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Efficient Powerplant Installation

Piston Engines

http://www.caro-engineering.com

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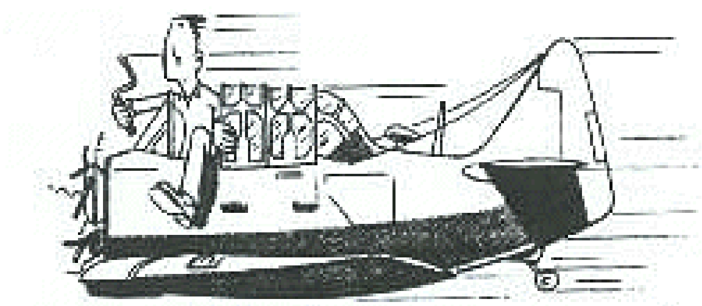
INTRODUCTION

This book is aimed at airplane homebuilders and everyone who enjoys working on airplanes. Installing an engine on an airplane can be a challenging task, especially if you have never done this before, and have only incomplete instructions or drawings. Many decisions have to be made, which will affect the safety and efficiency of the airplane when you fly it. In the following chapters you can find basic information and a lot of hopefully helpful hints for installing your engine. Everything is based on the experiences of others who have already installed their engines.

One emphasis of this book is on improving the performance you will get from your powerplant installation. One of the main areas is engine cooling, because this part is often left up to the builder or installer and many things can go wrong. This book explains how to achieve a well-cooled engine with a minimum of cooling drag. Included are solutions for several different configurations like tractor, pusher, air cooled and liquid cooled engines. Many illustrations will help the reader to visualize installations and problem areas. Not necessarily arranged in chronological sequence of how to install an engine, each chapter is dedicated to a component or system.

Another emphasis is on safety. What you don't know can still hurt you. So educate yourself about what you are doing, and this book will give you a lot of help. You are the one who has to trust the installation, and as someone who knows that you life may depend on it, you will hopefully be very thorough in your work.

Because this book only gives an incomplete overview of accepted techniques and practices required for some of the fabrication and installation of parts, it is strongly recommended that you have a copy of the Advisory Circular AC 43.13-1A "Aircraft Repair and Inspection Manual" available (it is available for free in electronic format on the FAA website).



Do not attempt restart if engine stopped because of obvious mechanical failure.

2. FIREWALL

2.1 Firewall Materials

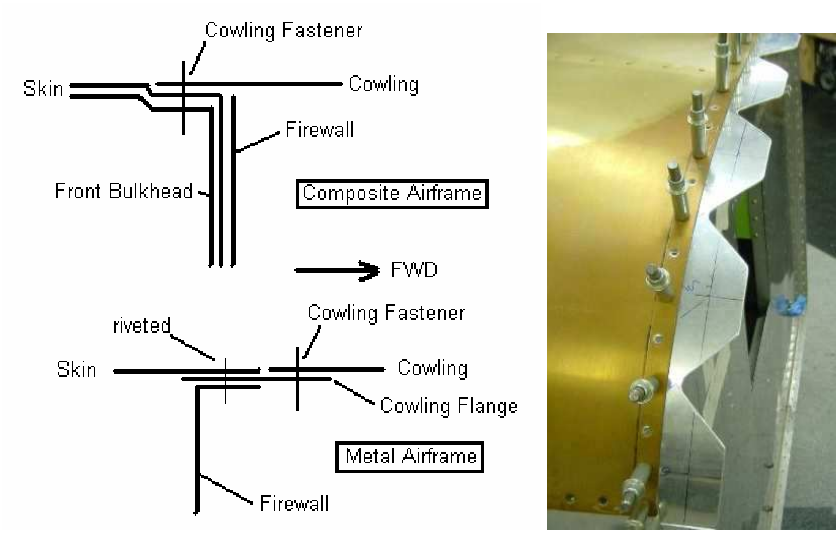
Let's assume that you are looking at your airframe, which may be almost complete except for that empty space where the engine needs to go. Because a running engine is a very hot chunk of metal and gets in close contact with flammable fluids (fuel, oil), it is a good idea to have something in between the engine and yourself that will protect you from high temperatures and smoke in case the fuel decides to find a different place to burn except inside the cylinders. Carbon monoxide from the exhaust is another consideration; it must be prevented from entering the cabin. The safest way to keep fire on the engine side of the firewall is to use a steel barrier. Stainless steel is the most durable solution, although mild steel can be used. Just make sure rust will not eat holes into it. The following materials are considered fireproof by the FAA and should be used as guidance for homebuilts:

