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Optimize Your Fuel System for Best Engine Performance

Nitro Secrets You Must Know!

The World Models Groovy 3D, reviewed by Dave Keough in our May 2007 issue, uses an inverted O.S. 70 Surpass 4-stroke. This plane is typical of the many that would enjoy superior performance using the Uniflow fueling system. Yet this superior approach to "fuel plumbing" is not widely understood outside pattern and helicopter circles.

The fuel system is one of the most important parts of your airplane, but how much do you really know about it? Do you understand the theory behind how it works? Did you know that there are several different types of fuel system architectures and do you know which one is best for your specific application? The more you understand about this part of your airplane, the better off you'll be. We are going to look at the glow engine fuel system in detail. A lot of this may apply to gas powered models as well, but in all fairness they should be discussed separately. Alright, class is in session. There won't be a test until you get to the field next weekend!

FUEL SYSTEM REQUIREMENTS

What do you expect from your fuel system? In practical terms, the fuel system affects engine performance, so that's really what you're concerned about. You want the engine to start easily, idle smoothly and reliably without "loading up" and you expect it to run the same whether the airplane is upright, inverted, climbing or diving. Is this what you get out of all of your airplanes? I bet most of them run pretty well. But maybe a few, particularly those with large carburetors or inverted engines, might cause problems for you. This is because either the fuel system type is not correct for the particular application, or something was overlooked during the installation. Since we know what we want, let's find out the best way to get it.

Dave Keough proudly carries his Groovy 3D aerobatic ship.

FUEL TANK CONFIGURATIONS

Before we get buried in theory, let's look at some basics. There are essentially two types of fuel-system arrangements in use today. Either one of these may be used in a pumped or non-pumped environment. First let's look at the fuel tank itself. In RC models we normally use a rigid or semi-flexible fuel tank. The control-line guys use bladders, but we RCers don't. We will focus on the more common rigid and semi-flexible tanks in most RC models today. That being said, let's look at how the fuel tank is built and what determines the way it will operate in your model under different conditions.

CONVENTIONAL SYSTEM DESCRIPTION

The first type I'm sure everyone has seen. It's used on almost every ARF airplane and is shown in the instructions included with fuel tanks from nearly every supplier. I call it the "conventional tank system." It usually has two lines: The feed or pickup line and the vent/overflow/pressure line. The feed line attaches to a weighted fuel pickup inside the tank called the clunk. This line

ILLUSTRATIONS BY DAVID BAKER

connects to the carburetor inlet and feeds the engine with fuel. The clunk assures that the pickup is always submerged in fuel regardless of the airplane's attitude. The second line is a rigid piece of tubing (usually brass or aluminum) and it runs to the top of the tank (when the airplane is sitting upright). It attaches to the muffler pressure line or it may simply be left open, exposed to the atmosphere. As long as air may enter the vent line, fuel shall be allowed to flow out of the feed line. It is important to understand this principle, otherwise you'll have a hard time understanding how the fuel system works. To fill the tank with fuel, you remove the feed line from the carburetor and pump fuel into the tank until it runs out of the overflow line. To empty the tank, you pump fuel out of the feed line. Air enters the tank through the vent line because it is exposed to the atmosphere. If it didn't, you wouldn't be able to pump the fuel out because you'd start to create a vacuum in the tank.

There is also a variation of the conventional tank system known as a three-line system. In the conventional three-line system there are two clunks. One is used as a feed line, but the other is only used to drain and fill the tank. It does not affect the operation of the fuel system except during refueling operations, because it is not connected to anything in the fuel system. When would you need a three-line tank? How about with a fully cowled engine where you don't have access to the carburetor feed line? In this case, the third line would go to a plug. This allows you to fill and drain the tank by removing the plug and attaching your flight box fuel pump. This type of three-line tank works the same as the more common two-line system as far as the pressure inside the tank is concerned. So far so good. But wait, there's more.

