroke, but now we're changing around and we're letting that hose change from a pressure hose to an exhaust hose, and the air will back up through what used to be the pressure port on the spool valve due to the fact that the striker hits the set collars and moved the detent in the spool to where it connects that port to the exhaust port, then it also connects on the other side, it changed the port that used to be an exhaust port into a pressure port, and now you're allowed to reverse the flow in the cylinder and allow the cylinder to have pressure at the back side, pushing the cylinder to the front, and putting the cylinder into the push mode. It is a 4-way spool valve, pressure, center, tapped ports. And in the center position of this spool valve—the actual spool in the ½" valve slides 5/8" to do all this action, and that's not much, 5/8" to change the spool valve ports from pressure to exhaust, or from exhaust to pressure, and it does this very efficiently, one of the greatest spool valves I've ever encountered, and absolutely it seems that the WABCO, which stands for Westinghouse Air Brake Co., this is an old spool valve, designed many many years ago, and it has been invaluable in the work that we're doing, and we highly recommend it. It's distributed by Rexroth Worldwide Pneumatics, it's just a super spool valve for this application. You may think that we've spent an awful long time on the left engine, but bear in mind that both engines, the left and the right, are sequential re-use engines, and they both use the air in one cylinder, and save the air that was used in that cylinder on that engine, and put it in a storage tank somewhere, and re-use the air in another cylinder on the same engine that has a larger bore and a larger power factor.

What keeps the air from going back, where you don't want it? All right, let's go back to the check valve, and the only one showing up on top of the engine, there are other check valves in the hoses, that go underneath the engine, and they go underneath the left engine and underneath the right engine. But let's find the Chevrolet emblem at the top of the grille on the car, and let's go to the left of that Chevrolet emblem, what would be about an inch-an-a-half linear measurement, and you'll see the spool valve tied to a pipe coupler that was cut in half and welded to the left engine motor frame combination re-use tank, anyway, that check valve screws into the pipe coupler fitting, and it allows the air that's going out of the spool valve on #1 engine and into the manifold, which shows up pretty clearly, that manifold that we're talking about, on drawing #4, you can see the two spool valves that we're talking about, that are located the farthest away from the center pressure port that comes up out of the top. Anyway, those exhaust ports are plumbed together, and the black hose circles around from that manifold and goes up and down and into that check valve and supplies air to the left hand engine motor frame/air re-use tank.

Now, the check valve has a reason. It isolates the air, the exhaust air from #1 cylinder into the left hand engine re-use tank. Boy, we're spending a lot of time on the left hand engine. But once we get the left engine operation down, the right engine practically doesn't need any talking about. One is the same as the other. Now, the check valve keeps the air from backing out of the re-use tank and driving the #1 cylinder in a direction you might not want it to drive, or it isolates the kinetic energy in the re-use tank. Once the exhaust air passes that check valve, it stays in the re-use tank. Now, the manifold that collects the air, the hoses manifolded together that collect the exhaust air from #2 cylinder, that manifolded air goes through a hose via check valve and crosses underneath the left hand engine motor frame, and goes into the right hand engine motor frame. Now if you'll look at drawing #5, you can find probably the best drawing of the hoses for the #2 cylinder on the left hand engine motor frame. Again, that drawing #5 is kind of confusing, you get to thinking that the engine you're talking about is the right hand engine, but it's not. At the top of these two engines sitting there in drawing #5, the cylinder you can't see, that's down, the stroke position is just off of the dead center position, you can see the spool valve, but the only portion of that valve you can see is just a little bit at the back by the pivot point. But anyway the bottom engine on drawing #5 is the left hand engine motor frame, and the spool valve to the 2-1/2" bore cylinder, and the hoses for it which are right down at the bottom of the picture, are very clear. You can see another picture of the check valve going into the motor frame, you can also see at the top of the left hand engine motor frame, you can see 1, 2, 3, 4 extra pipe couplers that were welded onto the tanks for optional use and for instrumentation, but that check valve is right there, and if you'll follow out of the top of the check valve, the hose goes up and makes a left, goes down and turns to the right, and goes right into the steel tubing and the two steel fittings that make up the manifold 16, or the re-use air manifold out of the spool valve on #1 cylinder. There's a very good view of it.

Also, you can find about one inch to the left of the check valve, you can see the hose fittings screwed into the pipe coupler, welded to the left hand engine motor frame, and you can see the hose on the hose coupling go up and make a u-turn, and come right down, looks like back toward you, and right down into the center port on the spool valve, on the 2-1/2" bore, #2 cylinder, on the left hand motor frame, and there you are, you got your ports laid out there. There's your black or your dark hose going into the top of that spool valve, you can see to the left and the right, the two pressure ports, they're alternating pressure and exhaust ports where the hose comes out of there and goes into the back of the cylinder to supply air for the push stroke, and also exhaust air out through the manifold for the pull stroke, you can see to the right of that manifold the hose there, which in the pull stroke will provide air pressure to the front of the cylinder, pushing the cylinder back for the pull stroke, and then when the spool valve actuates, you can see and visualize how the striker would hit the set collar and move the spool, and then that hose which would normally have pressure for driving the cylinder would have re-use air pressure, or exhaust air pressure, which would go out the exhaust port, and you can see the manifolding, what we call manifold 16 two times in this drawing #5.