- Mild steel, thickness 0.018 in (0.5 mm)
- Stainless steel, thickness 0.015 in (0.4 mm)
- Titanium 0.016 (0.4 mm)

Aluminum has a much lower melting point than the materials listed above. It would not offer protection from a fire because it would rapidly melt. Steel is heavy and a steel firewall adds several pounds to an airplane. Fortunately there is no need to use thicker material than what is listed above. Structurally such a thin sheet of steel is quite flexible and insufficient if you want to attach things to it. If the airplane has a structural bulkhead, wood or composite, the steel is added to it and carries no load. In a metal airplane, the steel firewall is reinforced with stiffeners.

The firewall will also act as a noise barrier. A combination of steel sheet with some backing material can make a lot of difference in cockpit noise level.
Some materials sold as "flexible firewalls" are usually not suitable for fire protection by itself; the temperature they can withstand may be much lower than the 2000°F a fire can generate. If you are not sure, request a sample of the material you would like to use and hold a torch to it. It should withstand it for 15 minutes before flames or smoke penetrates it. If your engine is installed in front of the cockpit, having an effective firewall is even more important than if the engine is installed behind the cabin, as in pushers. The airflow tends to blow flames aft, so it is less likely that heat and smoke would enter the cabin in the latter case.

Depending on how the airframe is made, the firewall (meaning the steel sheet) can be attached in different ways. Normally there are enough components attached to the firewall, which will hold it in place if it is a separate sheet on a composite bulkhead. The picture below shows typical arrangements for firewall and cowling flange on composite and metal airframes. First of all, the firewall will be held in place by the engine mount bolts. Anything else attached to the firewall will secure it further.



Picture 1 Firewall Flange Arrangements

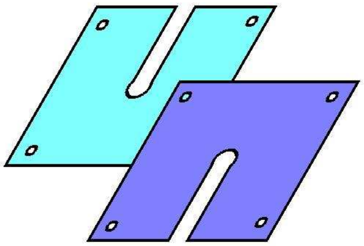
When you design your firewall and want to use flexible insulation or a thermal blanket on the engine side, make sure it is sealed so that it can not soak up oil. This would create a fire hazard and would add the weight of the soaked up fluid. You can use high temperature silicone (RTV) as sealant along the edges and at penetrations.
It is also recommended not to have anything which is easily flammable on the cabin side in close contact with the firewall. Fuselage fuel tanks and other items which might be flammable or have temperature limits like plastic lines should be spaced at least one half inch (12 mm) away from the firewall, further is better.

Another material which can withstand the 2000°F which can be expected in the case of a fire are ceramic fibers, sold for example as *Fiberfrax*. It has no coating and does not seal against fire or smoke by itself. It is mainly used as thermal insulation on the back side of a steel firewall. This may be a good idea in any case, just to keep the firewall from heating the cabin even under normal operating conditions. ¼" (6 mm) thick ceramic fiber blanket has proven to be adequate in tests for certified airplanes.
The space between the steel and the composite structure must be sealed to the cabin. Composite material will burn if the temperature is high enough. A thin steel sheet conducts heat very well and will be glowing red after only a few seconds of exposure to flames. A fire in the engine compartment must be prevented from heating up a composite bulkhead behind it, as not to release smoke into the cabin. The smoke from composites is extremely irritating and toxic and may cause more damage to the persons in the plane than the actual fire.

