make it almost impossible for you to form a bend near either end of a ¾" diameter steel (or aluminum) tube. Always start with a long length of tubing when bending it. The larger the diameter of the tubing, the greater its excess length should be. Allow an extra 12" on each end for tubing up to ¾" in diameter. Allow even more for larger diameters . . . you will need the added leverage it affords. If you find you need more leverage, you can always slip in a steel rod or slide a larger diameter tube over the end to serve as an extended handle of sorts.

Equipment Needed

You don't need much in the way of equipment or materials to make good uniform bends. These items are definitely needed.

1. You will need a large rugged vise. The effectiveness of almost any type bending device will be greatly improved by clamping it in a heavy duty vise mounted securely on a solid bench. In addition to freeing both hands (and in some cases, feet), it will enable you to more precisely apply the bending pressure to the tubing. A substitute for the vise would be a good solid immobilized bench to which you could bolt a bending device horizontally.
2. Some sort of bending device is essential for any bend exceeding, say 15° to 20° especially when that bend is concentrated around a small radius.
3. A filler material (sand, bending alloy or salt) for those hard to make bends.
4. Templates cut from plywood. How else can you check the bend you are making?

Tube Bending Devices

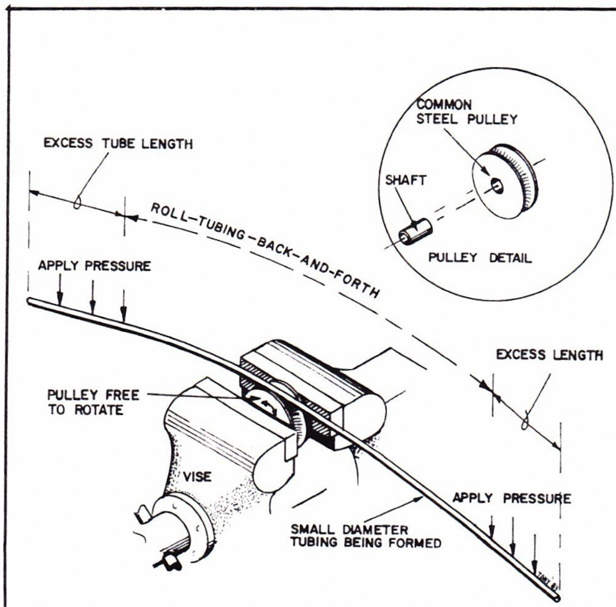
You can bend tubing successfully with just about any simple homemade tube bending device if it is properly made. You have a wide variety of types from which to choose.

Locally you might have access to some commercial tube bending machine. If so, great . . . just remember to bring your templates, too.

Others of you might be able to locate someone who has an Electrician's Conduit Bender and arrange for its use. It should allow you to make simple bends with a high degree of success provided it can accommodate the diameter of the tubing you need to bend. Most of the tubing we use in homebuilts is either ½" or ¾" in diameter (sometimes ⅝", too). If the tube bender you have access to is made for larger diameter tubing you probably shouldn't use it as it might cause your bends to flatten excessively. The design of an electrician's tube bender is simple enough that you could duplicate it for the size tubing you need to bend.

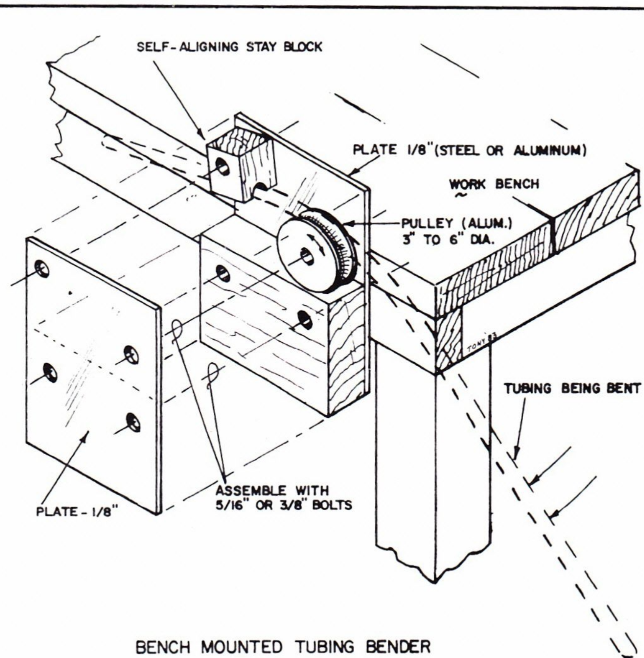
A simple plywood bending form nailed to a work bench is a good basic bending device for large bends in small diameter tubing. However, when cutting the form to shape you must make its curve sharper as the tubing will have a tendency to spring back. This sort of bending device is easy to use for uniform curves because you can fasten one end of the tubing and pull the free end around the form causing it to bend smoothly in one easy sweep.

An improved variation of the plywood bending jig (form) is one with its edges grooved to the diameter of the tube for which it is intended. The groove is important. It reduces the tendency for tubing to flatten and somewhat sharper curves or bends in the tubing are possible. An even greater improvement would be to make the routed groove somewhat deeper so that the tubing will nestle in it beyond its half diameter. This added depth permits the walls of the groove to exert a restraining effect against the tube's tendency to flatten. It is equally important, when making any grooved pulley or bending jig, for the grooved edges of the form to be strong enough to resist the flattening and widening of the tube. A wood form, particularly a plywood form, is rather weak in this respect so it should have considerable edge distance between the groove and the edge of the pulley, form, jig or whatever. A grooved aluminum "pulley" would be much stronger but is harder to make if you don't have a large hunk of aluminum plate or a metal working lathe. Figure 5 shows some options for making grooved tube bending devices, be they pulley types or the simple wood jig types. Figures 1 through 5 should give you enough ideas to help you devise a bending device of your own.



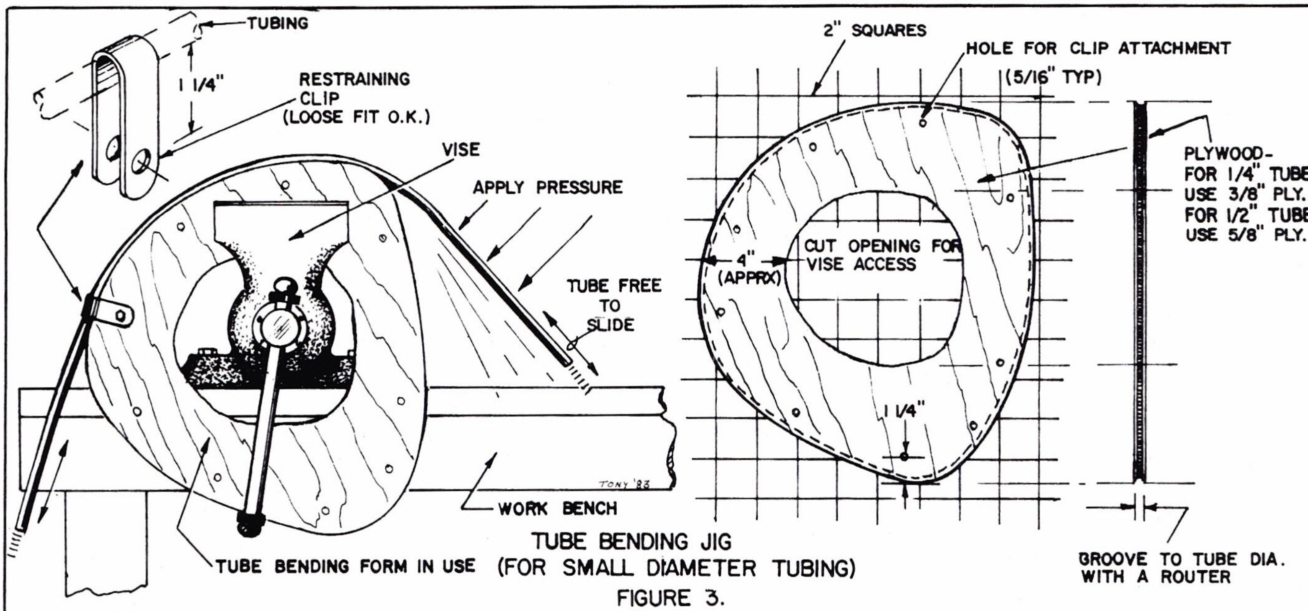
A SIMPLE RIG FOR SIMPLE BENDS

FIGURE 1.

