Chapter Fourteen
Metal Shop 101

Part I, Non-Ferrous Metals

Metalworking is "The Final Frontier" for today's ATM's. It means coming full circle from the early days of groups like the Springfield Telescope Makers, most of whom were machinists, to the days of the pipe thread equatorials of the post-war era, through the plywood and cardboard Dobsonian, and back to metal. Only this time, with the benefit of a century of advances in the tools, materials and engineering.

In Metalworking, the basic operations are the same as you use in woodworking: sawing, joining, milling, and finishing. The tools can be remarkably similar; in fact, they can be the same tools, with little or no modification. The main difference in cutting metal is the speed of the cutter and how fast the work is fed into the cutter, or as the machinists say, "the feed and speed".

Metals are broadly classified as ferrous and non-ferrous; that is, iron containing or iron-free. Steels, the alloys of iron, are obviously the first type. Aluminum, brasses, bronzes, zinc, titanium, and alloys of all these are the non-ferrous metals.

Non-Ferrous metals.

Aluminum alloys are the most likely materials for the ATM, based on strength to weight ratios, workability and availability. Brasses and bronzes tend to be too heavy for a given strength. Titanium tends to be too hard to work and expensive, but if you can get some, it seems to me that a titanium spider made from straps or pieces of thin sheet, or titanium truss tubes might be really neat applications for this still-exotic metal.

This section will emphasize aluminum. The advantages of aluminum include that you can make structures that are stronger than wood, hold up to humidity and dew better than wood, and require less maintenance than wood. Aluminum permits designs that are lighter, more open, more rugged, and easier to balance. It's possible to design the telescope and mount so that it can be cut or machined from rods, tubes, channels, angle, or other standard extruded aluminum shapes. You can often find the standard shapes in small cutoff scrap pieces that are less expensive than standard sizes to buy. You can make composite panels with aluminum skins and foam or plastic filler, making an even lighter structure with lots of excess strength.

Pure aluminum is too soft for engineering uses, so it is alloyed with other metals and subjected to various treatments before we use it. The alloy called 6061-T6 is a good all around alloy that is about as strong as “mild” steel. This is the type that you’ll see referred to as “Aircraft Aluminum”. The 6061 designation tells the composition of the alloy, while the T6 indicates the thermal treatment given to the alloy. Type 7050 is also good; stronger and harder than 6061, but not considered weldable, if that’s a concern for you (more about welding later). 7000 series aluminum is used in some mountain bikes. Like all metals, aluminum has a crystal structure, and the size of these crystals is one of the factors that affect how the metal handles. Large crystals are the result of being cooled slowly, and are a softer state than smaller crystals, which are often found in a brittle state. If someone has ever told you an aluminum object failed because it crystallized, they were referring to these small crystals, often the product of too much flexing or cyclic stress, what mechanical engineers call cold working. Aluminum is available as extruded pipes, solid bars, solid rectangular or square rods, tubes, right angle pieces, square channels, and rolled sheets. These manufactured shapes are made quite accurately – more accurately than someone without machine tools could hope to – and are therefore ideal for incorporating into a design.

All metals (actually, all materials) can be subjected to tests where a specimen is put under tension, and a plot of stress (force divided by area) against strain (the stretch it undergoes) can be generated. The metal will stretch, but like a spring under Hooke’s Law, it pulls back proportional to the applied force. At some point, the metal starts to elongate, but the force required to keep stretching it stops increasing, or increases at much lower rate. This is the yield point of the material, and is beyond where we want to use the material. If you continue to pull on it, the metal continues to stretch until it finally has a reduction in area – it necks down – and breaks. In brittle materials, the elongation doesn’t occur; when you exceed the piece’s yield strength, it breaks.