Do not locate any cabin air openings, fuel drains or vents, directly behind cowling openings. Flames may be blown out through the cooling air outlets onto the fuselage. If your fuselage structure is wood or composite, you should protect the firewall bulkhead and the surface immediately (about 10 inches aft of the opening).
You can use a metal shield or fire resistant (intumescent) paint. This paint, when subjected to flames, puffs up to a foam like bread rising, which provides thermal insulation to keep the material underneath from reaching a temperature at which it will burn (at least for a while). This paint is more commonly used to protect wooden buildings and can be painted over with normal exterior paint. This paint can also be used on the inside of the cowling to protect it and help contain a fire inside the engine compartment.
It is available from a number of places, see http://www.contegointernational.com/ or http://www.firefree.com/ or http://www.fireretardantsinc.com/fire_retardants101.html.

2.2 Firewall Penetrations

To make the firewall effective, do not cut any holes into it. Okay, but now you say what about those cables, cabin heat opening and fuel lines? There are exceptions of course. Some things have to penetrate the firewall. The opening for the cabin heat for example, must have a shutoff valve, which is as fireproof as the firewall itself (must be steel). It must seal well enough not to let any fumes through when it is closed. Engine control cables should be routed through fittings, to prevent them from chafing on the firewall. The fitting may also allow them to slide back and forth slightly, if engine movement requires that.

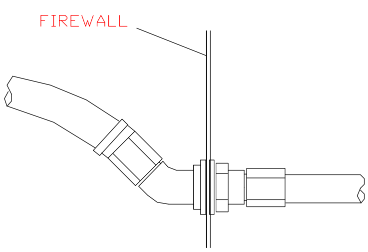


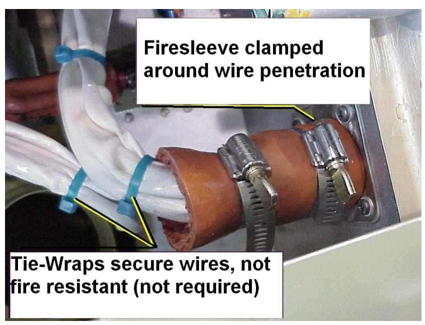
Picture 2 Firewall Penetration Cover Example

A simple way to seal a hole in the firewall for a cable which does not require chafing protection is shown here. The two plates are made from the same material as the firewall. They are mounted on top of each other and can cover a larger hole which may be needed to insert a connector or end fitting. They are attached with screws and sealed with high temperature silicone sealant.

Bulkhead fittings can be used in many cases. A typical application is a fuel line. Standard fittings are available from many suppliers. If they are made from steel, they can be considered fireproof and require no further protection. If they are made from any other material and are smaller than a size -8 fitting (1/2” line), they will need to be protected. A piece of firesleeve (woven glass fiber sleeve impregnated with silicone on the outside) will provide thermal insulation and prevent the fitting from melting. The firesleeve should be attached with metal clamps or safety wire.

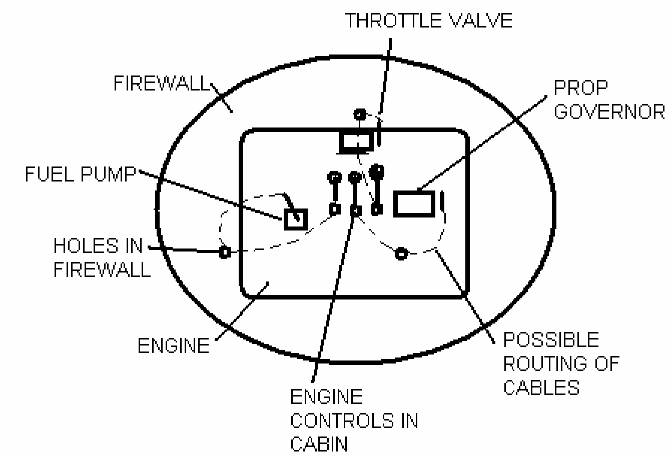
Instead of having many smaller penetrations, consider using one large, well protected penetration. Since the highest chance for actually experiencing a fire is where the exhaust is, and in most installations this is at the bottom half of the firewall, consider making all other penetrations through the top half of the firewall where possible. For the location of the fuel line penetration another consideration may be equally important. If it is located at the bottom of the firewall, it is very likely to get damaged in a crash, break off and leak fuel onto a hot engine. If you have the choice, find a location which is more protected.