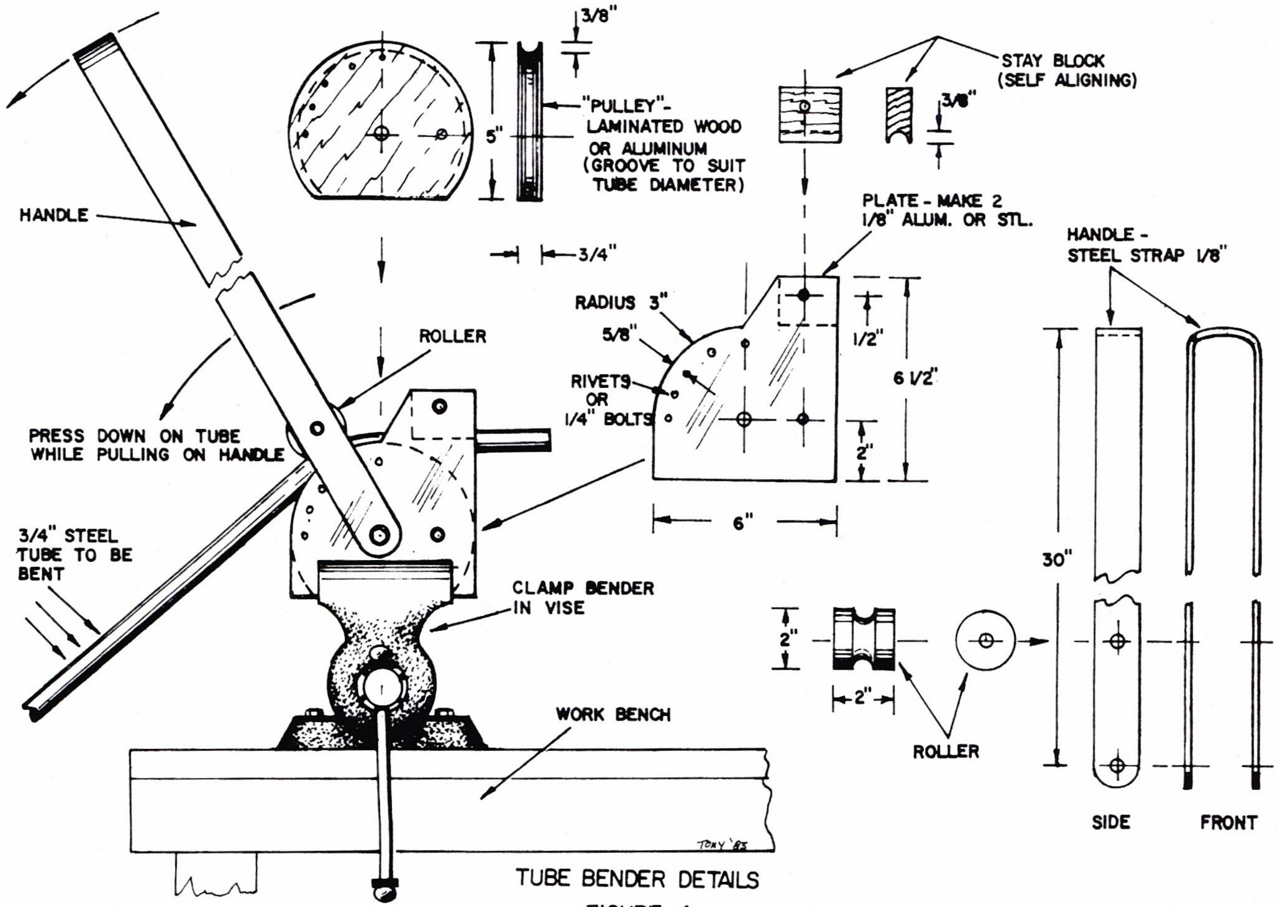


BENCH MOUNTED TUBING BENDER

FIGURE 2.



TUBE BENDING JIG
(FOR SMALL DIAMETER TUBING)
FIGURE 3.



TUBE BENDER DETAILS
FIGURE 4.

Bending Procedures

Tubing in aircraft work is usually bent cold. Contrary to what may seem logical and contrary to what you may have heard, attempting to bend tubing by heating it can turn out to be a lousy adventure. Most of us don't have the skill and patience to play with a hot bend and will usually get unhandsome results. The problem lies with localized uneven heating and poorly coordinated bending pressures . . . to say nothing of impatience. Pressing a hot tube against a bending form will surely cause it to flatten on the inside of the bend. Hand bending it without the aid of a form is likewise very difficult to do successfully. In short, bend it cold.

Heating tubing to a red hot condition does have a place in bending. Bending causes the metal to harden somewhat. So, by heating the tubing you can anneal it and continue the bending carefully after the tube cools. In other words, it is possible to make bends over a smaller radius if you anneal the tube once or twice as the bend progresses. This is a slow way but it can make an otherwise severe bend possible. There is another way to reduce the risk of making a poor bend. Use a filler material.

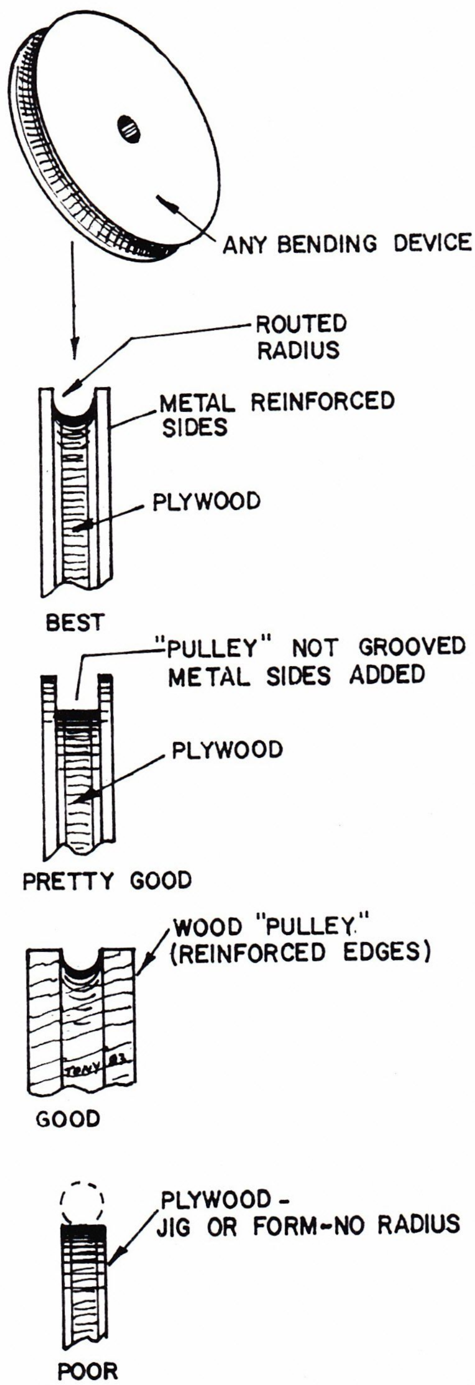


FIGURE 5.

The Use Of Filler Materials

It is easy to see that packing a tube you want to bend with a solid material like sand or a molten bending alloy will greatly inhibit the flattening tendency.

Before you attempt to bend any large diameter tube (3/4" or larger), you should fill it with densely packed sand. (I understand that salt works as well although I have never tried it.) The sand has to be dry and well sifted to remove all foreign matter and the larger grains of sand. Plug the bottom end of the tube with a wood plug and pour in the sand. Tap the bottom end of the tube repeatedly against a solid surface (concrete floor). After the tube is full of sand, the continued tapping will cause it to settle and pack more densely. Add additional sand. After the sand shows no further sign of settling, drive a wood plug into the top end of the tube being sure it bottoms solidly against the sand. Your tube is now ready for bending. The risk of a flattened bend will have been considerably reduced.

