Wire Termination and Connectors

I have been putting off writing this section until last; having difficulty coming up with the best words to describe some things that really need to be shown in pictures and/or demonstrations. We spent some of your subscription money last week on an accessory for our cameras; a bellows attachment that let us do some really close up photography on some small subjects. We're planning a series of slides for the seminars at Oshkosh '89 to show HOW TO and HOW NOT TO terminate wires. The needed details are beyond our present illustration capability and we're not set up yet to include photographs in this publication. So, until the photographic update of this section is in print, we'll take a whack at it with our best command of the King's English. . . . .

The act of reliably connecting a wire to another wire or to an electrical component is probably the easiest task to accomplish in your wiring installation. But until you understand what you are trying to accomplish and master a few techniques for doing it, it's easy to make joints that come apart; usually at inopportune times! There are three requirements for making the lasting connection: first, the connection must be electrically sound. Second, the joint must be mechanically secure. Third, unless the metallic conductor exposed in the process of making the joint is located in a very benign environment it must be protected from the environment.

All of you have probably seen the crimp on terminals that are sold in virtually every hardware and automotive store. A plastic case containing an assortment of terminals along with a crimping tool can be had for a few dollars. And, if you understand how they can be properly applied, even these el-cheapo tools and their terminals may have application in your electrical system installation. You may also find yourself faced with terminating a bundle of wires into a connector of one or more pins that mates in turn with one of your system's components. Strobe light power supplies come to mind as an example. Certainly, your avionics black boxes will have multi-pin connectors on the rear which you will have to deal with. Many times these units will come with some verbal or illustrated instructions for the application of connectors, but more often they do not. They were originally marketed to the aircraft manufacturers and fixed base dealers who, after they had fotched up their first few installations, presumably learned how not to fotch up the rest of them. Since many of you are only going to want one shot at this, let us see if we can do it right the first time!

The one thing you never do is wrap the end of a stripped wire around a threaded shank and mash it down under a nut or head of a screw! This may meet the intent of rule #1 for awhile but it misses #2 badly. I had a boss who told me once that ten "attaboys" in a row would get me a raise but that one "awshit" would wipe out all of the "attaboys" you had saved up and you had to start over. So in keeping with the spirit of collecting only attaboys, let's make connections that don't break off under stress and vibration a month after the airplane is all buttoned up.

RING TERMINALS FOR SINGLE STRANDS - SOLDERED

The only way to go to any threaded post with a wire is with a ring terminal soldered or crimped on the end. Solder? Did I say solder? I remember my first lesson in soldering. I was spending the summer fresh out of the third grade with an uncle who possessed an electrical engineering degree and was an employee of the local power company. He empathized with my interest in electronics although it was a long way from his particular field of expertise. I remember looking at a construction article, I think it was a one-tube radio in one of the Boy Scout publications; a merit badge project. I had been scrounging parts (albeit some incorrect or defective) and I was short the tools and skills to solder the stuff together. Uncle Bill got out his trusty 250 watt electric iron (about the size of a policeman's billy club) and a roll of solder. The solder was about the size of 10 gauge wire. He showed me a text book he had on the subject; the pictures gave step by step instructions for splicing and insulating house wiring and wires on power poles! We spread out on the basement floor and proceeded to stick the things together. It didn't work when I finished it but it didn't matter. Uncle Bill seemed satisfied enough with my performance that he allowed me to use the tools solo. Thus began my experience with a new technique. It was many years later before I truly understood the stuff and became really proficient with it. I now possess at least six different kinds of soldering tools and three or four different kinds of solder. Let me share some of what I have learned with you here and perhaps we can cut several years off of your learning curve.

Soldering, unlike welding, is a means for making a metallic joint between two metals made up of possibly different alloys using still a third alloy, the solder itself. Solder obviously melts and flows at temperatures much below the melting point of the metals being joined. Welding involves heating the two parts to be joined up to their melting points and then filling the gap with a filler rod of the same material. Solders are available in a variety of alloys for specialized tasks but the solder we are going to need is made from tin and lead. If you visit a well stocked solder supplier, you can find solder in bars, sheets, wire ranging from cat whisker thin to perhaps 1/2" in diameter and powdered. The ratio of tin to lead may vary from 5 percent tin/95 percent lead to perhaps 70 percent tin/30 percent lead. You may even find special solders with a little silver, bismuth or antimony in it. That just covers the metal aspect of solder, then we get into fluxes. Flux is used to break down the oxides (rust or corrosion) of the metals to be joined to make clean bare metal available to the molten solder. Fluxes also are used to coat the surface of the molten solder and keep it from oxidizing too. All metals react more readily with the air as their temperatures are increased in the soldering procedures. There are dozens of fluxes for soldering of various materials in as many different applications.