UNIFLOW SYSTEM DESCRIPTION

The second type of fuel system is not very common in R/C airplanes. It's popular on "3D" helicopters, but it was actually invented back in the early days of control-line modeling. It is called the Uniflow system. The Uniflow fuel tank always has three lines. It's actually assembled the same as the conventional three-line tank. So what makes it so special? It's not how it's built but rather how it's plumbed. It's a little more complicated than the conventional system, but in some installations it works much better. I'll explain why later. For now, just make sure you understand how to attach all of the lines and what their purpose is. First you must attach one of the clunk lines to the carburetor. This is now the feed line.

The rigid line that goes to the top of the tank is no longer going to be a vent/pressure line. It will only be used during refueling as the overflow line. Since it goes to the top of the tank, it will let you know when the tank is full because fuel will run out. Once you're finished filling the tank, you need to plug this line. Very important! You can use a plug or a "fuel dot."

Now what is the third line for? Well, what did we forget? That's right, the muffler pressure line. Here's where it gets complicated. You can of course just connect the line directly to the muffler. If the muffler or carburetor is easily accessible, that might work. Keep in mind you need to remove either the carburetor/feed line or the muffler/pressure line to fill or drain the tank. I also like to install a check valve in the muffler line to improve the effectiveness of the muffler pressure and to eliminate the possibility of fuel entering the muffler under certain flight conditions.

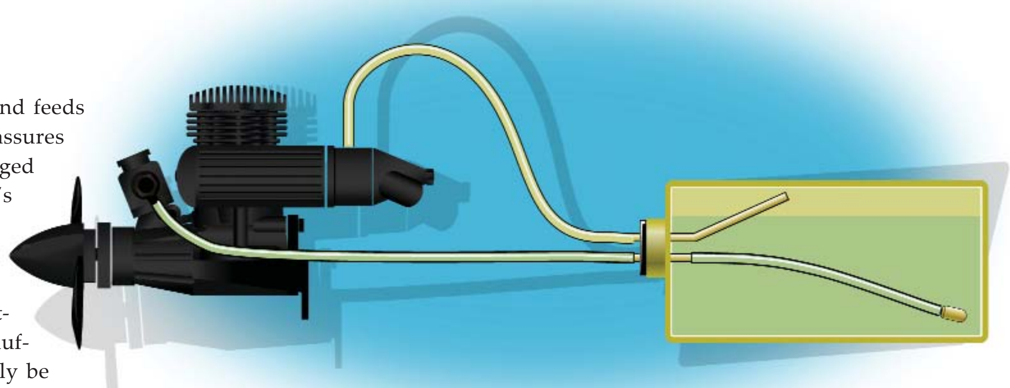

Figure 1
This conventional 2-line pressurized system is used on most models. Note that a "pressure line" carries exhaust pressure from the muffler to the air pocket in the top of the tank. A pressure differential between that applied to the pressure line versus the feed line leading to the carburetor varies as the amount of fuel decreases and as the aircraft changes attitudes or goes inverted. The Uniflow system eliminates this variance.