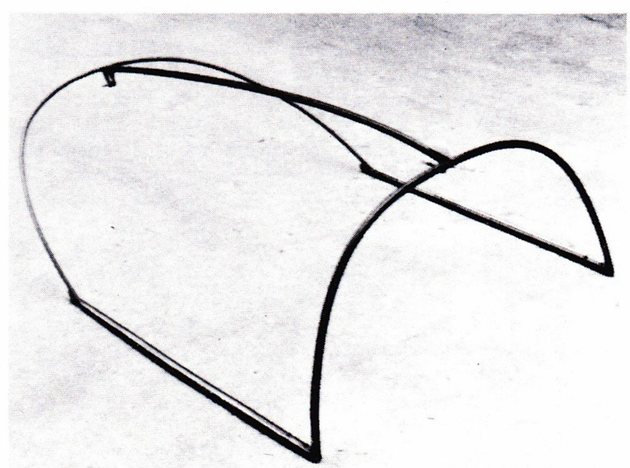
A more effective filler, of course, is any of the commercial bending alloys, CERROBEND, for example. These alloys have a very low melting point, some as low as 165° F. When this bending alloy is heated to its melting point it can be poured into the tube you want bent . . . sure, plug the bottom first. Cooling the tube in water will solidify the alloy and you are ready for the bending effort. After completing the bend, the tube has to be reheated to melt out the alloy. The material can be reused any number of times. However, since it is unlikely that most of us could find an economical source for a bending alloy, the sand treatment is and will continue to be the one most used by homebuilders.

More About The Bending Process

You cannot hurry your tube bending chore. It will ordinarily take much longer than you would expect. Allow yourself plenty of time for bends that do not have a uniform radius.

Most any bending device you use, with the exception of a template-like bending jig, will have a rather small diameter grooved pulley, roller or disc over which the tube will be bent. Obviously, you cannot bend the tube very much in any one place if your bend requires a radius many times larger than the bending device pulley. That means the bending process may become quite long as you have to bend a bit, check the bend in the tube against a template, etc. As an aid to checking the accuracy of your bend as you proceed, you should mark a center line around the tube to use as a reference mark keyed to your template. (Use a black laundry marker on aluminum tubes and a silver lead pencil on steel tubes.)

Do not forget to check the tubing after the bending is completed to be sure that it is not twisted, as viewed from the ends. Lay it on a flat surface for a quick check. If warpage is present, a twisting pressure in the proper direction will take out the warp. Recheck the tube's bend against the template again before congratulating yourself on a job well done.



The component parts for this canopy frame were bent around a 4" homemade aluminum pulley. The tubing was not filled with either sand or a bending alloy, however, the bends are probably the minimum radius possible without such a provision.

Push-Pull Tube Control System Installations

by Tony Bingelis

FIRST, LET ME set the record straight on one thing in the matter of push-pull control systems vs. cable control systems. Some very authoritative books and manuals state in absolute terms that the main disadvantage of using cables for control linkages is that their tension must be adjusted frequently due to stretching and temperature changes. This simply is not so . . . not in small sport aircraft.

I guess some expert, many years ago through logical reasoning, figured that such tension changes must take place in cables and duly recorded his conclusions as fact for posterity. In the years to follow, one writer after another perpetuated that same spiel as gospel.

However, I happen to have a personal acquaintance with one 14 year old homebuilt aircraft that has not had its control cables adjusted in all those years . . . nor has the need ever arisen. Another aircraft several years its junior likewise seems to defy the need for "frequent (or infrequent) adjustment".

Even though cable control systems are without this alleged fault, there are some aircraft designs that are better suited to push-pull control systems. Maybe yours is one of them.

Why Use Push-Pull Control Systems?

It is also said in those ancient tomes just referenced that push-pull tubes eliminate the problem of varying cable tensions (even if the problem is no problem . . . O.K.?). Anyway, one major attribute of a push-pull tube is its capability for transfering control movements through a single link (tube) positively and in direct proportion to the control input.

A single push-pull tube can transfer either tension or compression loads (stresses) whereas a control cable system can only handle tension loads.

It is well to reflect on the fact that, although individual cables are lighter than push-pull tubes, the cable systems, particularly in high wing aircraft, do require the fabrication and installation of many pulleys, brackets and guards. As a consequence, the cable installation tends to become heavier and more complex than you would expect. Additionally, the numerous pulleys and higher cable tensions generally result in a control system that may generate a need for heavy control pressures because of friction. On the other hand, push-pull controls are well known for their ease of movement so characteristic of friction-free push-pull systems.

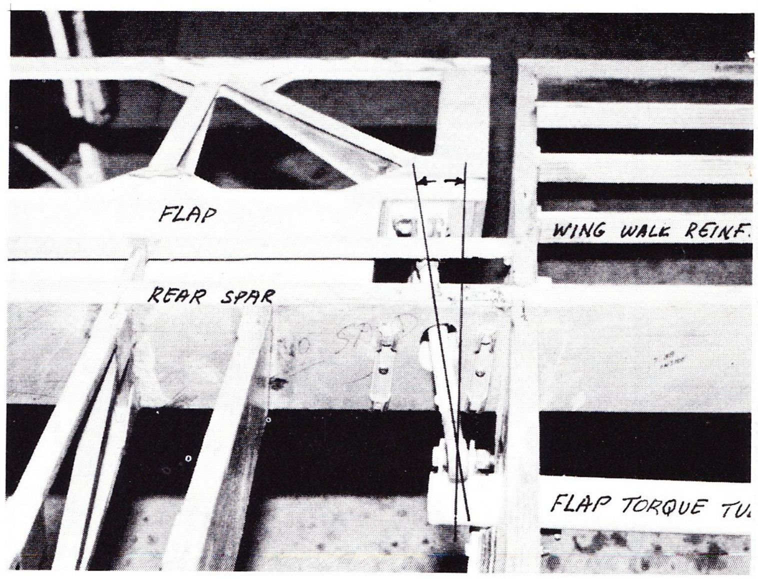
Where Can You Get Push-Pull Tubes?

Unfortunately, a homebuilder cannot go to one of his local discount stores and shop around for the correct length and size push-pull tubes . . . so, where do you get them? Outside of making them, that is.

Well, since we homebuilders tend to succumb to impulse buying and occasional scrounging, used push-pull tubes immediately come to mind. Where can you find used aircraft materials?

Outside of a lucky find at a builder-friend's shop, aircraft salvage yard, "Country Store or Fly Market" at a major fly-in, your chances of finding used push-pull rods suitable for your need is slim. Still, you may be able to bring home some push-pull tubes with rod ends on them that are exactly what you need except for their lengths.

One problem with most any used salvage or surplus tubes you may locate is that they will probably be very old . . . World War II stuff.



(Photo by Tony Bingelis)

Note the degree of misalignment possible in this push-pull tube installation. You should be able to rotate the tube slightly between your fingers . . . otherwise misalignment is too great.

Naturally, there is really nothing wrong with old WW-II tubes except that the grease in the rods will undoubtedly have become coagulated years ago and the bearings aren't functioning or they have a lot of drag due to that ungreasy grease in them.

Such bearings will have to be cleaned and rejuvenated (regreased).

Some aircraft supply catalogs list Bearing Regreasers that can do the job. A bearing degreaser is a small inexpensive device with a built-in grease fitting. The gadget is secured to a bearing and the old grease is purged out by forcing new grease through the bearing under pressure from a regular grease gun. Bearing regreasers cost less than most new bearings do. One catch though . . . each size bearing requires a separate size degreaser but they are well worth the few bucks that may be expended.

While it is true that there are still a lot of old World War II vintage push-pull rods and tubes showing up at the Fly Markets and Country Stores, not all of the old push-pull tubes you find will be that old. Due to production and design changes, aircraft companies scrap excess stock that often finds its way into homebuilder supply channels. These push-pull tubes are usually of good quality and are very attractively priced.

On the other hand, be careful to examine each tube closely for elongated or mid-drilled holes, poorly driven rivets, dents and other defects which may have been reason enough for its rejection in the first place.

If you cannot locate the exact length salvage tube you need, you could probably cut one down to the correct length. Since only one end has to be modified, this simple rework is an expensive way to get a needed tube. (See Figure 4)

I would point out, however, that it is difficult to impossible for most builders to match drill the rivet holes already drilled through the shank of the rod end fitting salvage from the cut-off end. You could, instead, disregard the existing holes and drill new holes through the tubing and into the rod end shank 90 degrees (perpendicular) to the original holes without weakening the rod end shank. Alternatively, you could install a new rod end terminal to replace the old cut-off one.

Avoid acquiring push-pull tubes with swaged or necked-down diameters on each end unless their length is correct for your purpose (most can be adjusted ½"-1"). They are more difficult to refit with a rod end after you have cut off one end that includes the swaged area. The reason, of course, is that you are left with the full diameter of the tubing and the original rod end will be too small for it.