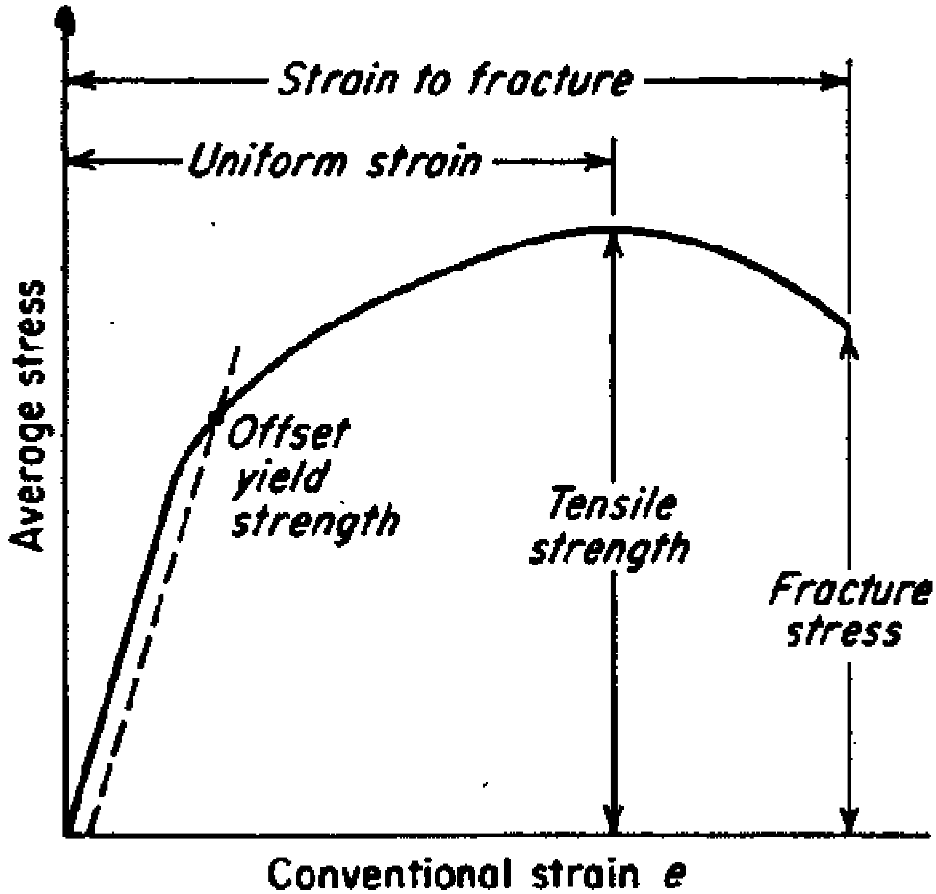

Figure 1 - A classic Stress/Strain curve for a ductile metal

Repeated flexing of a metal is called cold working, which leads to an increase in hardness and brittleness called work hardening. If this flexing is kept below some low level, called the fatigue limit, some metals – notably the steels – will never work harden. Aluminum is not one of these metals and does work harden. Once work hardened, the same flexure that was tolerated earlier in a part's life can lead to abrupt failure. Consider an aluminum rod holding a weight at its end, like a counterweight in a German Equatorial mount. This rod will go through a flex cycle regularly, at the resonant frequency of the combination. A steel rod can be loaded so that it never experiences fatigue failure; aluminum can not (although it's practical life time might be thousands of years). It is prudent to replace aluminum items subjected to repeated flexing for long periods to ward off failure, especially those things designed for lightweight applications. That said, while this might be a problem for bicycle handlebars, it isn't usually a concern in telescope mounts. If you have a design, perhaps a drive that uses a ribbon or belt or some component that gets flexed many times in every use, don't use aluminum. This is a better place for steel.

In summary, the advantages of aluminum over both wood and steels are higher strength to weight ratio, and greater humidity tolerance. Aluminum is cheaper than titanium, easier to work than steel, and safer to expose to the elements than wood or steel. Unlike wood, aluminum's properties don't depend on humidity, although it does change size with temperature more than some other materials (notably graphite composites). The disadvantages of aluminum are that its ultimate strength is not as good as the steels, and that it doesn't have a fatigue limit, like the steels do.

Cutting and shaping aluminum

For anything other than the smallest pieces you'll cut, a power saw is really the best way to work aluminum. If you have a woodworking table saw or power miter saw, all you need is a carbide blade to cut aluminum pipe, channel and other structural shapes. The blade is going very fast, but if you feed the work slowly (or reduce the saw blade speed) you can minimize the possibility of the metal damaging the blade or tool chatter causing the work to jump. Many shops replace the wood cutting blade on the miter saw with a composite cutting blade and call the resulting saw a chop saw. These will cut aluminum very well giving smooth cuts that require little touch up before use. (All metal cutting tends to leave a "bur", a sharp bit of metal left on the edge of the cut, which needs to be removed). In the case of a bandsaw, the woodworking bandsaw typically goes too fast, and you don't have a carbide blade. Here it would be best if you could slow the saw. Lastly, don't overlook the jigsaw with a proper metal cutting blade and cutting guide if necessary.

New on the scene is the carbide-toothed blade specifically designed for metal cutting: the "Morse Metal Devil" is an example. http://www.metaldevil.com/ These blades mount in a woodcutting circular saw and make short work of cutting aluminum or even stainless steel plate and tubing in large sizes. One of these blades can mount in your miter saw, your circular saw or even a table saw.

The number of teeth per inch on the blade should be a function of the thickness and type of aluminum. If you've bought blades for a jigsaw, you've probably noticed the "metal cutting blades" have a high number of teeth per inch. Cutting thin sheet and thin-walled pipe is where the idea originates that a metal-cutting blade should have over 20 teeth per inch (TPI). For thicker stock, fewer teeth are preferred. Somewhere around three or four teeth should always be in the metal being cut for best results. For large thick pieces of metal, fewer teeth per inch are preferred. And speaking of thick pieces of aluminum, like ½" plates, it might be easiest and best to get a machine shop to cut it to size for you, if you're starting from not having any tools. Several of the small metals dealers often one or two cuts free with your order. If you are going to be cutting metal rods or bar stock in sizes up to about 4" diameter, several of the tool companies sell a 4x6” bandsaw that can be quite serviceable. These saws will cut steel and even titanium as well as aluminum, with the proper blade.