Now, just what is it that the solder does? It is not a glue or adhesive. Nor does it make connection by simply surrounding and gripping the materials to be joined. Solder achieves connection by actually dissolving a small quantity of the base material into itself. Think of solder as a solvent for solid copper. If you were to make a micro cross-section of two wires twisted together and then soldered you will get a situation which is depicted in Figure 9-1. Note that in the interface between the tin/lead solder and the copper wire, there is a region where a small amount of the copper has actually become dissolved into and alloyed with the tin/lead solder. This layer isn't very thick because as the copper migrates into the solder, it alters its alloy and raises the alloy's melting temperature. So, the hotter the iron you solder with, the deeper the copper penetrates into the solder but at most the interface is only a few molecules thick!

Let's look at the topic of melting point for a moment. Figure 9-2 shows the nature of solder's melting point as its alloy is varied. The figure also depicts another characteristic of the various alloys of solder. Notice that an alloy of 63% tin has the lowest melting point of all the tin/lead solders. Note also that with all solders other than 63/37 there is an intermediate plastic phase between the liquid and solid phases. This 63/37 ratio is known as a eutectic alloy; it has little or no plastic range in the transition from liquid to solid upon cooling. Ever heard the term "cold solder joint"? What is being described is a joint wherein the solder has a dull gray crystalline appearance; is weak and almost literally crumbles when stressed. The way that the joint got that way was because of two factors: First, a non-eutectic alloy of solder was used. Second, the joint was moved while the solder was in the plastic range as the joint was cooling. Solution to the problem? Use the right kind of solder. For most of your applications, an electronic grade solder of 63/37 alloy, 0.062" in diameter and having an active, non-corrosive flux is recommended. Spend the few extra bucks and get a good name brand, my own personal favorite is 63/37 Kester Resin "44" in an 0.032" diameter. It might seem expensive at about $8 per pound but a pound will last you a long, long time and the quality is unquestionable. I've used the Ersin Multi-core electronic solders with pleasing results too. However, whichever solder you choose 63/37 is the MAGIC number to insist on.

The melting point figure also illustrates the phenomenon I mentioned earlier about the alloy shift raising the melting point as the copper molecules begin to dissolve into the molten solder. Note that as the alloy shifts away from eutectic, not only does its plastic range grow wider, its melting point increases as well. A little bit of copper causes the melting point in the solder/copper interface to take quite a jump thus preventing the wire from dissolving completely into the molten solder. Neat, huh? What are all the other kinds of solder for? Well, in my younger days it was a big deal to remove all the chrome from your car and fill in the molded channels with a material called body solder. In this case, the body man needed a very wide plastic range so he could sculpture with it. A 30/60 alloy was more to his liking. Eutectic solder would have been totally useless for this application! Here is an opportunity for a high tech practical joke, slip a bar of 63/37 into a body man's tool box. He'll go nuts trying to mold the stuff into any kind of shape! Just about the time it starts to soften it'll fall on the floor.

Now, as you make perfect joint after perfect joint with the right kind of solder, you can imagine all those little molecules of copper swimming out into a rapidly thickening quagmire of molten metal. You'll also know that the probability of a "cold" joint is almost zero as the joint cools.