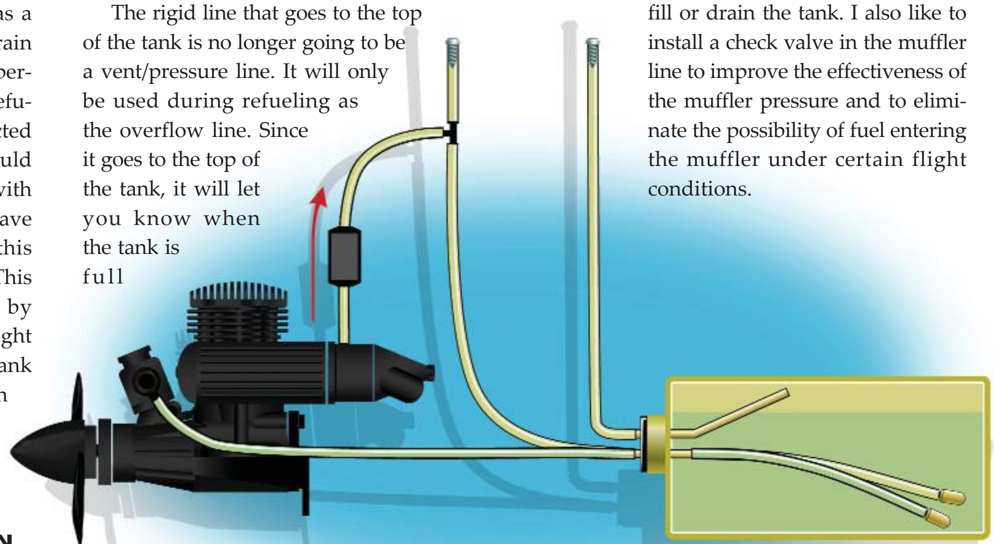

Figure 2
This is the Uniflow 3-line pressurized system. Note the check valve above the muffler. It permits pressurized gas to flow in only one direction—into the fuel tank. Note that the pressure line carrying exhaust has a clunk that is next to the feed line clunk. Both clunks are in the same relative position with respect to the mass of fuel. This takes the pressure differential noted in the first illustration out of the equation.

ILLUSTRATIONS BY DAVID BAKER

CONVENTIONAL TANK THEORY

Even though the conventional tank setup is one of the most widely used, I find that most people don't fully understand how it works. When you understand how it works, you will also understand why it doesn't work the way you expect it to sometimes. Remember, you can build a conventional tank setup with either a two-line or a three-line fuel tank. The plumbing is what determines how the system behaves. Since a picture is worth a thousand words, please look at the illustrations while you try to make sense of my explanation.

First, let's take a look at what's going on inside the tank when the engine isn't running. There appears to be no pressure in the tank at this point, but actually there is. First, there is always atmospheric pressure present at any point in the system. I shouldn't need to remind you that the fuel in the tank is a liquid. Try to remember that in any liquid, the pressure at any point in the system is equal to the pressure at any other point in the system at the same level. The level is important because the mass of the fuel affects the pressure in the feed line or, more importantly, the pressure seen at the carburetor inlet.

Since atmospheric pressure is everywhere (on the vent line and at the carburetor inlet) it basically cancels itself out of the pressure equation at this point. OK, take a minute to think about this and look at the illustrations. Now for the extra credit question: How do we determine exactly what that pressure is? Just keep in mind that at any point in the system that is lower than the fuel level, there is enough pressure to push the fuel up to the highest level even when no additional pressure is applied to the system. It's easy to see how installing a motor where the carburetor inlet is lower than the fuel level could cause problems now isn't it? Because of this, most model airplanes are usually designed so the tank is positioned where the fuel level will be below the carburetor fuel inlet. This is good. When the engine isn't running, no fuel will flow into the carburetor because it doesn't have enough of this unseen pressure to allow it to do so. It only has enough pressure to reach the same level as the fuel in the tank (which is lower than the carburetor fuel inlet).

PRESSURE DIFFERENTIAL

But wait, this is no good. How will the engine run if the fuel doesn't get into the carburetor? What can we do? Well, in order to make the fuel flow, we need to create a pressure differential. A pressure differential is achieved when two points in the system have different amounts of pressure. Sounds like an easy concept to understand, but how do we create something like that in the fuel system. That's easy. Flip the prop with the carburetor just above idle speed. This creates a vacuum at the carburetor inlet (needle valve). A vacuum may be defined (in our case) as any pressure less than atmospheric pressure. Since pressure is always seeking a "happy state" of equilibrium, fuel will flow into the carburetor because the pressure in the tank is higher than the pressure at the carburetor. The engine will run.

So why do we need to "pressurize" the tank with muffler pressure anyway? The correct answer is "We don't." If the carburetor creates a substantial amount of vacuum at its inlet, there will be enough differential pressure to allow the fuel to flow toward the carburetor even if it is higher than the fuel level in the tank. Some people say the engine "sucks" the fuel out of the tank. While this may be their way of understanding it, in scientific terms it is not correct. In science, everything "blows," nothing "sucks."