Figure 2 - The Ubiquitous 4x6" Bandsaw – courtesy of Grizzly tools

Figure 3 – A miter saw can be used to cut aluminum, especially with a "cutoff" or "Metal Devil" brand blade –courtesy of Makita

Figure 4 Bruce Sayre's beautiful 20" all-aluminum Dob at the Oregon Star Party.

The extruded aluminum shapes can be cut on any of these saws. Support the work to be cut and the piece that's being cutoff. As in woodworking, use a guide bar to help guide your cut instead of using a saw freehand when cutting metal. When dealing with sheet aluminum, a router is a very usable way of cutting material. A router with a carbide bit is essentially the cutting portion of a mill, and circles can be cut in aluminum sheet on the router table exactly as described in the woodworking chapter.

If you want to purchase tools specifically for working aluminum, a metal cutting bandsaw is a good start. These blade speeds on these tools are slower than a wood cutting bandsaw, but that's the main difference between them. If you have a wood cutting bandsaw, a table saw, circular saw or miter saw, don't be afraid to cut the occasional piece of aluminum on it, if you're gentle with your feed rate.

Somehow, everyone thinks of using cutting fluids while cutting metal. It's not strictly necessary, and you should read the instructions from your tool's manufacturer. Lacking specific instructions, a little paraffin, unscented candle wax or Gulfwax from the canning aisle of the supermarket, makes a good lubricant for cutting aluminum. It isn't very messy, and will help clear the metal chips from the cutting edge. I would never use this on my table saw, but would use it with a hacksaw.

The simplest way to cut sheet metal is with shears designed for this purpose, often called "tin snips" or "Wiss shears" after one of the brands. Shops that handle sheet will have large power shears that cut thick sheet. Shears may be useful for cutting thin metal skins into shape for parts of a scope, so don't overlook the obvious and easy tool.

Most ATMs associate metalworking with lathes and mills. While these are certainly the workhorses of the machinist, neither machine is essential to telescope making. They're certainly useful, just not as essential as a means of cutting, drilling and fastening metal. A lathe is used for making rotationally symmetrical parts, things that have a common center, but perhaps a range of different diameters or tapers. A tapered polar axis would be a great project for a lathe, and a lathe makes the construction of eyepieces easier than the simple methods that rely on drill presses and other tools. Lathes are also used to cut threads, including the wide array of thread sizes used for eyepiece filters and camera accessories.

Figure 5 - One of the popular imported "7x12" mini-lathes. Courtesy Grizzly Tool.

Lathes are usually specified and sold by two numbers; some measure of the diameter that can turn over its "bed" and some measure of the length of parts that can be turned. The most popular small lathes are around 7 x 12 in the US/UK – or able to turn pieces up to 7” diameter and/or 12” long. These are sold by the discount tool importers under a variety of brand names. Whole online communities have evolved to support users of these tools. The miniature model makers favor the smaller lathes; for example, the 3.5 x 8 inch lathes like the Sherline or the 4.5 x 9.75 inch Taig. If you only intend to, say, turn an aluminum tube to fit a pillow block bearing, or to fit a rod into a rollerblade wheel, the size you want to work is almost certainly less than 3.5 inches in diameter, and the smallest lathes are all you need. If you want to build your own eyepieces, perhaps 2 inch eyepieces and focusers, the same micro-lathes are all you need.

A couple of words of warning: the imported 7x10 or 7x12 lathes are widely considered to not be very usable out-of-the-box – they require some work by the owner to increase accuracy. This is not considered to be the case with the modelmaker’s lathes like the Sherline or Taig. This is not intended to advocate or endorse any particular brand, as other lathes may be just as good or bad, and the imports may become just as good. Finally, just because a lathe is called a 7x10, it is not necessarily the same size as another one labeled 7x10. Some models handle longer pieces than others because the sellers can be a little generous with their use of dimensions. Be sure to read the specifications.