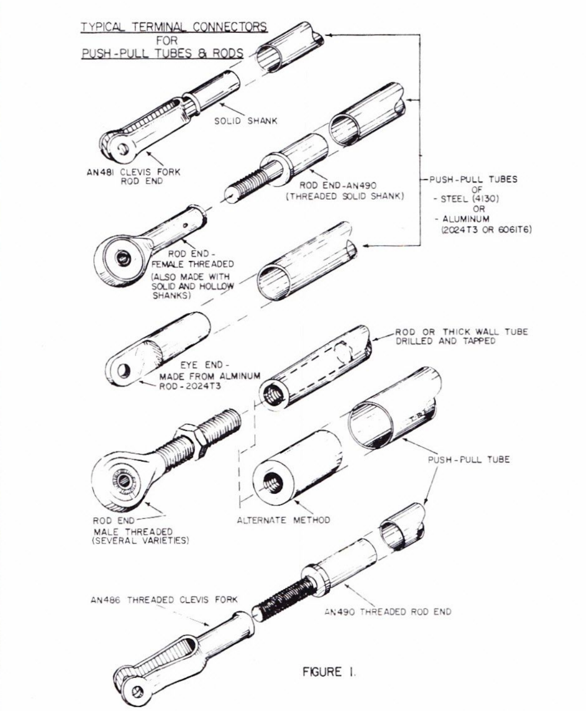


FIGURE 1.

On the other hand, there is no good reason why you couldn't make your own push-pull tubes and rods from new materials. It is a simple matter to select rod ends to fit a particular size of tubing because the catalogs generally provide this information. Incidentally, when assembling push-pull tubes, apply a wet zinc chromate film to the rod end shanks for corrosion protection.

How Push-Pull Tubes And Rods Are Assembled

This is covered in Figure 2.

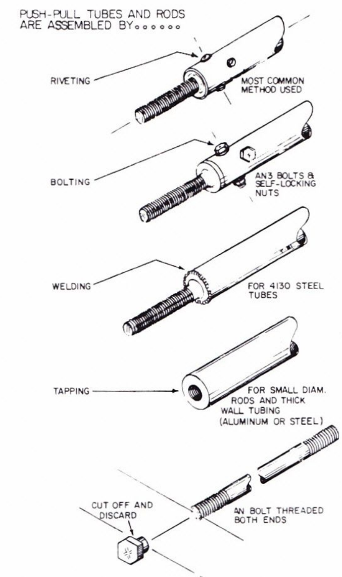


FIGURE 2.

Riveted Assemblies

Rivets are the most commonly used means for securing rod ends to push-pull tubes. Usually two rivets are inserted perpendicular to each other at each rod end. The rivets must be of aircraft quality (identifiable by the dimple in the rivet heads). Never, ever use commercial rivets in aircraft structural applications! They are too soft and too weak . . . and they are sure to fail you.

Rod ends with hollow shanks require extra care when riveting. That sort of riveting had best be done with a riveting gun as hammering the rivets down against a metal surface (or squeezing them in a vise) may collapse the tubing ends. Of course, rod ends with solid shanks can better stand hand riveting.

Bolted Assemblies

Another push-pull tube assembly method utilizes a couple of AN3 aircraft bolts secured with fiber lock nuts. I personally think bolts make an ugly push-pull tube terminal connection for smaller tubing sizes . . . one that is more apt to catch on some part of the structure and increase the risk of a control jam. Furthermore, a smaller diameter tube assembled with bolts is somewhat heavier than a similar riveted assembly.

Naturally, if a large diameter tube is being fabricated you would have no choice but to use AN bolts.

Some production aircraft (and homebuilt T-18s, I believe) use a rather large diameter thin wall tube (2" x .035") for the elevator linkage. Such a thin wall aluminum tube can handle the vibration and bending induced by compression loads and still provide a very light installation.

Welded Assemblies

Welded terminal ends for push-pull tubes are commonly used with steel tubes. The rod end to be welded to the tube should slip into the tube snugly. When ordering your rod ends, be sure they will fit the tubing you must use.

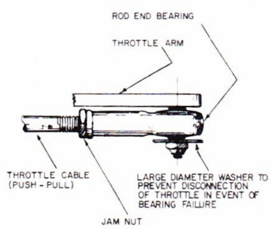


FIGURE 3

SAFEGUARD AGAINST THROTTLE FAILURE

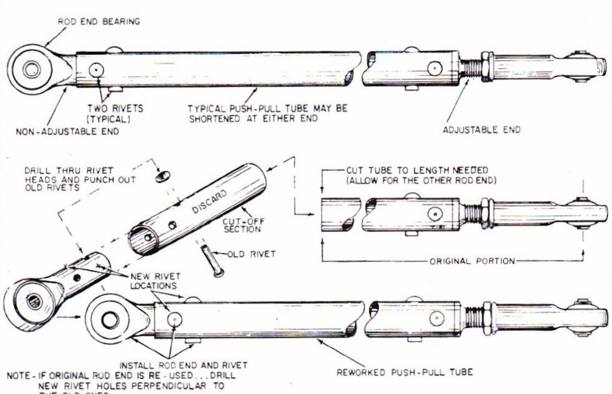


FIGURE 4.

OLD PUSH-PULL TUBES CAN BE SHORTENED

Threaded Rod Assemblies

Threaded rods (male and female) are most effective in shorter lengths. These push-pull rods may be aluminum or steel depending upon the design application. Short aluminum rods can be tapped to accept threaded male rod ends. Alternatively, short push-pull rods can also be made from standard AN bolts (1/4" or 5/6") of suitable length . . . simply by cutting the bolt head off and threading that end of the bolt. This fabrication method may be practical for push-pull rod assemblies not exceeding 8-9" in overall length.

One or both ends of a push-pull rod or tube may be made adjustable although it is a common practice to immobilize one end of the rod or tube. Still, with both ends adjustable you do have a greater range in adjustment should you need it.

Push-pull tubes are made of 4130 steel tubes or of 2024T3 aluminum tubes and are fitted on each end with rod end bearings or some other fitting. Sometimes a designer will designate 6061T6 for the aluminum tubing.

Remember that the maximum unsupported tubing length, diameter, wall thickness and material specification are an engineering determination and should not be left to an "I guess that's good enough" eyeball design evaluation. You had better know what you are doing when you make and install a push-pull tube (for the elevator control as an example). Due to its rather long length it might lack sufficient rigidity and flex excessively under higher control surface loads. Furthermore, the effects of vibration on tubing as well as the connecting linkage must be considered.

Installation and Adjustment

Rod end bearings have been known to literally come apart after the peening retaining the ball races somehow failed allowing the bearings to become disconnected. This sometimes happens at the throttle control linkage at the carburetor. It is a wise builder who takes the precaution of installing a large diameter washer between the nut and the bearing to prevent its total failure. To be successful in preventing this type of failure, the washer must have a diameter somewhat larger than the hole in the bearing flange (see Figure 3).

When you install a rod end of the self-aligning type bearing, you must be able to see or at least detect a slight movement in the push-pull tube or rod when you rotate it between your fingers. Check for this freedom of motion in both extreme control positions.

A self-aligning rod end will accommodate quite a bit of misalignment but be sure you do not exceed its limits. See the photos for an example of where a deliberate misalignment may be necessary in a push-pull tube installation.

The maximum angle of deflection or misalignment will be reached when the outside diameter or the rod end's head touches the side of the fitting, fork or clevis in which it is bolted.

To obtain the maximum benefit of a rod end bearing, its inner race must be securely clamped to the attaching fitting or structure otherwise the bearing action may not be activated and the rod end could, instead, rotate around the bolt.

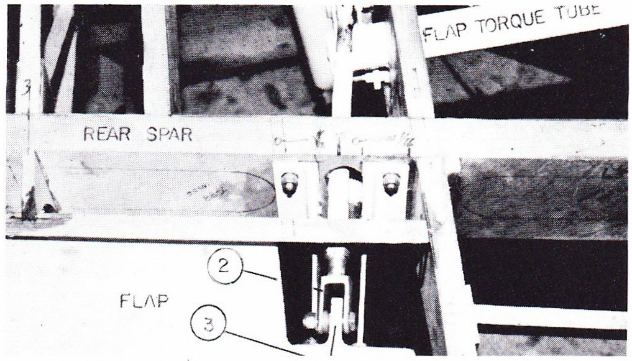
Push-pull tube actuated bell cranks (and similar push-pull tube linkages) must be limited in travel to prevent an inadvertent "locking" or jamming in an extreme position or by being rotated past center. In addition, push-pull controls should have positive stops built into the system at both ends to limit the travel range of ailerons, elevator and rudder. One of the stops may be located at the control surface.