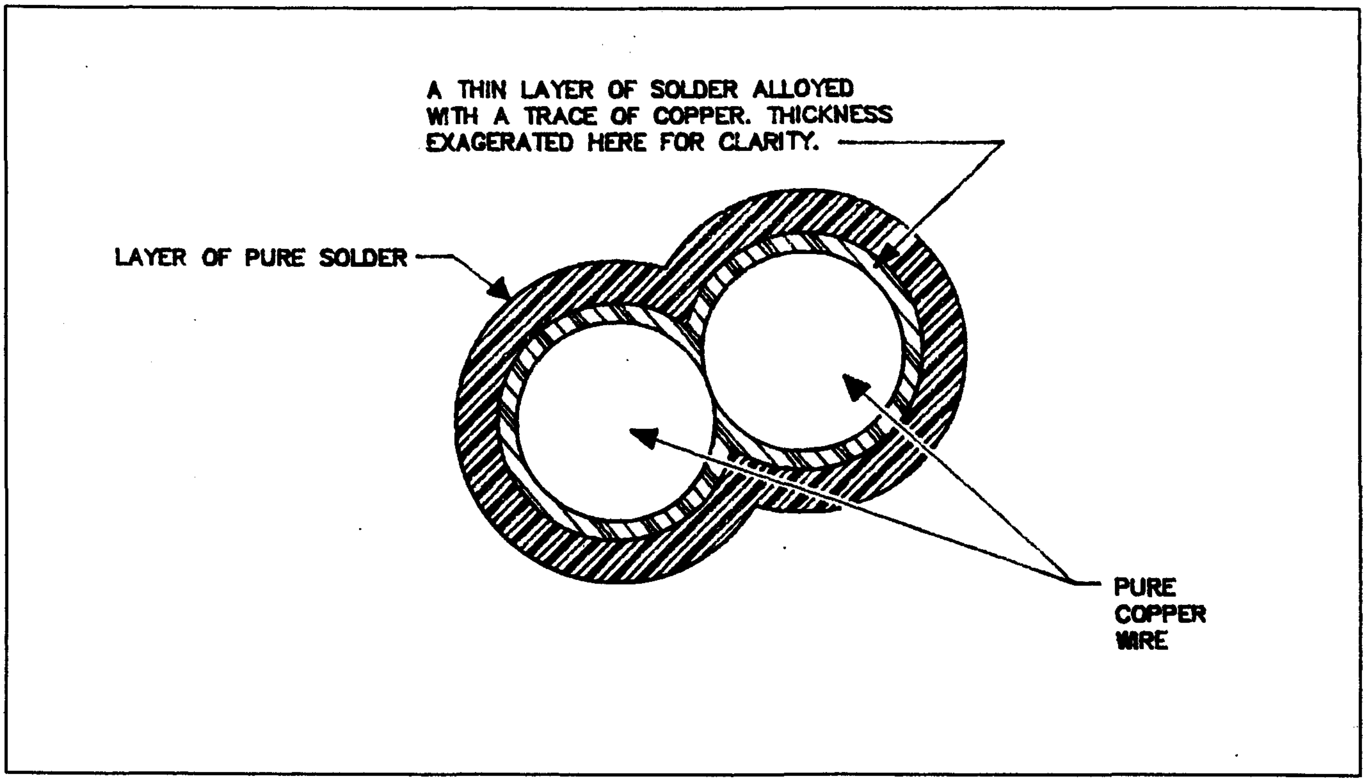

Figure 9-1. Anatomy of a Soldered Wire Joint.

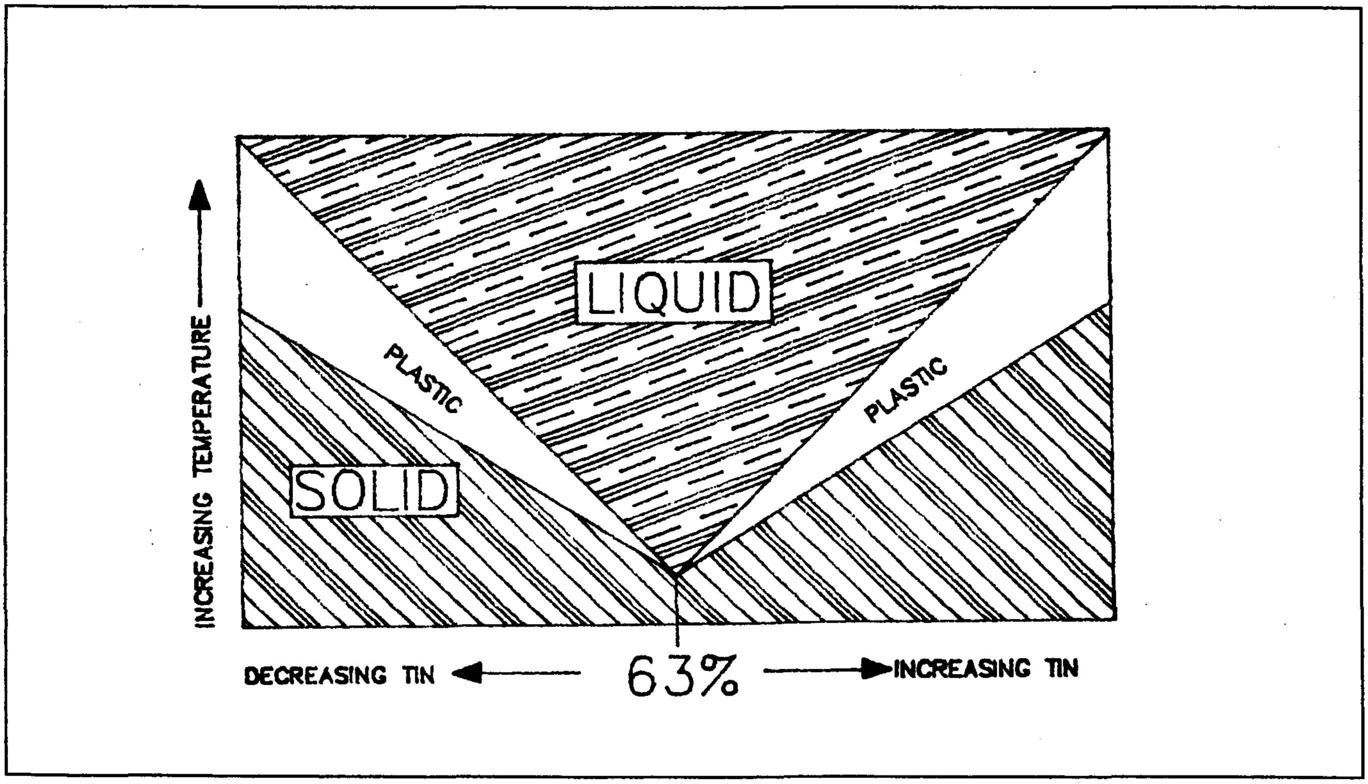

Figure 9-2. Solder Charactersitics Versus Temperature and Alloy.

Once the alloying process is understood, the need for clean metal and a good flux is more apparent. Oxides of the metal do not alloy with the solder and indeed prevent alloying by the good metal underneath. The flux helps carry away small amounts of oxides that have formed since the metal was last cleaned. If you follow the rule in the previous section about using only tinned wire, cleaning will not be a serious issue for you. Tin is a very stable material compared to copper and a freshly stripped, tin plated wire is ready to solder with no further concerns about cleaning.