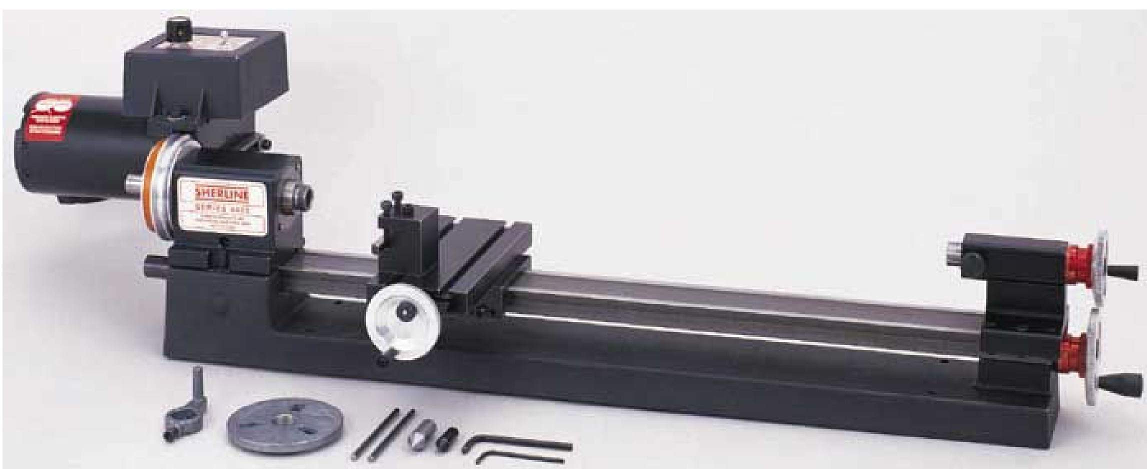

Figure 6 - Sherline's long bed lathe, model 4400. Courtesy Sherline

A mill is a machine that shapes metal by moving a cutting tool over the object to cut away grooves, remove bulk material, or cut to final size, among thousands of uses. A mill can do many of the jobs of a lathe, if properly set up, so it’s reasonable to ask what the difference is. The essential difference is that on a lathe, the work is attached to the motor and rotates as the cutting tool moves against it, while on a mill the cutting tool is attached to the motor and the work moves against it. For example, an automobile engine valve could be made on a lathe; the crankshaft that pushes it is made on a mill. A mill is capable of reproducing itself, while a lathe isn’t.

Mills will be specified the same way as lathes – by a combination of numbers describing the size of their X-Y table and Z-axis motion. They also are sometimes described by the numbers of axes of motion they allow. You may see a mill referred to as a three-axis mill, X, Y and Z, or as a six or eight-axis mill. A knee mill is one where the table can be raised and lowered. The same tool importers sell a variety of mills, and the model makers mills are again represented by Sherline and Taig. The modelmaker's mills will handle a part around 4" x 8" x 3" thick, for example, while the next step up in size may get you to 6" x 14" x 10". The most respected name in full size manufacturing mills has historically been Bridgeport, and many metalworkers look long and hard to find a used Bridgeport they can give a home to.

How big a lathe or mill do you need? Invariably, one inch larger in some direction than what you've got!

Figure 7 - Sherline's model 5400 mill. Courtesy Sherline.

The cutting tools that are used on lathes and mills are a subject of their own. You may be surprised to know that while a fine cabinetmaker wouldn't be caught dead without a carbide tool, home machinists often prefer "high speed steel" (HSS) tools instead. These tools can be sharpened or on a bench grinder, or shaped to a custom cutting profile. The major tool suppliers offer free catalogs that carry a wealth of these tools. Lathe cutting tools are available in carbide or HSS. Mills are single or double-ended, so that you can reverse them in their holder and get a longer life out of them, in HSS, carbide or Titanium Nitride coated. There's almost a tool for every possible cut, so a few hours with the tool suppliers' catalogs can teach you much. See the references at the end of this chapter.

The last tool I'll go over is the drill press. This is familiar to woodworkers, and the same small benchtop drill presses that many woodworkers own are great for metal working. The drill press gives you added accuracy in drilling a straight, vertical hole; or a hole at an angle other than 90 degrees to the work. Low cost drill presses have an adjustable table that will tilt with respect to the line of the drill bit, but radial drills will allow the head of the drill press to rotate with respect to the work. They also allow the drill to move along a rail or set of rails, like a radial arm saw does, giving more flexibility in the placement of holes on a piece of work. Drill presses are usually specified by the size of a piece they'll cut to the center of. That means an 8" drill press, for example, will drill to the center of an 8" piece – 4", or 4" in from the edge of a bigger piece. The "radial drill press" in Figure 8 can drill at compound angles to the table, and to the center of a 16" circle.

Figure 8 - A Radial Drill Press - Courtesy Grizzly Tools

It may surprise you that one of the most common uses for a milling machine in industry is as a very sophisticated drill press. The mill has a very accurate X-Y table and can locate the spots to drill quite accurately. Yes, you can add an X-Y table to the drill press, but if the mill is idle, why not use it? Many hobbyists add a “sensitive drilling attachment” to their mill – an accessory that allows you to lower the drill bit by hand and feel how it’s interacting with the metal instead of using the mill controls to lower the bit.

CNC, Computerized Numeric Control, is a form of machining where designs are turned into the tool paths required to make them, and the machining is all done under computer control. Both mills and lathes are CNC’ed in industry – called machining centers and turning centers. The machinist’s art is still needed, because when shaping metals to tolerances around .001 inch, the flexing of the tool and work become significant, and the machinist or designer must fully understand how to produce the part, and not an expensive piece of scrap metal. Exotic technology for the ATM; it’s another hobby that can consume all of your time and leave no time for actually building or using telescopes.