For That Final Inspection

After you have completed your final installation and have adjusted the linkage to obtain the required travel and proper control surface alignment, check to see that each threaded rod end is screwed into or onto its mating terminal sufficiently to engage at least 3/8 to 1/2" of the threads. Rod end bearings with internal threads will have a small inspection hole through their shanks. The mating terminal ends should always be screwed in far enough that a test wire probe cannot be poked all the way through the inspection holes.

Each end of a push-pull tube with an adjustable end fitting should be safety-wired or locked securely with a thin jam nut (checknut) snubbed up against the rod end to keep it from unscrewing.

Activate all push-pull control system assemblies through their entire range of movement to be sure that none of the tubes exhibits even the slightest binding or frictional resistance throughout the entire range of movement. Be sure there is no play in the terminal fittings or in the rod ends — and if you treated your push-pull tubes gently during installation you will have avoided scratching or denting them and the installation should look as good as it works.



(Photo by Tony Bingelis)

A typical push-pull tube installation. This one is fitted with a self-aligning rod end (1) bearing on one end and a fork fitting (2) on the other. Flap hinge (3) has a built-in uniball bearing.

CG LIMITS

. . . from page 81

flection is greater than that required at higher altitude because the ground effect reduces the downwash at the tail, requiring more up elevator to maintain equilibrium. The reduction in downwash also increases the lift on both wing and tail.

When the CG is located at the forward limit established by this second method, the elevator can develop just enough downward lift to bring about a stall at minimum speed during landing. If it is ahead of this point, hotter landings will result.

It is advisable to allow a margin of elevator travel over that required to develop maximum lift in ground effect to be available for flare-out. This margin is usually about five degrees up elevator.

The range of CG desired, therefore, establishes the size of the horizontal tail and elevator. It follows that the wider the range, the larger the tail. The single seat airplane can thus have a smaller tail than an otherwise similar four-place craft.

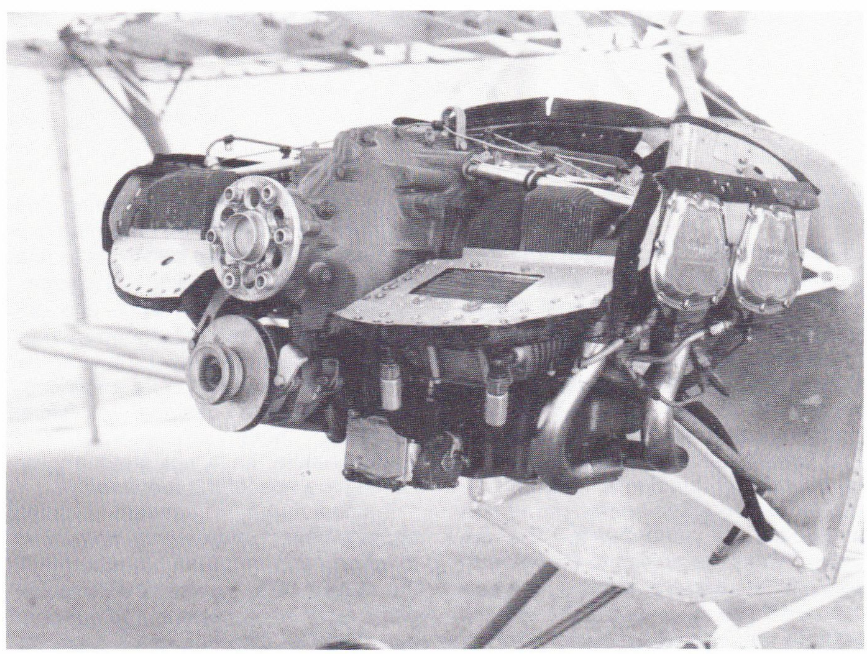
The foregoing discussion is limited to the case with the stick-fixed and with the propeller windmilling. It also disregards the effects of vertical CG location on longitudinal stability.

Allowing the elevator to float freely can have either a stabilizing or destabilizing effect, depending upon whether the elevator floating increases or decreases the restoring moment of the horizontal tail.

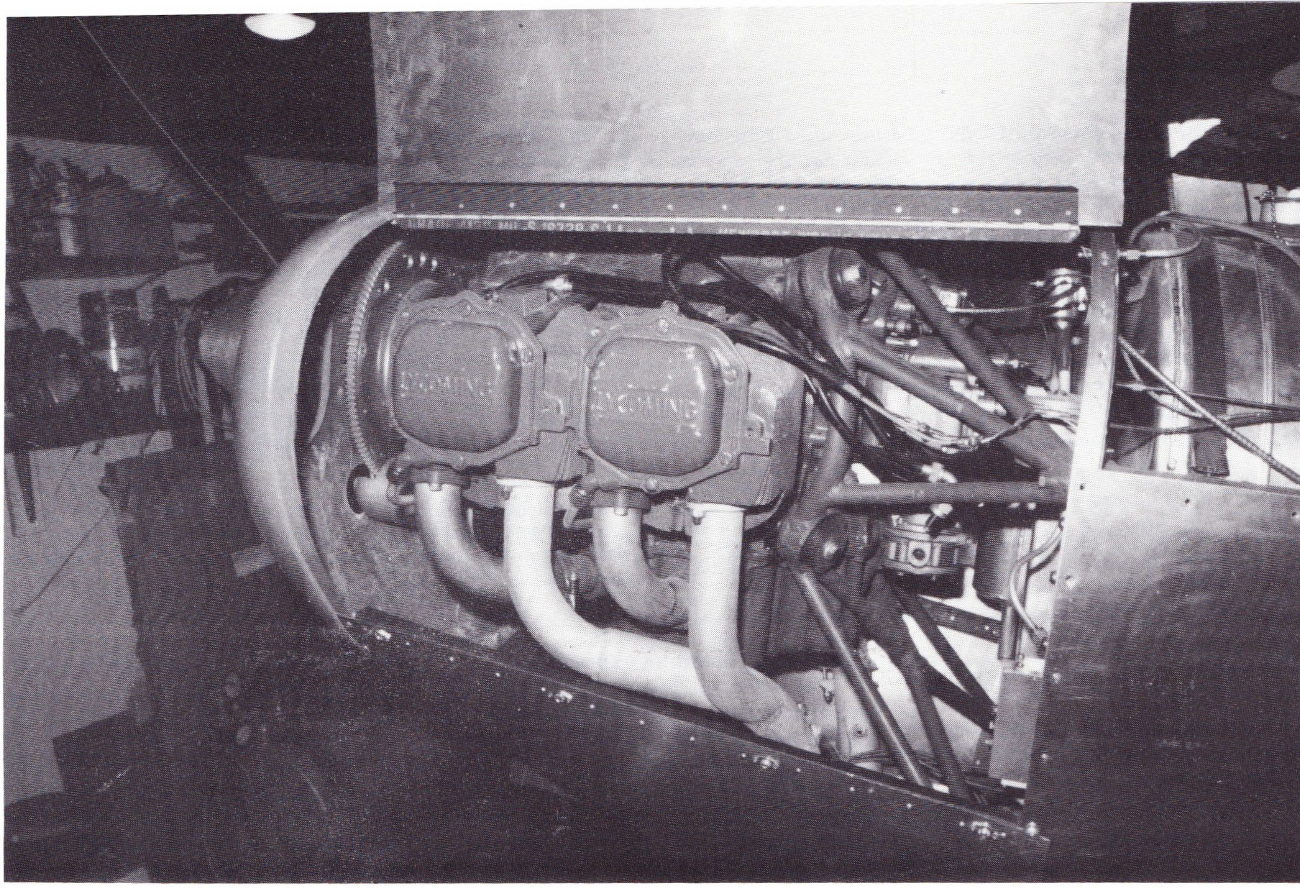
A running propeller can have a profound effect on longitudinal stability and equilibrium. The effect is destabilizing and thus the neutral point is farther forward for power-on conditions. Usually a margin on the aft CG limit is allowed for power effect. The magnitude of this margin can be determined by wind tunnel tests or by judgement based on experience.