The reason for all this discussion about solder is because when properly applied, soldering is a very versatile, low-cost method for terminating wires. Figure 9-3 shows a solder lug available from electronic supply houses that has a shape of particular interest to homebuilders. The unsymmetrical, dog-bone shape lends itself very nicely to being soldered to the end of a wire and then having the joint protected by a length of heat shrink tubing (see the Digi-Key Catalog). The shape allows the shrunk tubing to get a good grip on the assembly and provides coverage for some distance either side of the solder joint. If you would rather not invest in crimp on terminals and associated tools, this method of terminating wires in ring type terminals is most acceptable, perhaps even preferable, for use in airplanes!

RING TERMINALS FOR SINGLE STRANDS - CRIMPED

The tradeoffs between soldering and crimping are not terribly compelling to the homebuilder. Crimped terminals are the product of choice for factories. There is no heat involved so careless applications of soldering irons to paint, plastic, carpets and upholstery is not a problem. Crimped terminals are also a bit more compact and look better than their soldered and heat shrink covered cousins. But, they are more expensive, they perform no better and they require proficiency in another kind of skill.

Hand tools for applying crimped terminals range from $10 to $200. The differences in them lie in the quality of the end result. Expensive crimp tools have precision dies which are brought closed against hard stops thus insuring the proper upset of the metals in the terminal/wire interface. These tools also feature ratchets in their mechanisms that insure that the tool is operated through a full crimp cycle thus preventing inadvertent under-crimping. I own several such tools. I also own some of the $10 variety and over the years, I have acquired the skill and knowledge needed to produce adequate crimps with these tools as well. It takes a bit of practice and some knowledge as to proper application which we'll get into now.

If you are going to use crimped terminals, consider the AMP Preinsulated, Diamond Grip (PIDG) products in the Digi-Key catalog. There are also some lower cost ring terminals in the catalog by the 3M company. These are roughly equal to AMP's Plasti-grip line of insulated terminals. I don't recommend these but I would prohibit them only in the engine compartment. Here's why: when crimping any preinsulated terminal on a wire there are TWO crimps to consider. The first is about one third of the length of the insulator back from the ring end of the terminal. This crimp forms the metallic barrel of terminal down onto the exposed wire, the second crimp is about two thirds of the way along the insulator from the ring and it forms the insulation of the terminal around the insulation of the wire. Mind you that the second crimp does not have to get a death-hold grip on the wire like the first crimp does. All you are needing to do with the second crimp is immobilize the wire behind the first crimp so that vibration doesn't put additional stresses on a wire that you have just stressed by mashing it!

If you look in the wire end of a new PIDG terminal, you will find a thin copper liner inside the plastic insulation grip. The plastic portion of a preinsulated terminal forms rather nicely around a wire at room temperature but at elevated temperatures found in an engine compartment, the plastic tends to return to its original BC (before crimping), round shape! The support for the wire is thus degraded or lost completely. The PIDG terminal has a metal sleeve in its insulation grip that prevents the terminal's wire grip from digressing due to temperature extremes. The terminals sold in automotive stores are almost assuredly of the pure plastic form of insulation grip. I won't tell you not to use them but I don't like 'em for airplanes.

Now about these low cost tools. The dies shown on the tool in Figure 9-4 are of the type that are used on the preinsulated terminals. These jaws are shown on the opposite side of tool's pivot from the handles but I have seen tools where these dies are on the inside of the handles; it doesn't matter. Do not use any crimp tool that penetrates the side of the terminal. There are a number of low cost tools for crimping uninsulated terminals that punch a sort of indentation on the side