Sign making shops sometimes have CNC routers that are used to cut panels of plastic into intricate shapes. ATMs have contracted with these companies to produce cut out plastic panels for composite aluminum/plastic assemblies, or to cut the aluminum sheet composites they’ve already made. Of course, ATMs have made their own CNC routers as well.

Measurement and layout

Metal can be laid out precisely with steel rulers, scribes to mark lines that will be cut, and precision measuring tools used to check the part’s size. When you cut a line, you will have a scrap side of the cut that you should keep the cutting tool on. Extrusions, like tubes used for a truss, can be cut on the chop saw and their ends should be quite square. If cut with a hacksaw, they can be squared up with a hand grinder. After cutting, most tools will leave a small burr of sharp metal on the pieces; a light touch with sandpaper or a fine file will remove this safety hazard.

The golden rule of working metal should be hung in every shop: “Think about the cut three times, measure twice, and cut once”. Metal is unforgiving. If you drill a hole in the wrong place, your options are to throw out the piece with the mistake, live with the mistake, or come up with some way to put metal back so you can drill the hole again. Putting metal back on the work is pretty hard to do. As Joe Martin of Sherline says, “there is no metal white-out”.

When you design a mount, be it in metal or anything, you should always consider how you’re going to put it together. Design in the places where fasteners go, and make areas that receive them thicker if need be, or oriented differently so that a straight fastener can be used.

Fastening and joining aluminum

The most direct, and generally the best, way of joining aluminum pieces is with screws. Aluminum can be drilled to pass a machine screw and stainless hardware used. Thick pieces of aluminum can also be drilled and tapped so that the screw directly engages the metal, but aluminum is not the best material for tapping. Stainless screws have tendency to pick up bits of metal and “gall” or jam. Still, for pieces you expect to put together a few times, and not be subjected to repeated cycles of assembly and disassembly, tapping aluminum for stainless steel screws is done commercially so don’t be too afraid of doing it. If the metal is hard anodized, the galling problem is minimized, and screws can be used freely. Hard anodizing adds a couple of thousandths of an inch to the metal, making the hole smaller, so the anodizing process needs to be controlled well. As for the style of screw, Phillips style screws are more resistant to their heads being damaged than conventional flat-blade screwdrivers. The most robust screws are those that are driven by a hex or Allan wrench.

As mentioned in the woodworking chapter, a hand operated drill, or cordless drill/screwdriver is probably the most commonly owned tool, and is a great thing for joining assemblies. The variable speed type is handy for driving screws.

In truss telescopes, a block of wood split to allow hardware to compress around the tube is a common way to attach truss tubes so that the joint can be knocked down for travel. There are hardware screw mounts that can be pushed into a truss tube and accept a machine screw. Finally, the simplest way of attaching truss tubes to their structure is to hammer the tube flat over a few inches, drill a hole in the newly-formed flat sheet, and put a screw through it.

Figure 9 Termination for two truss tubes - Moonlite Telescope Accessories.

Figure 10 - Moonlite Telescope Accessories 1" Captive Truss Tube Connector

What if you need to fasten two pieces of aluminum and you only have access to one side? Say you're putting together two pieces and there's no way to get a wrench onto the far side to hold a nut while you tighten it? What if you need to join two sheets, each so thin that you can't tap them for a screw and you can't put a nut on the far side? Enter the "POP Rivet", a trademarked name for a riveting system designed by the Emhart Fastening Technologies Company. According to the company's information, "The 'POP®' Open type blind rivet is a hollow rivet pre-assembled on to a headed pin or mandrel. Rivet bodies are available in a range of materials for complete work piece compatibility".

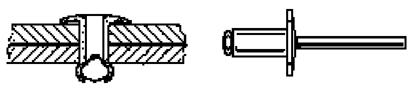

Figure 11 - POP rivets before and after setting. Courtesy Emhart

A POP Rivet can be installed with a hole large enough in diameter to clear the rivet body. The rivet is put in place and a tool used that sets the rivet by pulling out the mandrel. They are available in styles that seal up to 500 PSI, which would prevent dew or rain from entering a box sealed with these rivets. Specialized versions are made for joining thin or fragile materials, too. POP Rivets are cheap, but the tool required to mount them must be bought, and that adds some cost. It's a cost that you'll only need to put up once, though.

The biggest drawback to a riveted assembly is that it is a permanent joint. To remove it, you need to drill out the rivet and replace it with a new one when you re-assemble the parts.

What if you can't access it enough to put in a rivet? This is something that needs to be considered in design, but sometimes you get into a bind where you can't get a fastener in place. You might consider welding. Welding aluminum is a specialized area, requiring an inert gas system such as TIG (Tungsten Inert Gas) or MIG (Metal Inert Gas) to keep the aluminum from oxidizing under the heat of the operation. This is not as exotic as it used to be; MIG and TIG systems are available from the big tool importers such as Harbor Freight and Grizzly for nominal prices, and Argon is available at welding supply stores for the inert gas. Still, it would take an extreme amount of telescope making to justify such a cost. There are systems that allow you to braze aluminum, using a propane-oxygen or oxy-acetylene torch. If you don't have the capability, you can usually find a shop in town with experience that will do the job for a nominal fee. Of course, welding is even more permanent than a rivet. You can't take your assembly apart at all.