Now, when you apply muffler pressure to the vent/pressure line, the muffler pressure helps create a higher pressure differential than what can be achieved by venting the tank to the atmosphere and relying on the carburetor vacuum alone. This is especially important when the airplane is in a vertical climb and the tank is much lower than the carburetor. As we should remember, the mass of the fuel affects the potential of the fuel to flow out of the tank. When the tank is much lower than the carburetor inlet, the mass of the fuel actually reduces the pressure seen at the carburetor and this makes it much harder for the fuel to leave the tank. That's why we use muffler pressure. This creates a large enough pressure differential to allow fuel to reach the carburetor inlet regardless of the airplane's attitude.

To prove this, start the motor, set the needle valve slightly rich, then hold the nose of the airplane up. I bet the motor leaned out slightly didn't it? Try it again with the muffler pressure line disconnected from the tank (temporarily plug the pressure tap on the muffler). You'll need to reset your needle valve to allow for the lower pressure differential caused by removing the muffler pressure source. The motor should lean out quite a bit when you raise the nose of the airplane now.

So this all works well enough to supply the engine with fuel under all conditions. What could cause problems? Remember, even when the engine was not running, fuel tried to leave the tank. The only thing that stopped it was the fact that the pressure differential wasn't high enough to push it

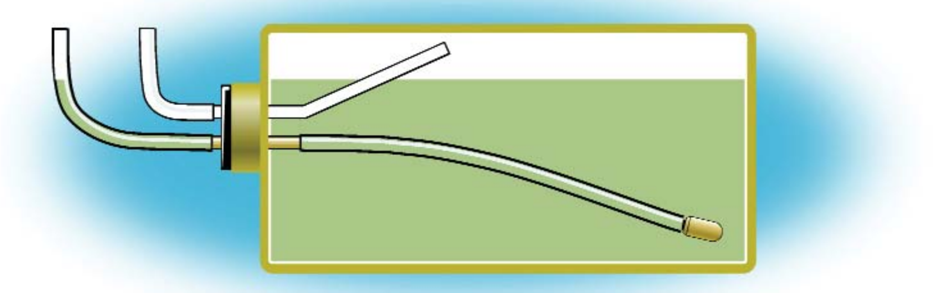

Figure 3

This conventional 2-line system is shown in a static condition with the pressure line disconnected (making it a vent line) and the engine off. There is atmospheric pressure on both the vent line and the fueling line, but the mass of fuel has overcome that to rise to its own level in the feed line.

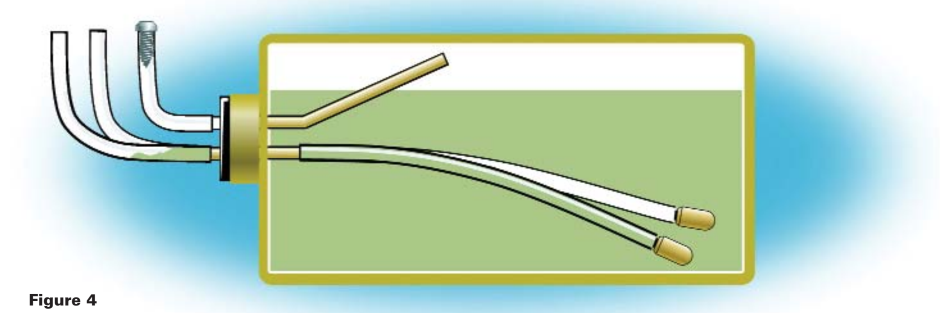

Figure 4

This is a Uniflow 3-line system with a plugged vent line and equal pressures at the clunks at the end of the pressure and feed lines. For this reason, the fuel does not seek its own level in the feed line and pressure must be applied to the tank via the pressure line to deliver fuel to the carb.

"uphill" into the carburetor. Now imagine if the carburetor was lower than the level of fuel in the tank. Fuel would run out of the tank until the level of fuel in the tank is at the same height as the carburetor.