Picture 3 Examples of Firewall Penetrations, Bulkhead Fitting (left), Wire Penetration (Right)

Cables and electrical wires have to be protected with grommets to keep the firewall from cutting or chafing them. All holes must be well sealed to prevent carbon monoxide from entering the cabin. For the layout of the firewall, start with a list that includes everything, which will be mounted to or routed through the firewall. Come up with a plan where each one needs to be. Before you drill any holes, take a look at the engine or installation drawings and figure out where all the levers are, which will require a cable for actuation. Draw up a sketch and mark the approximate locations of the levers. Then draw up the locations of where the cables come from in the cabin. The hole in the firewall should be somewhere in between those two locations.



Picture 4 Locating Holes in Firewall, Bulkhead Connectors, Eyeball Fitting for Control Cable Penetration

Repeat the same thing with all other hoses, lines and wires which need to penetrate the firewall. Draw up those items, which need to be mounted on the firewall bulkhead. Check where you may have items on the cabin side of the firewall and mark those areas as not available for holes.

It requires planning ahead to drill at least some if not all of the necessary holes before you install the engine. Once the engine is in place, there might not be enough room to drill from the engine side. That may not be an issue if you can get easily to the firewall from the cabin side, but in many planes that access is restricted. In any case, think and measure twice before you drill, a hole in the wrong place is one hole too much.
To drill stainless steel, use a small sharp drill to pre-drill, then open up the hole to the required size with a large drill. Use slow speed and a lot of pressure. To reduce the chance of the drill bit grabbing the material on thin sheets, special drill bits are available which prevent that. You can recognize them by their pointy tip in the center. The cutting starts at the outer edges. A step drill is also helpful for the larger holes.

2.3 Sealant Materials

Dan Horton performed a burn test on several sealant materials and documented the results:

Cotronics Resbond 907GF (single compound, not so sticky, difficult to apply, hard when cured)
Rectorseal Biotherm 100 (single compound, silicone, sticks well, rubbery when cured)
Flamemaster CS1900 (two compounds, does not stick well, like soft rubber when cured)
3M FireBarrier 2000 (single compound, silicone, sticks well, rubbery when cured)
Permatex Ultra Copper (single compound, silicone, sticks well, rubbery when cured)

Picture 5 Sealant Burn Test Setup

The different sealants were applies to a stainless steel sheet both on the surface and around wire penetrations. The one in the center uses a plastic bushing. A steel pass-through fitting is used with FireBarrier as sealant on the left side. This sheet was bolted to a frame with a burner directed at the one side of the sheet. The burn rig was calibrated to approximately 2000ºF. The right picture shows the setup with a different firewall insulation material burning.

Picture 6 Sealant Burn Test, Backside of the Panel

About 30 seconds into the burn, the CS1900 has burst into flame. All three silicones are also outgassing flammable material, but not as bad as the CS1900. The burn exhibited by these four samples is not a bad thing, as the purpose is to form an insulating char. The Resbond appears to be inert. The Biotherm and FireBarrier samples are exhibiting some degree of intumescence, swelling and expanding. At the 6-gauge wires; so far all the sealant samples are holding up but the wire insulation (Tefzel) is burning away. At about 45 seconds the Ultra Copper strip sample has burst into flame. The Biotherm sample had flamed slightly and then fallen away leaving some adhered residue. The CS1900 has peeled and fallen away cleanly, not even leaving a mark. Resbond and FireBarrier are doing fine. At the steel pass-through, intumescent FireBarrier is squeezing out of the gaps in the joint. Same is true at the plastic bushing (center). So far all the plastic bushings are holding up ok, which means all the sealants are doing a decent job of slowing heat transfer; in thick sections they are serving as insulators. At the front of the panel after about 1 minute, all the pass-through samples have remained intact and formed an insulating char. Of the strip samples, only the FireBarrier and Resbond remain adhered. The difference is mechanical; the 6-gauge wire is keeping the sample in place over each of the bushings. At the back of the panel at about 1-1/2 minutes, the snap bushings are now melting. The copper wire cores are very hot, so the Tefzel insulation is beginning to soften and swell. All the strip samples have peeled away, except for the Resbond.