Welding aluminum is expensive to get started in without friends to loan you everything, and for one or two telescopes and mounts, it makes economic sense to find a shop to do it for you. It makes as much sense to strive to not require welding. Certainly a telescope or mount can be designed so that welding is not required. You must design all joints and functions carefully to get around welding, particularly places where thin plates of metal join at right angles. By bending plates and providing an overlap, screws or rivets can be used. One of the main reasons for welding in industry is to prevent nuts and bolts from working loose, as may happen in high vibration environments. If the assembly is under a tensile load, this will result in the bolt deforming the hole and the parts not fitting together properly any longer. Your mount isn't a high vibration environment, so there's no real reason to weld it. A lock washer will go a long way to eliminating the possibility of parts working loose by putting the bolt and nut under spring tension and forcing threads against each other. Welding is a complex subject and if you need to get something welded, it's far cheaper to hire someone who knows how to do it than to buy the equipment and learn. Like CNC machining, if you want to learn welding, it's another hobby that can keep you busy for long periods and not making telescopes.

You can consider the cost of the fastening to go up roughly in the order listed. Stainless bolts and nuts, or threaded pieces, are the cheapest, with rivets next higher in cost (including buying the tool) and welding the most expensive.

Finishing aluminum.

As we said, one of the advantages of aluminum over steel is in its humidity resistance. Aluminum alloys don't oxidize in a way that's destructive. While the oxide of iron (rust) peels up from the surface of the metal, exposing fresh metal to rust, aluminum oxide bonds tightly to the surface reducing further corrosion. Aluminum oxide is very hard (naturally occurring aluminum oxide is better known as sapphire, while one specific color is called ruby), but brittle so it can crack. Aluminum left outside doesn't look as good as a sapphire – it gets an unattractive, dirty-white deposit, so some effort in finishing is worthwhile.

A few years ago, the "bright aluminum" finish was very popular in mountain bikes. The finish, a clear coat over polished aluminum, proved difficult to maintain, though, as any little ding in the clear coat would allow exposure of the underlying aluminum to the elements and discoloration followed. You can try the same finish with clear spray paints, like Krylon, and keep a good coat of car wax on the telescope. A clear coat for aluminum that has a good reputation in several circles is called "XIM-900" from XIM products in Ohio.

Paint doesn't always adhere well to aluminum, though, and some effort is required. Clean the metal with whatever solvents are needed to remove the hand oils or shop grease. Aluminum is subject to attack by acids and bases so don't expose to very strong cleaners for long periods of time. Soaking aluminum parts overnight in a saltwater solution to roughen up the surface might actually help paint adhere. Look for paints that are specified for aluminum; marine or aviation shops are good places to start looking. The Krylon Duplicolor® paint products include a primer said to be excellent for aluminum, their product DAP1690. Other colors can be used over this.

There's an exotic form of painting called powder coating that uses powdered paint which is then melted onto the work, producing a hard finish that adheres well and produces an extremely durable finish. The powder used for the process is a mixture of finely ground particles of pigment and resin, which is sprayed onto a surface to be coated. The powder is usually applied by spraying with a gun that electrostatically charges the powder as it exits the tip. The powder is applied directly to a clean, bare metal surface, with no primer or base coat (I've read that powder coating can also be applied to glass, ceramics, temperature resistant plastics and even wood). The part that is being coated is electrically grounded, causing the charged powder to cling to it. After coating, the part with the loose powder clinging to it is placed in an oven to cure. In the curing process, the powder melts and flows over the surface of the object without drips, runs or sags. In one approach, the powder doesn't melt and flow, but actually undergoes a chemical reaction in which the paint molecules cross-link or polymerize. Either way, the result is a highly durable finish in a wide variety of colors, glosses and textures. Check for local shops that might be able to do this for you. Some hobbyists have done their own powder coating, using a toaster oven for small parts or a home made oven to cure the paint. When you consider it just on a cost basis, it probably makes more sense to contract this work out – but I know that some ATMs would never consider having anyone else do any of their work for them. These guys will invest in the hardware to powdercoat their work themselves, even if it doesn't make economic sense.