This is the dreaded siphon effect that plagues inverted motor installations. Anyone who has siphoned gas out of an automobile has seen this firsthand. The only way to stop it with a conventional tank setup is to install the tank lower in the airplane or pinch off one of the fuel lines when the engine isn't running. Yes, you can pinch the vent line and it will stop the fuel from flowing. If air can't get into the tank, fuel can't get out.

FUEL MASS

The other thing that happens is not so obvious. Since the mass of the fuel affects the pressure in the feed line, what happens as the fuel level in the tank gets lower during flight? Obviously this affects the pressure seen at the carburetor inlet—it decreases as the mass of fuel decreases. Just like your eardrums feel being underwater at the bottom of a shallow pool compared to a deep pool. This is why you set your high-speed needle valve a little bit on the rich side, yet still end up landing the plane with a slightly lean condition.

Why does the motor start to slowly lean out? Sure, the prop unloads, but that happens quickly. The amount of fuel in the tank significantly affects the fuel mixture. Under severe conditions, the engine may actually run so lean that it quits. This usually happens on final approach. How many "unexplained" dead-stick landings have you seen? Science is wonderful.

UNIFLOW THEORY OF OPERATION

To understand how the Uniflow system works, try to think of it as a "balanced" system whereas the conventional tank arrangement is inherently unbalanced. Remember how the fuel mass affects the pressure in the feed line? In a Uniflow system, the fuel mass does not directly affect the pressure in the feed line. It's not magic, it's physics.

All Uniflow systems require three lines. The line at the top of the tank is always plugged during normal operation. That leaves the two clunks for pressure and feed. Now, since both of them are at the same level in the tank (the bottom, whatever the aircraft's attitude) the fuel mass is exerting equal pressure on both of them. It's trying to push fuel out both of the lines, but atmospheric pressure is trying to push it back in. Remember for fuel to flow, there must be a pressure differential. Since the pressure on both lines is the same, no fuel will flow.

Now, when the engine starts, the vacuum in the carburetor throat creates the pressure differential the same way it does with a conventional tank system. There is now atmospheric pressure on the pressure line and a vacuum on the feed line. Since the pressure always wants to be in a state of equilibrium, fuel will flow out of the feed line into the carburetor. If you apply muffler pressure to the pressure line, the pressure in the feed line is exactly the same! This is very different from the way the conventional tank arrangement works, due to one important thing: the fuel mass.

I'll say it again: in the Uniflow system, the pressure caused by the fuel mass does not affect the pressure in the feed line. The fuel mass is taken out of the equation. This means that you can set your needle valve for optimum performance (allowing for prop unloading of course) and still be assured that the level of fuel in the tank will not affect the mixture. No more rich/lean conditions during the flight. Well if it's so good, why isn't it as popular as the conventional two- and three-line systems? In all honesty, there are some tradeoffs along with the good.

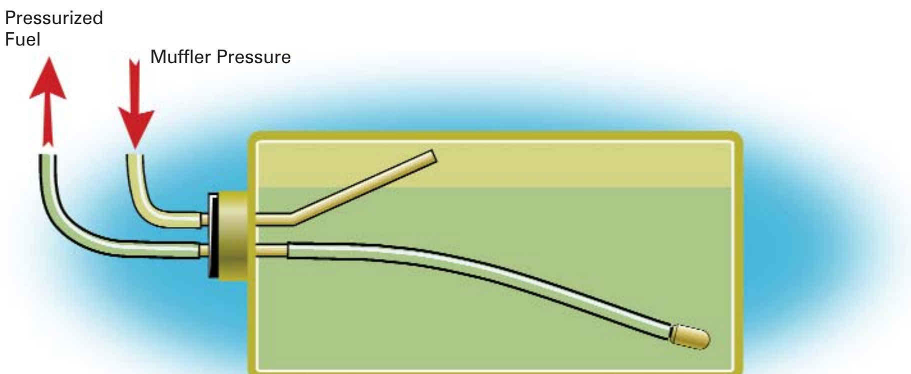

Figure 5
Air pressure greater than one atmosphere enters this conventional 2-line system via the pressure line to push fuel up the feed line into the carburetor.