If you'll look at #2 cylinder you can see the hose that comes out of the exhaust port at the front of the spool valve, you can see the hose coming out of the exhaust port at the back of the spool valve, you can see the T-fitting where the two hoses tie together, and you can see a length of hose just curl up, the end of the hose curls up and points to #2 cylinder, and it hasn't been hooked up yet, but when these engines are put in the car, this hose will go over, it will go through a check valve and then into the right hand engine combination motor frame and re-use air tank. And then the air will come out of that motor frame, the right hand re-use motor frame, and into the center port of the spool valve, and we start the process all over again. So we can go back to our engine drawing and maybe keep this drawing #5 handy to look at. The re-use of air means once we put the exhaust air from one cylinder into a re-use tank, we need a check valve to keep the air isolated in that tank, and then the only way the compressed air can get out of that tank is via a hose to the next larger cylinder. That way we do our best to get the same amount of force to each crank as the first crank, we try to get the same amount of force on the next crank and then on over to the next engine.

Now, I might add that these two engines are separated mechanically. The right engine does not drive the left wheel, and the left engine does not drive the right wheel. So in this particular case we do not need a differential, in case one wheel is running faster than the other. In this particular engine setup, if you're turning left, the left engine will have less distance to turn because the wheel will be turning a shorter radius than the right wheel, and consequently the left engine won't be running as fast as the right engine. If you turn right, then the left engine will either be running faster, or depending on how you look at it, the right engine would run slower. So they're not tied together mechanically, however the exhaust from cylinder #2 goes underneath both motor frames and goes into the right hand engine motor frame, then air comes out of the right hand engine motor frame and we can see, if we'll locate the spool valve on the paper just about an inch above the right hand headlight on the car, if you see the spool valve there just to the left of the right hand engine motor frame, we can't see the shaft from #3 cylinder, and we can't see the rod end from #3 cylinder, but we can see the timing rod that protrudes out from the #3 cylinder spool valve, and we can see the two bolts at the front of the spool valve, which bolt the spool valve down to the plate, and lets the spool valve sit on top of the plate, which is tied to the front mounting bracket on the cylinder by use of the jam nut, all right, the spool valve sitting there, between the two nuts we can see the Westinghouse Air Brake name plate on the spool valve, now if you'll note just slightly above in the drawing of that nameplate on the spool valve where the two front bolts bolt the spool valve to the plate, you'll see a hose coming out from the area which would be the front tapped port of the 3" bore cylinder, the #3 cylinder, the hose comes out and makes a u-turn and comes right back into the pressure port of the spool valve, then you can see the other pressure port of the spool valve to the right, about an inch, and you can see the hose come out of there and make a right u-turn back, and you can't see it because it ducks under the grille, but it's heading into the tapped air port at the rear of the #3 double-acting cylinder.

Now, the hose coming out of the right hand engine motor frame/air re-use tank, you can see it going right down and looping up and going into the center port on the spool valve. The two items not so easy to recognize are the two exhaust ports on the spool valve, which are the two ports farthest away. You can see a hose go out and duck underneath another hose, and a hose go out just right above the grille on the car, come out of the spool valve and duck underneath, and you can actually see the fitting where the two hoses T together, and then that hose from there takes the exhaust air from #3 spool valve after being used in #3 cylinder, takes that exhaust air, and the hose goes from that T, down and through a check valve and into a re-use air tank, which goes across from wheel well to wheel well, and it's made out of 4" square welded steel tubing. Now the exhaust tank that goes underneath the engine is larger than the engine motor frames. The engine motor frames are 3" square welded steel tubing, and the re-use tank that takes the air from the 3" bore cylinder on the right hand engine, that exhaust air from the 3" bore cylinder after it's used in the #3 cylinder, it goes via the manifold and down from the manifold into a hose, and down through a check valve and into that re-use tank stretching from wheel well to wheel well. It is larger because we've had an increase in volume in the air, a decrease in pressure, but we still have to have an easy flow and an abundance of cubic feet of compressed air, even though it's at a lower pressure, and we need to have it available to use in #4 cylinder.

So then from that tank we have a hose coming up, and supplying pressurized air to the spool valve on top of #4 cylinder, and if you'll look at the drawing we have, drawing #3, you'll be able to see the #4 cylinder there, and the spool valve sitting on top of #4 cylinder you can only see three ports, and the other two ports which are the exhaust ports point away from us in this drawing. We simply have two hoses tied hoses tied to the fittings that screw into this spool valve, and go down and into the tailpipe and back to the back of the car like a conventional tailpipe, except the air is cold coming out of this cylinder, because of the decrease in pressure.