Metal workers often finish aluminum in surface finishes that alter the metal itself: anodizing is the most familiar. While you can allow the surface to oxidize in an uncontrolled fashion by simply leaving it outside, anodizing is a treatment that produces a controlled, thicker aluminum oxide layer on the surface of the piece. Black anodizing is familiar on many astronomical products. Aluminum oxide is a very hard, scratch resistant material, so it makes a good finish for items likely to be bumped around. The aluminum piece is dunked in an acidic solution and exposed to a low voltage, high current electrical current flow. The voltage is around 24 VDC, with current near 15 amps per square foot of surface to be treated. This can be done in the presence of dyes and other coloring agents so that a very wide range of colors are available in anodized finishes. Because of the nature of the process, consistency is hard to achieve and the commercial houses spend much engineering effort to achieve uniform results. A commercial finishing operation is probably your best bet, although some amateurs are learning to anodize themselves.

In ATM work, the cost of finishing goes up in the order these choices were listed: do it yourself painting, powder coating, and anodizing. A couple of cans of spray paint will cost you a few dollars a piece. Powder coating will cost you more, and anodizing will probably cost the most. It's not uncommon for anodizing shops to charge a modest setup fee and only add charges if your parts require more work than their basic setup.

Part II – Ferrous Metals – Steel

It's best to think of steel as not a metal, but a group of metals. Steels consist of iron and other alloying elements, but it's the addition of carbon that creates steel. The amount of carbon in the steel along with the other metals used, and the treatment the alloy receives determine the properties. ATMs will probably use only the more common alloys, and the largest choice left to us will probably be plain carbon steels vs. stainless steels.

Compared to aluminum, steels are denser, harder to cut with simple tools, and more prone to corrosion (except for the stainless steels). Steels are stronger than aluminum alloys. Cast iron and cast steels are often used in pillow block bearings, and pipes, for example, so if you're constructing a "plumber's special" mount out of plumbing store parts, this is what you'll use.

Carbon steels, as mentioned, constitute a very wide range of alloys. Here's a look at some of the most common alloys available to the home machinist and ATM. One of the most common alloys you'll encounter is C1018, found in the cold rolled steel (CRS) pieces you'll find in some hardware stores. C1018 is a free machining grade that is often employed in high volume screw machine parts applications. It is commonly employed in shafts, spindles, pins, rods, sprocket assemblies and an incredibly wide variety of component parts. Hobby machinists often use steel with lead added, which improves the machinability at the cost of introducing a mildly toxic metal. 12L14, or "Ledloy", as it is sometimes called, is widely available from metals dealers. It offers inherent ductility combined with fine surface quality and can be bent, crimped and riveted. Parts turned on a lathe, or surfaced on a mill are left with a smooth surface that requires little or no work. 12L14 has become the favorite carbon steel for machining - especially on light weight lathes. C4130, an alloy with some chromium and molybdenum, is widely used. It is easy to machine and form, ductile (bends easily), easy to weld, and has good strength. C4130 is found in structural uses, such as aircraft engine mounts and welded tubing applications. Adding a little manganese yields C4140, an alloy with better toughness, good torsional strength and good fatigue strength. C4140 has found its way into even more applications than C4130. It is weldable, and formable (although its higher toughness than 4130 means it takes more force to form it than it does to form C4130). Thousands of high end bicycles are made every year out of chrome-moly steels like these.

As of July 2006, the European Union is strictly limiting lead and other substances considered hazardous. While it is unknown at this time what effects this will have on the availability of 12L14 steels, it doesn't sound good.

All of these steels are subject to corrosion, some worse than others. Iron oxide forms at the surface and flakes off, leaving more fresh iron exposed. The process is eventually destructive. In an effort to eliminate this, stainless steels were developed. Stainless steels are formed by increasing the amount of chromium in the mix to greater than 12%. A thin, protective layer of chromium oxide forms on the surface that adheres tightly (similar to aluminum oxide) and protects the iron from the oxygen. Some types of stainless have as much as 17% chromium. Some add nickel. As in the other steels, various alloys are constructed for their specific properties.

A quick aside: a false item of "common knowledge" is that stainless steel is non-magnetic; that is, not attracted to a common magnet. This only holds for the high nickel stainless alloys. The low nickel alloys will be attracted to a magnet like any other steel. One of the most commonly used alloys in the marine industry is 316 stainless. It has increased corrosion resistance compared to many other grades. It is 16% chromium and 10% nickel and is non-magnetic. Another common stainless is 416. This alloy uses no nickel and less chromium (12%): it is magnetic, but is used for its excellent machining properties.

Joe Martin, the president of Sherline, makes an interesting observation about stainless steel. Many young engineers use stainless for everything, whether the object needs protection from corrosion or not. It's best to think of stainless steel as an exotic metal, and use it only where necessary. He states that if every young engineer had to machine the parts they specify out of stainless, a lot less of it would be used. As counterpoint, here in Florida and the southeast US, including the gulf coast states, stainless is not an "exotic" material: it's a necessity. Any non-stainless steel items are best considered expendable, temporary purchases. I've had pieces of steel show corrosion after one night out of their protective wrapper.