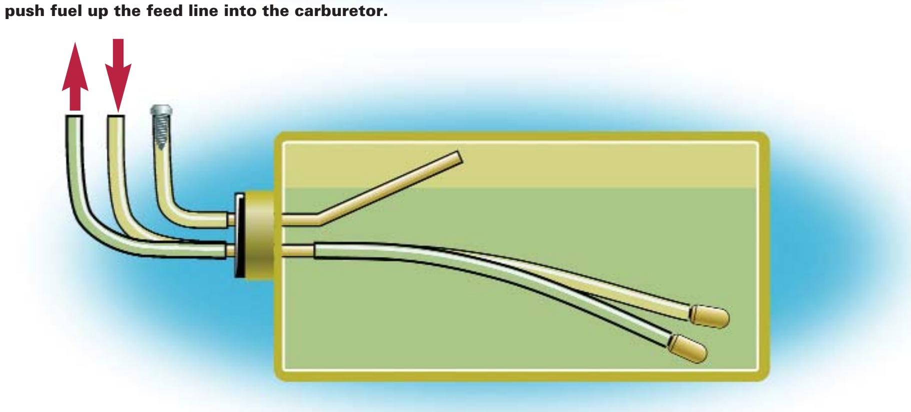

Figure 6
A pressurized Uniflow 3-line system in operation. The adjacent clunks of the pressure and feed lines are in the same position relative to the fuel mass. This ensures a consistency of pressure with respect to both lines. This, combined with the check valve shown in the second illustration, dramatically improves the consistent delivery of fuel to the engine in all attitudes.

WHY A CHECK VALVE?

The most common problem you see with a Uniflow system is fuel in the muffler. It is very difficult for this to happen with a conventional tank setup because the pressure line is not submerged in the fuel (unless the airplane is inverted). This happens more easily in a Uniflow system because the pressure line is always submerged in fuel, and sometimes the pressure in the tank is higher than the muffler pressure. This condition occurs if you suddenly back off of the throttle. The easy solution is to use a check valve in the pressure line between the tank and the muffler.

This has the added benefit of allowing you to place a 'T' between the tank and the check valve. Run the 'T' to a fuel dot and you've got a good way to fill and drain the tank. Of course if you do this, you will experience a slightly rich condition if you suddenly close the throttle. It's not a problem if you move the throttle stick as smoothly as you should.

Now if you've taken my advice on installing the check valve and the 'T' you'll run into another issue. Filling the tank is no problem. The problem occurs when you try to empty the tank. The check valve opens and air leaks into the line, causing the fuel pump on your flight box to cavitate. This makes it nearly impossible to pump fuel out of the tank. To prevent this from happening I place a plastic or rubber cap over the muffler outlet when I drain the tank. This prevents air from entering the system and also keeps your plane from making a mess on the way home from the field.

MAKING THE RIGHT CHOICE

So now you're asking "When should I install a conventional tank system and when should I use the Uniflow?" Either one may be used in any application. There are, however, times when one would be the better choice. The conventional tank setup can be used on just about anything that has an upright or side-mounted motor. As long as the top of the tank is not any higher than the needle valve, you should have no problems with carburetor flooding, unreliable idle or any of the other common fuel-system maladies. You can even use it with an inverted motor where the fuel level may be higher than the carburetor at times (although this is not really ideal), but I wouldn't recommend doing this with an engine that has an air-bleed carburetor.

If you like to keep things simple, it doesn't get any better than the two-line conventional tank setup. That's probably why it's so popular. It does however suffer from the fact that as the fuel level becomes lower in the tank, the fuel pressure at the carburetor inlet decreases and thereby the fuel mixture will become leaner. If you're using a pump this is not an issue because the pump will supply enough pressure regardless of the level of fuel in the tank and this pressure should stay the same throughout the entire run. It's also possible to use a check valve in the pressure line to increase the system pressure. This works almost as well as having a pump and it's less expensive, but you'll still see a slight mixture change as the flight progresses.