The vertical location of the CG relative to center of lift also affects longitudinal stability. On a high wing monoplane that has the CG located below the aerodynamic center, an increase in angle-of-attack causes a diving moment about the CG. This adds to its stability. The opposite is true when the CG is above the aerodynamic center.

All this theory won't give the novice designer enough information to calculate exact CG limits, but it should make him aware of the importance of CG location. The safest practice for conventional designs is to locate the CG for the initial flight test as near the 25 percent chord point as possible. Then by gradually and systematically moving the CG with sand bags, determine the rear limit where the ship will fly hands-off and the forward limit which will permit good landings. If your loading requirements demand limits which do not fall inside those determined by flight tests, you will need to make design modifications, add ballast, or place added restrictions on loading. Since all of these solutions are undesirable, the novice should certainly seek the assistance of an experienced designer if his planned CG range is large, such as in a multiple passenger design.



Lycoming engine installed in an Acro Sport showing dynafocal motor mount. Note baffles — which are an integral part of any engine installation as they are vital to providing proper cooling for maximum engine efficiency.



Engine compartment and cowling of Acro Sport built by Warren Curd and Dick Browne.

Cowling and Cooling of Light Aircraft Engines

HISTORY

Although the Wright brothers' first flights in December 1903 were with a liquid-cooled engine, the light weight advantage of direct air-cooled engines has been apparent almost from the first.

Most light airplanes down through history have been powered by air-cooled engines, and it is safe to assume that virtually all have been plagued by some cooling problems. This is because cooling takes engine power that is needed for performance. The designer wants the engine in his plane to cool, but because he wants all the performance that he can get, he will not tolerate any unnecessary allocation of cooling power.

Available engine power, on the other hand, is intimately tied to cooling and the output of a given size of engine has increased at about the same rate as has the improvement in cooling technology.

Both airplane performance and engine service life are influenced by how well the designer solves the cooling air flow problem. It is all too frequently apparent that the designer of small airplanes, both professional and amateur alike, have not given engine cooling the attention it requires.

Technologically, current small airplane powerplants may be compared to military and air carrier powerplants of the middle 30's. Economics will place some technical aspects out of our control. However, there is much room for improvement. Many of the techniques advocated by researchers of 30 years


John Thorp and his Sky Skooter.

Photo by Norm Petersen

Age old open cowl of J-3 Cub has cooled engines for fifty years but has also slowed them down as the drag is very high for this cooling system.

ago for the improvement of the then current military and transport powerplants are applicable to little airplanes of today. We can do well to review the earlier works of Weick, Biermann, Schey, Brevoort, Campbell, Pinkel, Stickle, Silverstein, Manganiello, Theodorsen, Taylor, and others on this subject.

What is Cooling?

Waste heat from the combustion process is conducted through the cylinder wall material to the outer surface of the cylinder where, in direct air cooling, it is wiped off by cooling air flow.

To reduce the quantity of air which would need to flow past the surface to hold temperatures to acceptable structural limits, fins which increase the radiating surface of the cylinder are used. Fin proportions have more often been dictated by manufacturing considerations than by cooling needs. The problem is to get enough cooling air in contact with the cooling fins to hold temperatures within acceptable limits without consuming a disproportionate amount of cooling horsepower.

Before and during World War I, when airplane speeds were low and the problems of manufacturing adequately finned cylinders were mainly yet to be resolved, engine rotation was employed to provide windage to insure contact of cooling fins with enough cooling air. The rotary engine cools almost as well running on the ground as it does flying, and offers a number of other intriguing advantages.

Unfortunately, rotating such a large mass of intricate machinery brings in many other problems and, except to antique fans, the rotary engine is now only a nostalgic memory.

The motorcycle approach of leaving unbaffled cylinders out in the air stream was used for some time . It is intriguingly simple, but the need for more performance through increased engine power and lower powerplant drag pretty well rules out this system for modern design.

Most contemporary light airplane cooling systems may be characterized as having an internal flow system, in which the finned cylinders are bathed, and an exterior shape more or less conforming to the requirements of the airplane's exterior contours. The power requirements to provide adequate internal flow should be as small as possible, at the same time, the exterior shape of the cowled engine should offer little or no more drag than that portion of the airframe which it replaces. These then, along with good engine operation and adequate service accessibility, are our objectives in powerplant design.

What does Cooling Cost?

For current contemporary unsupercharged light air-cooled engines used in most small airplanes today, about 20 cubic feet of air per minute is required to cool to acceptable temperature limits each brake horsepower being used. For cylinder finning, as we know it today, this amount of cooling air-flow will provide adequate cooling and provides us with a simple index to design or evaluate a light airplane powerplant.

If the sum of all of the open areas between the fins of an air-cooled cylinder, capable of putting out 25 horsepower per cylinder, added up to 8.2 sq. in., and we flow (20 × 25) 500 cubic feet of air per minute through the fins, the velocity through the fins will be 144 × 500/8.2 = 8800 fpm = 100 mph = 147 fps.

Most small air-cooled engine cylinders will have about 8.2/25 = .325 sq. in. of fin passage area per horsepower, and to flow 20 cfm/hp will require approximately 100 mph through the baffles. If the passages are smaller, the velocity will need to be higher. If the passages are more generous, the velocity can be proportionally less.

We now have an index for proportioning all cooling air-flow passages. For conservation of energy, we would like to keep the velocity through the system constant at all points. This is not possible, but at least at 100 mph, all passages should have an area of approximately .325 sq. in. hp for most engines that we will be using. This index can be refined for a specific engine by determining actual passage areas and later correction factors for inlets and outlets will be discussed. At least, we know that the cowling inlet and outlet for a 100 hp airplane climbing at 100 mph will be approximately 32.5 sq. in. in area, and climbing at 65 mph they should be more like 50 sq. in.

Knowing the cooling air-flow quantity and velocity, we can calculate the power required to cool.

Photo courtesy of Bruce Stainbrook

Very neat opening on Bruce Stainbrook's Avid Flyer provides cooling air for the Cuyuna 430 and exhausts out the lower gill.

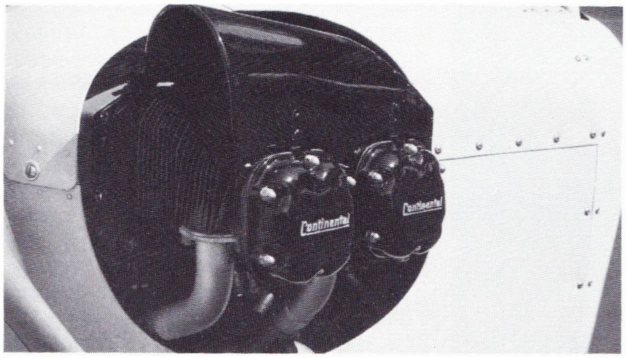
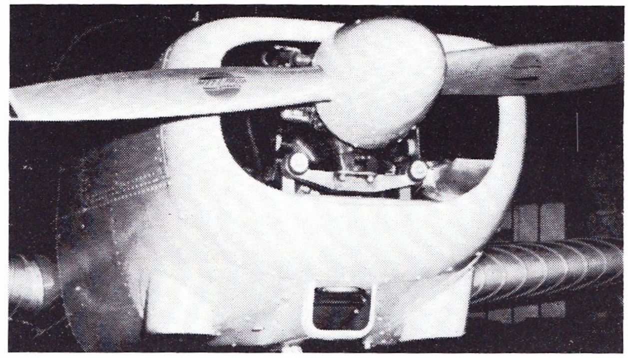


Photo by Norm Petersen

Eyebrow type of airscoop builds airpressure to force cooling air down past the cylinders. This very sanitary installation is on the Rag Rose by Ted and Sharon Travis, Flushing, MI.



Leo J. Kohn Photo

An improvement over the previous arrangement, the modified "Sky Skooter" employed many new ideas in cowling and augmentation.

If the total dynamic pressure associated with the required velocity through the fins is dissipated in producing the required air-flow, a simple calculation shows a sort of idealized minimum cooling power requirement.

HP = DV/375 where:

D = qA and

q = .00256V (2) = Dynamic pressure

A = Passage area in sq. ft.

= .325/144 = .00226 sq. ft., per hp 100 mph

HP = .00226 x 25.6 x 100/375 = .016 or 1.6 percent of total hp required to cool at 100 mph velocity through the baffles.