Conclusions: None of the tested sealants should be applied to the **cabin** side of the firewall, only to the engine side. The outgassing will be a hazard to the occupants. The main benefit of the sealants is to slow the heat transfer during a fire to give you a chance to get the airplane on the ground. To provide this protection, the sealant must be spread thickly around the firewall penetrations. Close-fitting steel fittings are more durable and effective as a smoke and fire barrier than plastic bushings.

During normal operation, silicone is suitable to keep out moisture, but it has limited fuel, oil or hydraulic fluid resistance. Use it only in areas which are unlikely to be in permanent contact with those fluids

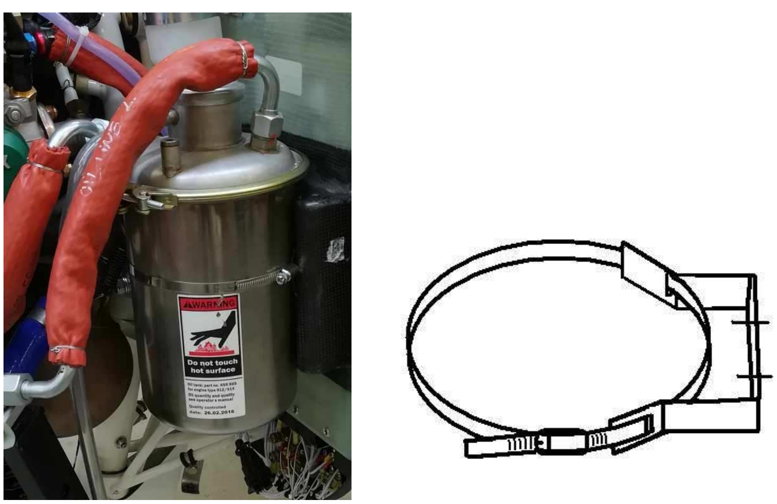
2.4 Items on Firewall

One of the items that usually ends up on the firewall is the brake fluid reservoir. It must be installed high, well above the rudder pedals with the brake assemblies. Having it in the engine compartment allows easier access than having it in the cabin. It is recommended to use a fireproof container (steel). The one in the picture below the fitting extends through the firewall so that no brake lines are in the engine compartment. It is attached with two bolts.

Picture 7 Fuel Pump and Gascolator (left), Coolant Overflow Bottle (center), Brake Fluid Reservoirs (right)

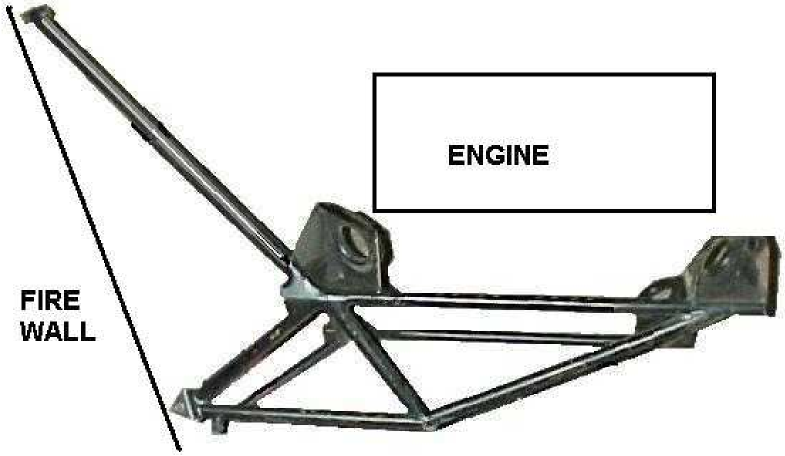
The voltage regulator is another candidate for the firewall. It can be installed in a convenient location near the alternator, as long as the heat radiated from the exhaust does not get to it. Provide a heat shield if necessary. Heat shields are best made from a reflective material. Aluminum works well; stainless steel is good but heavier.