TIPS FOR SUCCESS

The Uniflow really helps with inverted engine installations. It is much more tolerant of the low carburetor position because the fuel mass does not create the potential for fuel to flow "down" toward the carburetor when the motor isn't running. It is not entirely immune to the dreaded siphoning effect but it is much more resilient. Because of the unique pressure conditions in a Uniflow system, some details need to be considered when you plan your installation.

First, I recommend using a check valve in the pressure line, but only if you're using an engine with a two-needle carburetor. An air-bleed carburetor has limited capabilities as far as controlling the idle mixture and you'll end up with an extremely rich idle condition. This is because using the check valve really increases the system pressure. I have run inverted motors with an air-bleed carburetor with a Uniflow setup (no check valve) and they run much better than with a conventional two-line setup. The idle quality is improved tremendously. The only problem I've experienced has been fuel in the muffler (which translates into an over-rich condition/deadstick) after sudden throttle movements. Usually a combination of setting the idle speed a little bit higher and careful use of the throttle eliminates the condition.

So what's the best choice for your airplane? Hopefully now you have enough knowledge to make that decision on your own. The best advice I can give would be to make sure you understand everything discussed thus far. If you don't have confidence in something, then by all means don't use it. If you're still undecided here are a few simple guidelines:

— Air-bleed-type carburetors should not be used in inverted-engine installations. If you must use an air-bleed carburetor on an inverted engine, the Uniflow system is the best choice.

If the carburetor inlet is positioned higher than the fuel level, either type of fuel system may be used with good results.

— You may use a check valve in the pressure line on either a conventional tank system or the Uniflow system to increase the overall system pressure.

— The level of fuel in the tank affects the mixture in a conventional tank system. In a Uniflow system it does not.

— The conventional two-line system is very simple to build and easy to install and operate. The Uniflow system requires more parts and careful installation.

Don't be afraid to experiment with different things in order to achieve maximum performance. As always be safe – you don't want to lose a model because of something unexpected!

TUNING FOR MAXIMUM PERFORMANCE

Two-needle carburetors are preferred over air-bleed types, but either one should produce acceptable results provided it is properly tuned. Most engines will actually run quite well with the factory idle mixture settings if you've installed a conventional fuel tank system and the fuel level is not higher than the carburetor inlet. The Uniflow system usually requires more adjustments to make the engine happy. On any new installation, it's a good idea to check the mixture settings when you hold the airplane in every attitude (nose up, nose down, upright, inverted). Some people like to set the high-speed needle with the engine running at full throttle and the nose of the plane pointed straight up. This is a good idea because it helps to prevent an over-lean condition.

The high-speed needle valve should be set first because it affects the idle mixture. Adjust it to let the engine run a few hundred RPM less than peak. With a Uniflow system, you can set the needle a little bit leaner (higher RPM) than you would with a conventional system. If in doubt, start on the rich side, take off and fly. If you need more power, or the motor sounds "burbly," set the needle slightly leaner and try again. It's better to be a little bit rich than too lean.

I have yet to see a motor that was damaged by running it too rich. OK, breaking in an ABC motor is an exception. Remember, if you make large adjustments to the high-speed needle valve, you will need to readjust the idle mixture as well. The idle should be smooth and just slightly rich. Not so rich that the engine loads up and quits, but rich enough to allow for the prop to unload when the airplane is flying. You want a clean transition from idle to mid range. If you've installed the fuel system properly and adjusted the carburetor correctly, you should be rewarded with reliable operation every time you fly. A dead stick condition should be an indication that something has broken (a pin-hole leak in a fuel line for example) not an everyday occurrence. You should be able to fill the tank with fuel, attach the glow plug igniter and spin the prop. The engine should start easily and run reliably throughout every phase of the flight. If not, then you're doing something wrong even if you don't realize it. Maybe now you have enough knowledge to figure out what that is! ✪