Actually, we never do nearly this well. In the first place, the power is put into the airstream by the propeller, which is 50-60 percent efficient in a climb to possibly 80 percent efficient at high speed. Then we have the inlet orifice efficiency, upstream duct efficiency, baffle efficiency, downstream duct efficiency and outlet gill efficiency, each a multiplying factor less than unity to reduce the overall efficiency.

We know of some fan-cooled air-cooled engines that cool for 5 to 6 percent of engine output. Some helicopters are fan-cooled for 8 to 10 percent of engine output.

The best ram-cooled air-cooled engines in a fixed-wing aircraft that we know of cool for 8 to 12 percent of the total power available.

If this is the best that can be done, then it takes little imagination to see poorly designed and executed installations taking twice this amount of power to cool.

If external protuberances to the cowling of a 100 hp airplane add only a half-square foot of drag area, we soak up about 4 percent more power in climb and as much as 16 percent at high speed.

Paradoxically, the cleaner we make an airplane design, the larger percentage of cooling horsepower becomes.

On a 1930 biplane design, it was acceptable to leave the cylinders exposed. The Beechcraft "Bonanza" has very low cooling drag, but on such a clean airplane, the state of the art in powerplant design is not consistent with the refinement of the rest of the airplane. On some otherwise clean airplane designs, the powerplant drag (cooling and external) may account for 30 percent to 50 percent of the airplane drag and power required. No wonder airplane designers frequently miss achieving performance expectations. Refinement of powerplant installation on a clean airplane is worthwhile. Conversely, on a dirty airplane it may not pay off. If your airplane design is otherwise already refined, what area of improvement offers such large rewards?

What are the Elements of a Cooling System?

The elements of a conventional direct air cooling system as applied to a small airplane may be generalized as follows

The original Thorp "Sky Skooter" featured an engine cowling which, while conventional in its louvre openings, was exceptionally clean.

Photo by Norm Petersen

Canadian registered Bushmaster utilizes a small opening on each side of the gearbox on the Rotax engine. Cooling air is exhausted from a gill on the bottom of the cowling.

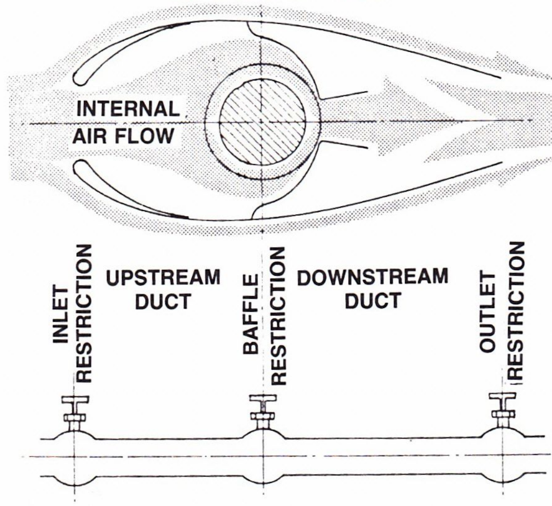


FIGURE 1

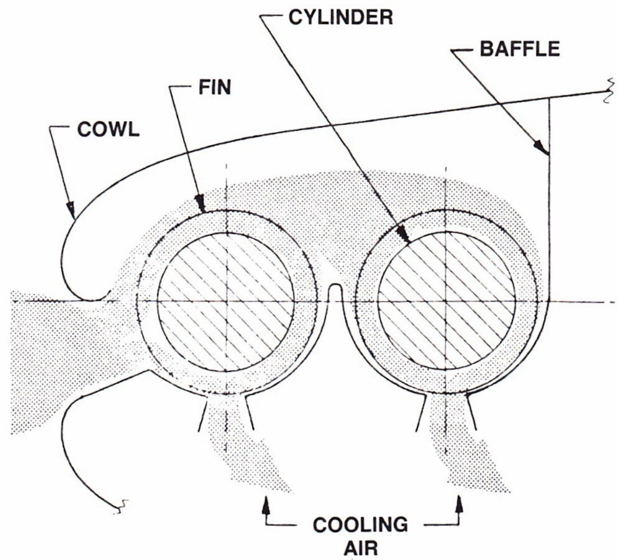


FIGURE 2

(see fig. 1). The internal flow system is analogous to a hydraulic system with three valves and two connecting pipes.

The resistance to fluid flowing through the hydraulic system is equal to the sum of the resistances of the inlet valve, plus that of the pipe to the baffle valve, plus the resistance of the baffle view, plus the resistance of the pipe to the outlet valve, plus the resistance of the outlet valve.

The total internal flow drag of the cooling system is the inlet drag, plus the upstream passage drag, plus the baffle drag, plus the downstream passage drag, plus the outlet drag.

It is obvious that closing any one valve or collapsing either pipe will completely stop all hydraulic flow. Just so with the air.

Also, it may be seen that the resistance at any part of the passage will have an effect on the total flow, and therefore will have an effect on the flow resistance of each of the other parts. This is also true with an air cooling system. If we restrict the outlet, all internal flow will decrease, and the drag of upstream elements will reduce. One of the functions of cowl flaps is that of a valve to reduce cooling air-flow, and drag when the speed is increased and therefore need for cooling is reduced. If cooling fins are small, resistance at the baffles will impede cooling air-flow regardless of inlet or outlet conditions. If the inlet is too small, or in unfavorable flow location, nothing done to baffles or outlet will have much effect on cooling.

The five-series resistance system analogy is, of course, an over-simplification, but it is a useful concept in analyzing cooling system problems.

Possible Areas of Powerplant Improvement

All refinement of an air-cooled powerplant installation will start with the baffle.

Leaks in the baffle area will mean that the cowl inlet and outlet will flow more air with attendant power consumption, with no improvement in cooling. Non-cooling air-flow in most powerplant installations will nearly equal the legitimate cooling air-flow. Air that does not flow through fins or a radiator is wasted air-flow for all practical purposes. Seal up the gaps and make baffles fit tightly against the cylinders, at least at outlets.

NACA L-767, issued originally as advanced restricted Report 3H16 by Silverstein and Kinghorn, shows means of improving baffle design. These baffles will reduce cooling horsepower required for a given level of cooling over those normally used on light aircraft.

When applied to one bank of a four-cylinder engine, these baffles might look like fig. 2.

These baffles accelerate the air as it flows through them. Cool air is entrained with the hot, and the turbulence produced minimizes pressure losses at the baffle outlets.

No part of an airplane is subject to more conflicting design considerations than the nose cowling of a contemporary small airplane. As a generalization, it is probably safe to say that the inlets are of the wrong size and in the wrong location. This is because no single fixed inlet can be ideal for such a range of angles and velocities. To make things even more difficult, the propeller in front of the nose cowl stirs up chaos in "big gobs".

Nose cowls tend to be blunt because engine makers put the front cylinders right up as close to the propeller plane as it can be placed. The blunt nose cowl stops most of the air in its tracks. It is then given rotational velocity by the "clubby" shank of the propeller. Centrifugal force due to rotation gives it outward velocity so that some of the ram pressure recovery of the cowl inlet is lost.

Also, most inlets are near the top of the cowling for baffling convenience. At high angles of attack (climb conditions where cooling is critical) flow over the top lip of the cowling is accelerated, reducing pressure and, in some cases, causing the air to flow out at the top instead of in. Evidence is pretty clear that the cooling air inlet or inlets should be below the center line of the propeller for maximum inlet pressure in the critical climb condition. Probably a better than conventional arrangement would result from having two inlets 120 degrees apart below the center line of the propeller, and with this use a three-blade propeller. This way both inlets would be subject to a pressure rise due to blade passage at the same time. The result would be increased baffle flow where, with a two-blade propeller the pressure rise in one inlet would cause out-flow of the other.

A single low inlet is probably a good compromise arrangement for a two-blade propeller if the inlet width can be relatively narrow and with sufficient volume behind it in a plenum chamber so that the inward flow, due to a passing propeller blade, does not turn around and come out again before the next blade causes another pressure rise.

With a long propeller shaft, a single low inlet, which takes no gain from pressure rise due to blade passage, and which is outside the influence of pressure reduction due to propeller shank windage (rotating air mass), is probably a good choice. However, this is only true if the extra distance of air travel and extra turns are not excessive.