Working with steels

Once you start working in steel, you have to have tools specifically designed for cutting it. Here's where that "Metal Devil" blade in the chop saw or that 4x6 bandsaw is required, with a slow hand feeding it. Steel is sometimes rough cut with an oxy-acetylene torch, then cut to size with metal-cutting bandsaws, or even ground to final shape with a handheld power grinder. To my way of thinking of it, a bandsaw is indispensable. Cutting and even drilling hardened steel with the hand tools commonly available to the homeowner is an exercise in frustration – if not a lesson in how to burn out a tool's motor (don't ask me how I know).

The small mills and lathes mentioned in the aluminum section will cut steels. You can turn a pipe to a final dimension in a miniature lathe. For milling large pieces, the lack of horsepower in the smaller machines is one reason that

12L14 Ledloy has become a favorite alloy of the home machinist. Can you work stainless in modelmaker's tools like the Sherline lathe and mill? You can, if you go slowly and don't ask too much of the machine. Treat stainless steel as an exotic that you can cut if you have to, and work carefully. Read up on the machining properties of the metal you choose.

Steels can be joined with the same techniques as aluminum. Drilled holes with through-bolts, or tapped holes for screws are both good options. Steel generally taps better than aluminum. Rivets work well on steel also. Finally, there are more options for welding and brazing than exist for aluminum. Relatively simple arc welders and oxy-acetylene brazing torches can be found in stores ranging from Sears to more specialized tool dealers, and can be used on steels. By the way, metal workers and woodworkers have different definitions for the term "butt joint" that I used in the woodworking chapter. In woodworking, this is two boards joined at right angles. In metal working, it's two pieces joined in line, edge to edge.

A form of construction with steel that is widely used in large telescope mounts is frame and skin construction. In this construction, a frame of steel bars or angle shapes is made into the frame for the structure, and then a skin of thin steel sheet is fastened to it. The fastening is usually done by welding, but could also be done with metal screws or riveting. The skin reinforces the frame adding stiffness at much less weight than a solid metal casting. You should be aware of costs here. Getting single pieces of steel sheet cut to finished sizes for frame and skin construction is likely to be expensive, and it may be a technique best left to manufacturers who work in high volumes.

Finally, steel does not anodize so it should be finished with paint or powder coating. Protecting non-stainless steels is important. An advantage of steel is that all of the paints developed for the auto industry are available, so an easy to find series of paints in a truly wide variety of colors is available. Stainless steel can be left with fine sanding as its finish, perhaps 600 grit (for comparison, the standard floppy disk metal door is finished to 180 grit). Stainless finished this way is so attractive that it is used as a jewelry metal.

What is the role of steel?

A good question at this point is why should I use or not use steel. Steel will give you a higher ultimate strength than aluminum, although the strength to weight ratio favors aluminum by a small amount. Stated another way, a telescope made of stainless steel might have smaller components than one made of aluminum, but both instruments can be designed for comparable strength. The cost differential is harder to quantify, as that has as much to do with your tools and abilities as the material itself. If you can work aluminum yourself, but pay high prices for getting steel cut and finished to size, you'll likely find steel to be more expensive. If you can buy all your metal as scrap and cut it to size, you'll end up at lower cost than if you buy dimensionally-sized pieces.

In the final analysis, the material you use is as much a function of the tools you have and how comfortable you are working the material as it is a function of how "good" the material is in some characteristic. If you're more comfortable with cutting and joining steel than aluminum, use it.

Some large tool companies – providers of tools and cutting bits.

Enco (800) USE-ENCO http://www.use-enco.com

Grizzly (800) 523-4777 http://www.grizzly.com/products/index.cfm

Harbor Freight 800-423-2567 http://www.harborfreight.com

MSC (800) 645-7270 http://www1.mscdirect.com/cgi/nnsrhm

Sherline (800) 541-0735 http://www.sherline.com/

Other handy resources.

Online metals **(800) 704-2157** http://www.onlinemetals.com/

Pierce Metal Supply

http://www.onlinemetalsupply.com/storefrontprofiles/default.aspx?sfid=96027

Speedy Metals 1-888-744-4140

http://stores.ebay.com/SPEEDY-METALS-1-888-744-4140

References and further reading:

1. ALCOA, Alloys and Tempers, 1999, Aluminum Corporation of America

2. Hadco Aluminum, Comparative Characteristics of our Alloys, published online at http://www.luminum.com/, 2002, Hadco Aluminum Co., New York, Florida, Pennsylvania

3. Hadco Aluminum, Engineering Data, published online at http://www.luminum.com/ 2002, Hadco Aluminum Co., New York, Florida, Pennsylvania

4. Emhart Fastening Technologies, PopRivet® Technical Information, published online at http://www.emhart.com/products/pop/Default.htm

5. Askeland, Donald R. The Science and Engineering of Materials, 1984, PWS Publishers, Boston, MA

6. Principal Metals, Principal Metals Online, data sheets on many series of steels. Published online at http://www.principalmetals.com/properties/step1.asp

7. Martin, Joe, Tabletop Machining, 2001, Joe Martin, Sherline Products, Vista, CA