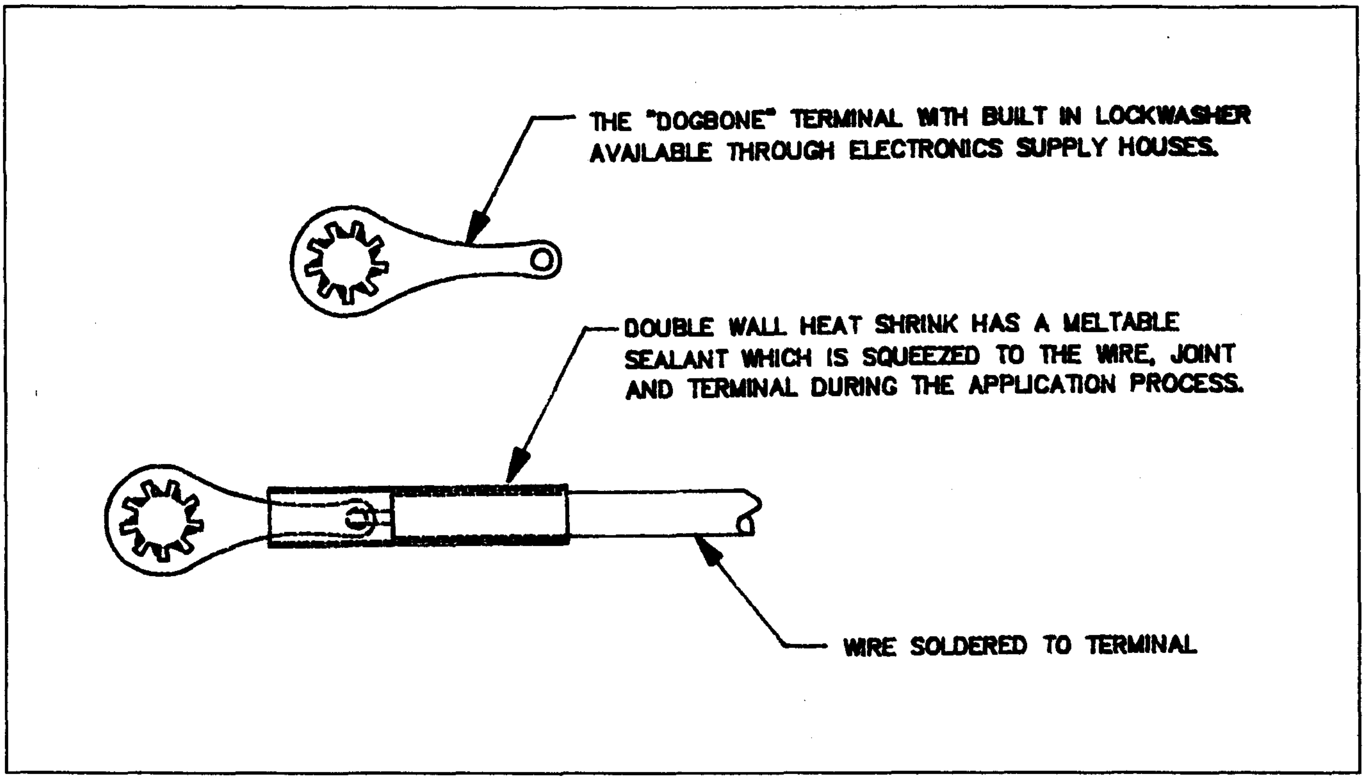

Figure 9-3. The "Dogbone" Terminal for Soldered Wire Terminations.

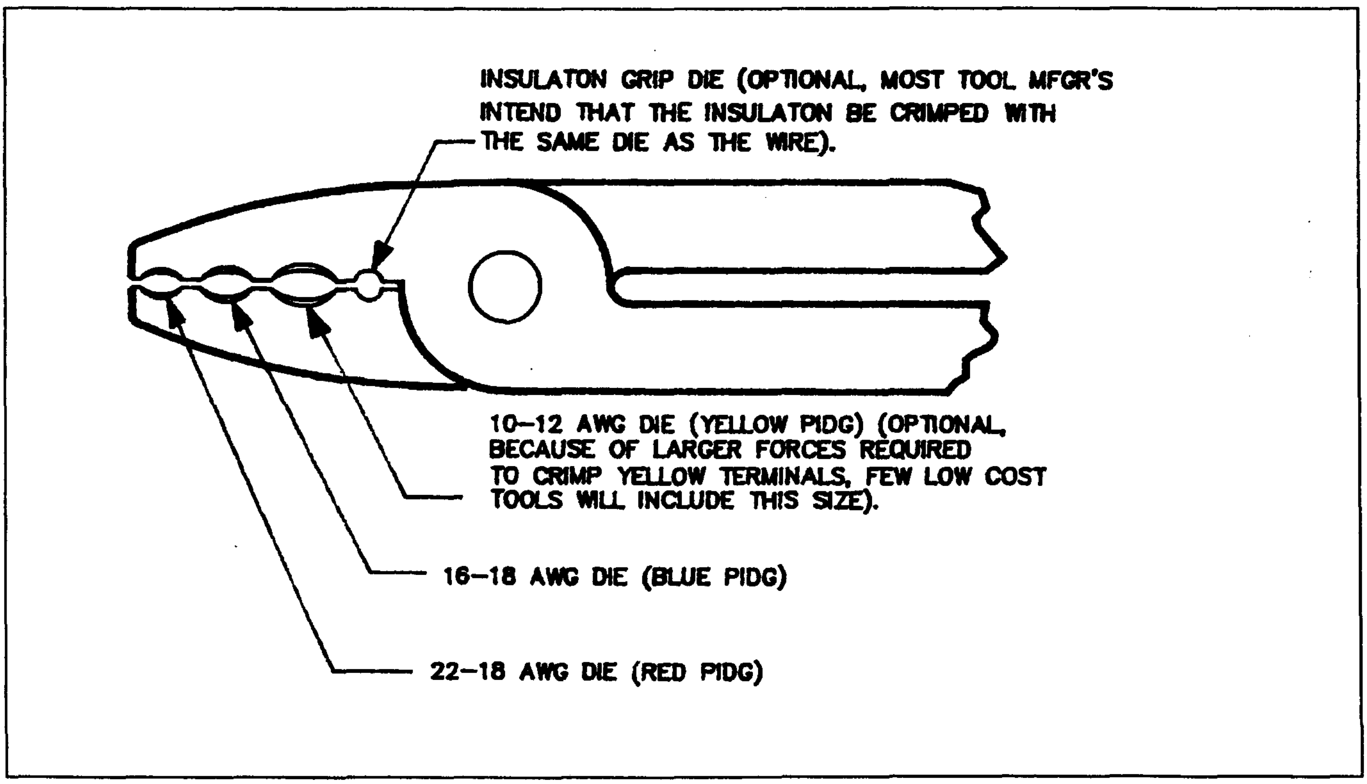

Figure 9-4. Tooling for Preinsulated Ring Terminals.

of the wire grip of an uninsulated terminal. Neither these tools nor the uninsulated terminals should be used on an airplane.