The low opening with up-cooling air-flow, as used on early "Navions" and "Swifts", would have been more successful if it had not been for the exhaust stacks which thoroughly heated cooling air before it got to the cylinders.

Up-flow cooling has other problems, but just considering the air inlet alone, the early "Navion" cowling was one of the best yet devised for a horizontally opposed light airplane engine. A large diameter spinner covering much of the non-effective propeller shank will minimize the out-flow propeller problem. A propeller spinner must be carefully designed or it will introduce service problems out of proportion to cooling and drag benefits.

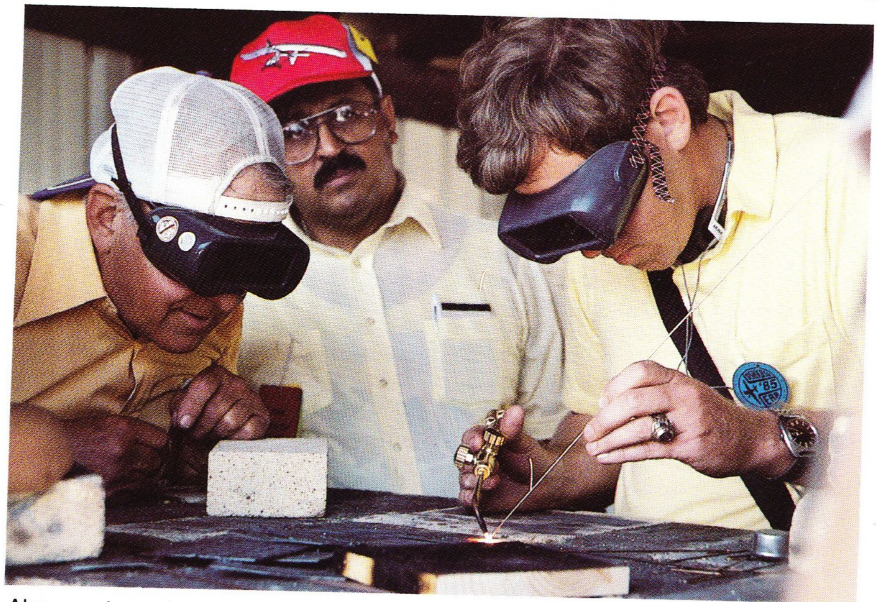
The cooling air-flow outlet on most small airplanes shows little design consideration. It is almost as though just before first flight someone decided that cooling air had to get out, and obliged by snipping out a hole in the bottom of the cowl. The outlet is in the bottom usually to serve the dual purpose of allowing for drainage of engine oil seepage. Since heat rises, it would be easier to get it out the top. Of course, no one relishes the thought of oil on the windshield, and if the outlet were just ahead of the windshield the pressure build-up in front of the windshield would reduce the desirability of the top outlet anyway. However, for engine nacelles on wings, there seems to be little excuse for not having the cooling air outlet at the top of the cowl.

Outlets at the sides and bottom of the cowling can be improved by bringing cooling air-flow out parallel to the slipstream instead of perpendicular to it. Openings should be of an area to bring cooling air velocity out at airplane velocity at some airplane speed where drag should be at a minimum.

If all little airplanes had a speed for best climb of 100 mph, much of the difficulty of designing a good outlet would disappear because the ram alone at 100 mph will cool contemporary opposed unsupercharged light airplane engines, and the outlet would only need to get air out smoothly.

Because most light airplanes have their speed for best climb (critical cooling condition) at something less than 100 mph, ram pressure will be less than the usually required 5 in. of water pressure difference between upstream and downstream side of baffles, and less than atmospheric pressure is required at the cooling air outlet to make up for ram deficiency. Low pressure is usually produced by accelerating the air flowing over the outlet to something more than free stream. To many aerodynamicists, the flare on the cowling outlet gill is anathema. It does for sure increase the drag of all parts of the airplane downstream by causing many of them to operate in turbulent, if not separated, flow. It is not so sure that it will produce the required low pressure, because separated flow is largely unpredictable, and frequently a high pressure wake will show up just where the pressure needs to be low. A smooth curve on the gill to accelerate flow is forgivable, if this is the only way that the required baffle pressure can be attained. The usual stalled flap on the outlet is nauseous. Real performance gains may be had just by eliminating it.

To summarize this all, engine cooling is more important than many builders realize. It is the one item that is frequently overlooked, but many times could be the answer to solving performance problems. When you're building and designing your light plane, keep engine cooling on your mind. And, as you're designing your cowl, remember it has to do more than just look pretty and add to the aerodynamic flow of your machine — it has to provide for cooling air to the engine at the same time.



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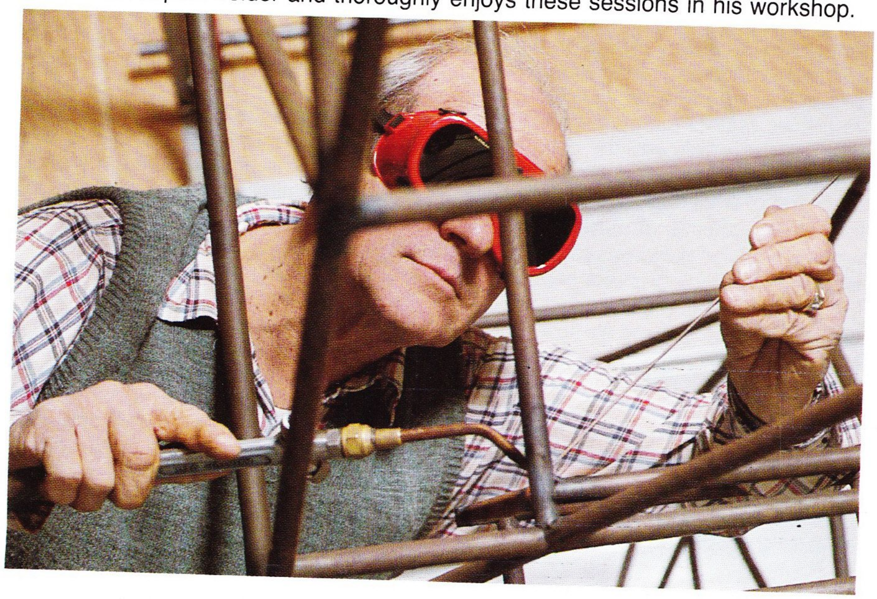

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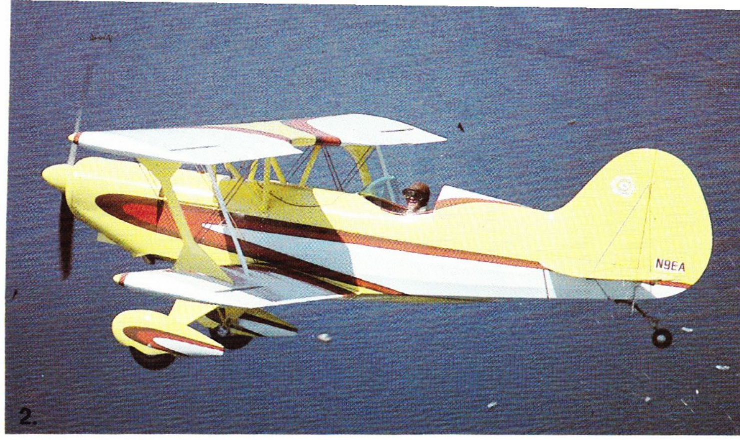

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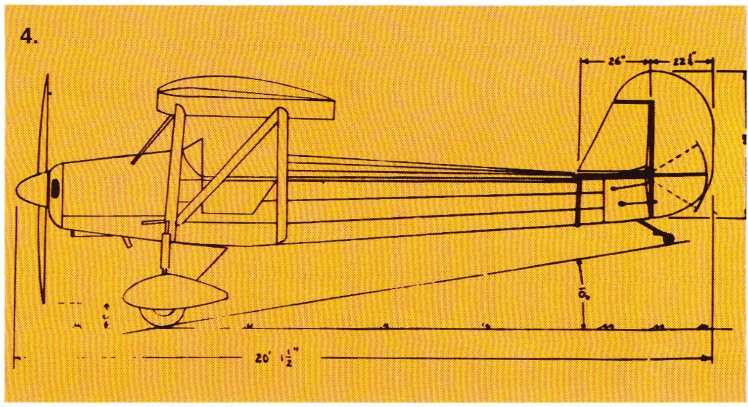

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