Fuel pump and gascolator may be installed in the engine compartment, but I would only do this as a last resort. Both contain fuel and are not easy to fireproof. In this picture, a steel line was used between the two components. The advantage of having the gascolator in the engine compartment is that it can be drained through an opening in the bottom of the cowling.
The coolant overflow bottle (aluminum) of a liquid cooled engine was attached to the firewall in this example. It is held in place with a clamp through two brackets. Obviously, it does not need to be fireproof.
Some engines (dry sump) require a remote oil reservoir. The oil bottle in the following example is attached to the firewall with two brackets and clamps. The bottle should be mounted as low as possible to keep the oil in the bottle when the engine is not running and not let it drain back into the engine. If the items you attach are heavy, you may need to reinforce the firewall structure locally. This is especially important if your firewall is just a metal sheet. Bolting or riveting a doubler or angle profile to the cabin side will help.

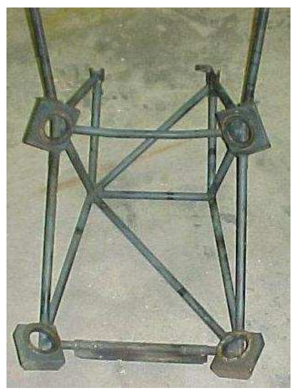


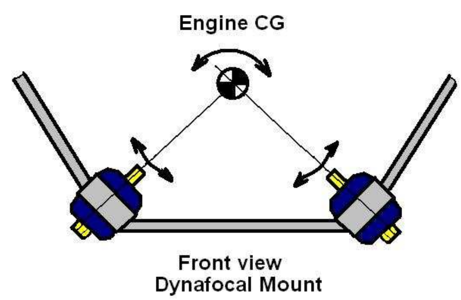
Picture 8 Remote Oil Reservoir and Attachment Bracket, Rotax

3. ENGINE MOUNT



3.1 Engine Mount Types



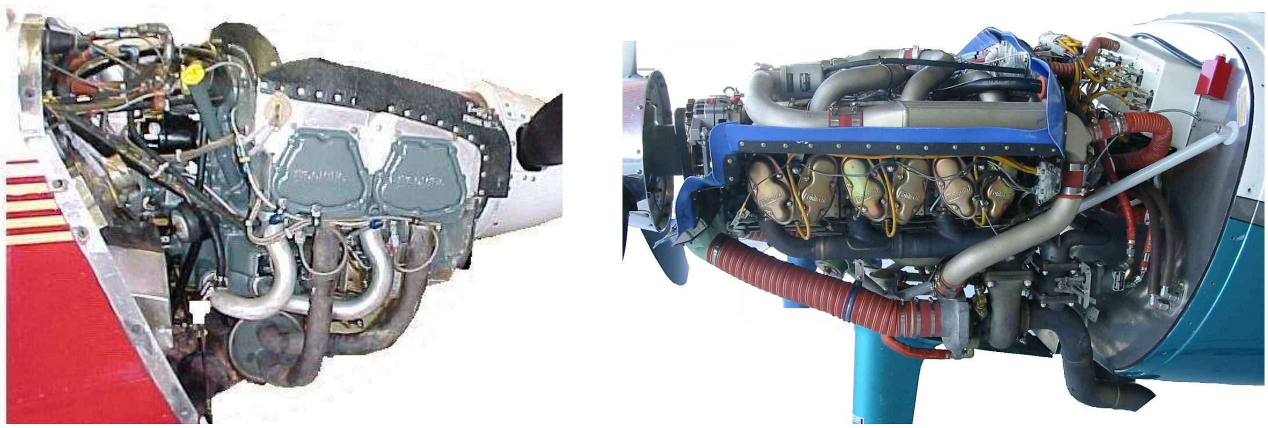


Picture 9 Rear Engine Mount for Lycoming Engine (left), Bedmount Style (right), Concept Dynafocal Mount

An engine mount is the most important part between the engine and the airplane. It provides support for the engine and makes sure the prop stays pointed in the right direction. It also provides convenient support for all those little items that can be clamped to it. What type of engine mount is needed is determined by the engine. Engine mounts are basically divided into bed mounts, where all the attach points to the engine are underneath the engine and rear mounts, with attach points behind the engine. Both types of mounts shown here are dynafocal mounts. Note that the attachment bolts (mount to engine) are not parallel. The angle of the engine attach points is such that with torsional engine movement the rubber shock mounts are stressed in shear. This way the shock mount's vibration damping is maximized. Unfortunately this makes bolting the engine to the mount much harder compared to a version where the bolts are parallel.