First, study the terminal you are about to crimp on the wire. It is the right size for the wire? A red insulator on a PIDG terminal indicates an 18 to 22 AWG wire range, a blue insulator is for the 12 to 16 AWG wires and a yellow is for 8 to 10 AWG wires. Are there dies on the jaws of your tool marked to suggest which die is appropriate for the terminal? Insert the wire into the terminal; the insulation should bottom out against the back of the wire grip portion of the terminal and inside the insulator such that the bare strands just barely emerge from the ring side of the wire grip. Study the situation for each type of terminal you use and learn the proper strip length for each.

Now, with the wire firmly bottomed out in the insulator, grip the terminal in the crimping tool with the tool centered over the wire grip and with the jaws parallel to the plane of the ring. Put a squeeze on it. Relax the squeeze a little and try to pull the wire out. Put a 5-pound or so pull on it. If the wire pulls loose, you didn't squeeze hard enough. If the wire stays in, take the terminal out of the tool and look at your crimp. Did the plastic extrude out from under the tool so that any metal is exposed? Did the plastic crack down the sides? Does the thing just look squashed? If so, you squeezed too hard! Cut the terminal off and try again. The object is to "calibrate" your squeeze to the task; its not difficult but it does take some practice and a little critical observation of your results. There is a wide range between too little and too much for our purposes.

Once the wire grip crimp is mastered you are 95% of the way there. Next, using the next smaller die opening or perhaps a special die designated on your tool for the purpose, put another crimp on the terminal's insulator to close it snugly down around the insulation of the wire. Now look at the finished terminal installation. Are the two crimps nicely spaced on the insulator and are they both parallel to the plane of the ring? This isn't a critical issue but it is one of craftsmanship. In airplanes that would otherwise have taken show honors, I have seen the good PIDG terminals applied with a pair of Vise-Grips. Were I on the judging committee I have the errant builder go wash and wax the winner's airplane and then we'd talk about the rework needed to make his own airplane's electrical system **reliable** as well as neat.

TERMINALS FOR THE BIG GUYS

The red, blue and yellow PIDG terminals will take care of most of your wire-to-stud terminations but how about those big honkers that run from the battery to the starter contactor? There are PIDG terminals for these wires too but even the production hand tools for these wires is a hydraulic actuated ram! Consider getting these terminals installed for you by a local FBO or perhaps an electrical contractor. I've seen these tools and terminals for big wires used by many wire installers in the various buildings I have been employed in. Just cut your wire to exact length required; allow for the addition to length when the terminal is added. I suspect that a local contractor could provide and apply PIDG terminals (or their equivalent) for a few dollars per end. There is a home brew alternative to the PIDG terminations.

You can make custom terminals for big wires by selecting a drill just larger than the bundle of stripped wire strands. Cut a 1" piece of 1/2 or perhaps 3/4-inch soft copper tubing and mash it flat in a vise with the shank of the drill inside. You'll find it not difficult to pull the tubing down tight over the drill stem mandrel thus forming a flat shape with a tubular passage down one side. Drill an appropriately sized hole in the flat to go over your contactor terminal. Use a spotfacer and/or get a good grip on the thing with a vise or Visegrips when drilling. The copper is soft and likes to snag on the drill. A spotfacer makes a nice hole with much less tendency to snag.

Strip the cable back 1" and put the flag terminal on it. Use a large iron (200 watts or more) or a low flame on a propane torch to solder the terminal to the wire. "What !!!!", you say, "What about insulation support?" In these bigger wires, adequate vibration protection can be achieved by supporting the wire against structure close to the terminal. A PIDG terminal would be nice and do it all in one whack but a homemade flag terminal is just fine too and very inexpensive.