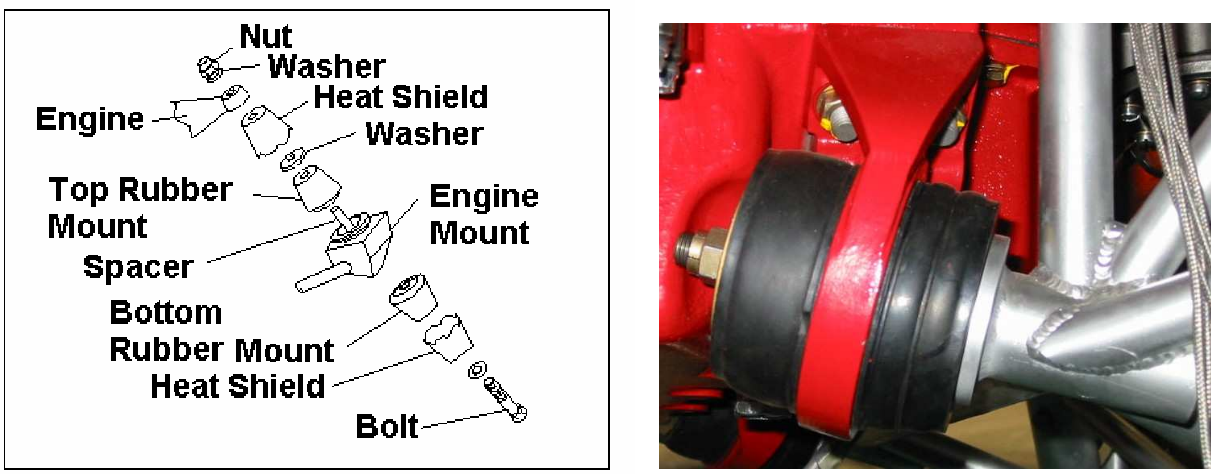
Bed mounts allow the engine more fore and aft movement than firewall mounts. If you are using a bed mount, plan on having no less than 1/2 inch clearance (3/4" is better) between anything attached to the engine mount and the cowling or components mounted to the airframe. Most of the movement is in the direction of flight (fore and aft), but when starting and stopping, the engine typically rotates around the longitudinal axis more than you would expect. The vertical motion by comparison is fairly small.

Most engine mounts use rubber shock mounts. These serve to dampen the vibration caused by the engine. Rubber ages and cracks especially fast in a hot environment. Protecting the rubber from the exhaust heat radiation increases its life. Use heat shields if necessary. A thin piece of aluminum will reflect much of the heat radiated by the exhaust. Silicone rubber mounts (made by Barry for example) have better heat resistance and will last longer than rubber.



Picture 10 Lycoming Engine with Firewall Mount, Continental Engine with Bed Mount

Not all engine mounts use dynafocal mounts because they are expensive to fabricate. A lot of the smaller engines (<100 hp) just use straight mounts with some rubber discs for vibration damping, which is less effective.



Picture 11 Dynafocal Shock Mount Assembly, Continental Style (left), Lycoming Style (right)

The dynafocal style top rubber mount may be different from the bottom one (or front and back as in the right view in the previous picture), do not swap them. One is loaded in compression, the other one primarily in shear. The bolt takes up all of the tensional loads. The following picture shows a comparison between a new mount and an old, sagged mount. Ask the supplier or look at the spinner - cowling (mis-)alignment to find out what the limit is. On some types of shock mount the bolt is threaded into the engine case. In this case the bolt needs to be secured with safety wire (with a special washer if bolt head is not drilled for safety wire).

Most airplanes use engine mounts which are separate structures that are bolted to the firewall (Mooney, Piper, Cirrus). This has the advantage that the engine is well accessible from all sides when the cowlings are removed. On others the engine mount is part of the aircraft structure (Cessna 210, Skymaster front engine, Pulsar XP).