Years ago my first mobile ham radio installation was in a 6-volt, 1941 Pontiac coupe. My transmitter was in the trunk of the car and used a 600 volt dynamotor to produce the necessary high voltage for the output stage vacuum tubes. The dynamotor draw was just over 40 amps (with a 25 amp generator, I didn't get into long-winded transmissions, especially at night!). I remember using soft copper tubing to fabricate flag terminals that were soldered to the cable that ran back to the

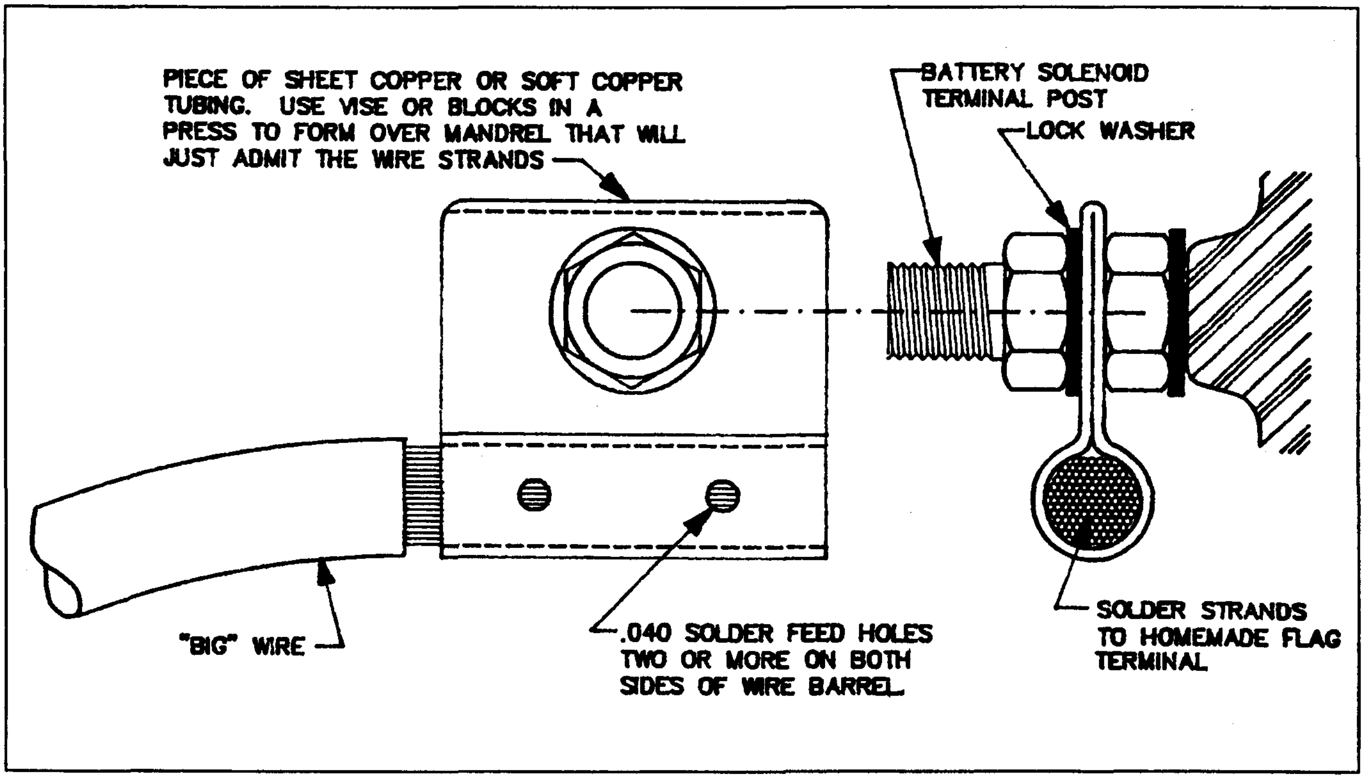

Figure 9-5. Home Made "Flag" Terminals for Big Wires.

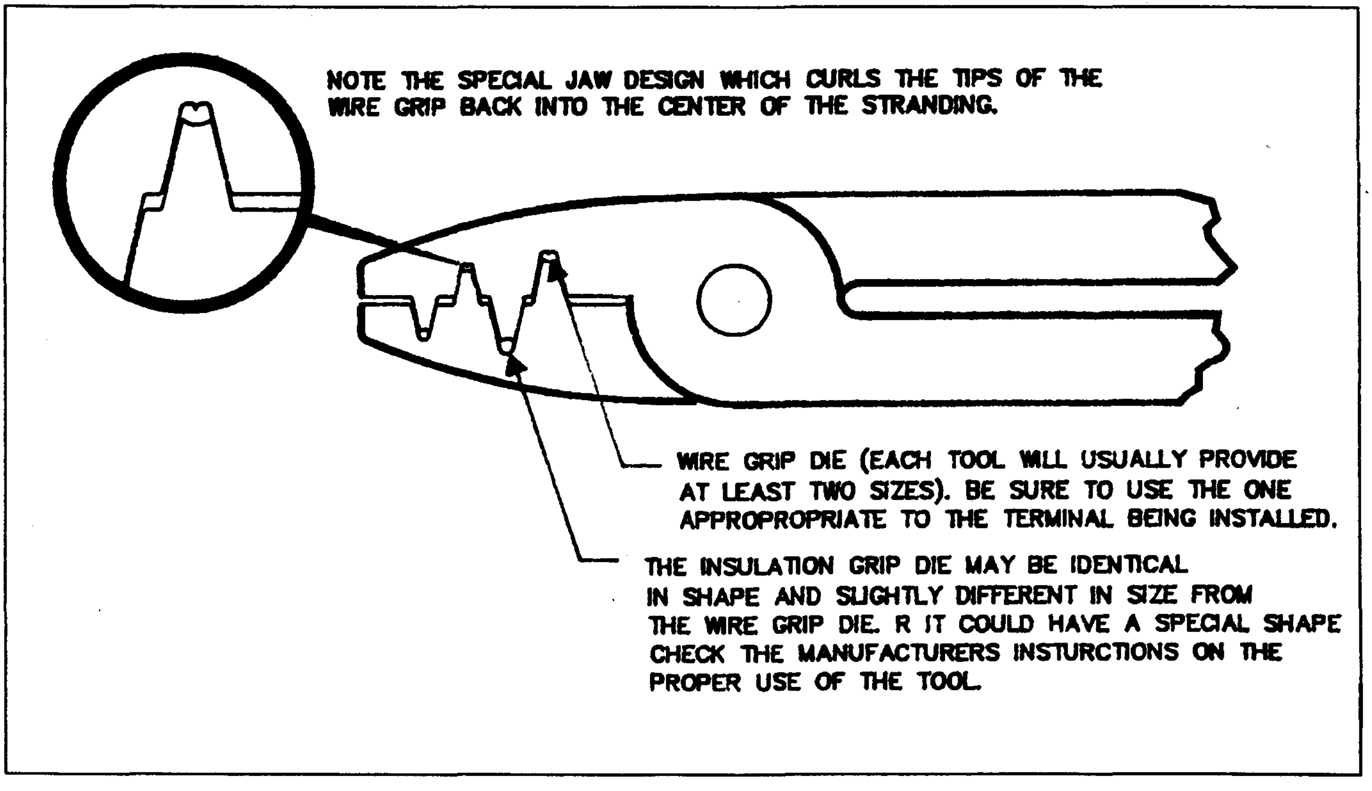

Figure 9-6. Tooling for Sheet Formed Pin and Socket Connectors.

trunk. When your system only runs 6.9 volts to begin with, a few hundred millivolts drop was a significant percentage of total system voltage. Let's see. . . 4 AWG wire is 6 AWG steps from 10 AWG that means 1/4th milliohm per foot. 12-feet from battery to trunk yields 3 milliohms of wire. 40 amps times 3 milliohms was 120 millivolts drop in that wire. In 1960, I hadn't the foggiest notion of how that analysis would come out. Furthermore, I didn't have any instruments accurate enough to see how bad the drop was. It is interesting to note 28 years later that the 4 AWG wire (the biggest I could find at the Boeing surplus yards) had been a pretty good choice!

MULTI-WIRE CONNECTORS

It is almost a sure bet that you will have to deal with some multi-wire connectors at some point in the completion of your airplane. Many of the avionics products will have connectors which pass multiple wires from the airframe systems into the interior of the black boxes. The Whelan Strobes use AMP Mate-N-Locks. You might also find it expedient to use a multi-wire connector at say, the wing root for convenient opening of a wire bundle when removing a wing. Cessna starting using the AMP Mate-N-Lock series plastic connectors while I was in their employ in the late 60's. Many eyebrows were raised, mine included when we saw these sheet metal, crimp on pins supported in plastic housings. Up to that time, wires bundles needing occasional breaking were fabricated with mil standard metal shelled connectors with soldered pins or a perhaps a sleeved knife splice (See the Digi-Key catalog PIDG listings) was put into every strand in the bundle. More often than not, the wires that ran out to removable portions of the airframe, like a wing, were run in unbroken strands. The poor guy in the field had to deal with cutting and splicing the wires if he removed a wing.

Cessna, like the automotive industry, was finding it more efficient to install wire bundles in the assembly stations for the various pieces of structure and some economical but reliable form of connector was needed. The Mate-N-Locks filled the bill nicely. Digi-Key stocks these connectors along with the Molex brand multi-wire devices. They also have low cost tools for terminal application. The dies for these tools are illustrated in Figure 9-6. These are very different from the dies for a PIDG installation. Note that the pins for both the Mate-N-Locks and the Molex connectors are formed from hard copper sheet. The pins have both insulation and wire grips. The funny looking dies are shaped so that during the crimp, the sheet metal tabs on the wire grip are rolled back into the center of the wire strands. The same form is applied to the insulation grip. Another nice feature of these types of plastic connector is that the pins are installed by simply pushing them into the back side of the housing until they "click" into place. Furthermore, they may be removed for replacement of damaged pins by means of extraction tools which are also handy if you have "clicked" a wire in to the wrong hole!

Until we can give photographic coverage to the proper installation of the sheet metal pins in the Molex and Mate-N-Lock type connectors, experiment with them a bit. They are inexpensive enough that you can afford to sacrifice a few housings and pins in your education. Take some scraps of wire and put some pins on them. Look at your results. Two grips; one for the wire and one for the insulation. The pins are listed as different part numbers for different sized wires. Make sure that you observe the limits on these and don't try to use the wrong size pin on a wire. It is possible to put two or even three wires into a single pin on these connectors; just pick a pin that has enough wire and insulation grip capacity to get its 'arms' around all the strands and their insulations.