Principles of Paper Models

Construction, Design, Thoughts

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Forward

I would like to thank everyone that prodded me and encouraged me into writing this book. I hope you, the reader, enjoy it and I hope it gives you some meaningful information.

Special thanks go to all of my friends that encouraged me to undertake this project and for helping to turn my word vomit into coherent writing.

- Dr. Nancy Hoalst-Pullen
- Parker Huellmantel
- Etienne Roserie

Through the book you will find terms defined in the footer of many pages. These terms can also be found in a glossary at the end of the book. Beyond that, I will be including offsite links and annotations as needed. Those annotations can be used for further reading and research if you desire.

I am self publishing this book and distributing it for free over the internet. This way as many people as possible can utilize it. If you think it is worth something, please drop a few dollars in the tip jar. Knowing that people are getting value out of all the work that goes into a project such as this makes a big difference. The writing easily consumes several hundred hours to compose, edit, layout, and make presentable. Thanks.

If you wish to download any of my public models, you can do so here:
http://insanityunlimited.com/modelplans/

-Dave

QR code for the tip jar:
Paypal Link

Introduction

If you are reading this, then you likely have an interest in model building of some manner or another. I will be approaching this set of topics from the standpoint of paper models[1][2] (also known as card models). I hope this book ends up meeting your needs as a technical guide and one that propels you through many years of an enjoyable hobby. You never know, you may find a way to turn this hobby into a side business or career. That last part I am still trying to figure out and is a little bit more difficult. Overall, I want to present information to you and I hope it opens up new possibilities that you will enjoy and generates more ideas.

When I first began building models I was about five years old. The models I constructed were made of plastic[3]. As you can imagine for a kid, they were rarely painted and included plenty of glue fingerprints. My skills were quite rudimentary, but I enjoyed seeing these constructs come together. There was something magical about turning a large number of discrete parts into a project that was more elegant and more complicated than the original pieces.

At this same age I would visit my grandfather's model railroad[4] layout in his basement. He had constructed it to appear like the western side of Columbus, Ohio in the late 1950's and 1960's. Very little prefabricated scenery from the hobby store met his needs, so he made many of the buildings from scratch[5]. I knew that he built them out of balsa, cardboard, cardstock[6], and other hobby supplies. But having only been exposed to plastic models myself, I could not and did not comprehend how a paper model might work. Intuitively, it felt like working without pre-shaped parts would be significantly more complicated than that of a plastic model. Not only did you need to assemble the parts into a finished model, but you also had to form and construct the parts prior to assembly.

As happens with kids, my interest in making models waned and changed, and I stopped building for a number of years. While in grad school a friend convinced me to take a break from schoolwork to go to the hobby store as a relaxing diversion. While there I stumbled across a large plastic kit of the USS New Jersey[7]. For not a lot of money I grabbed the plastic kit and supplies to complete it. Working on that model for a 20-30 minutes every day kept me sane through the end of school and was very fulfilling.

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[1] "Paper model - Wikipedia." https://en.wikipedia.org/wiki/Paper_model. Accessed 9 Oct. 2018.
[2] Paper model (n.): A model made primarily of paper or cardstock. Also known as a card model.
[3] "Plastic model - Wikipedia." https://en.wikipedia.org/wiki/Plastic_model. Accessed 9 Oct. 2018.
[4] "Rail transport modelling - Wikipedia." https://en.wikipedia.org/wiki/Rail_transport_modelling. Accessed 9 Oct. 2018.
[5] Scratch build (n.): A model made without utilizing a prepared kit. From the phrase "from scratch", meaning that there is no defined kit or set of parts.
[6] "Card stock - Wikipedia." https://en.wikipedia.org/wiki/Card_stock. Accessed 9 Oct. 2018.
[7] "USS New Jersey (BB-62) - Wikipedia." https://en.wikipedia.org/wiki/USS_New_Jersey_(BB-62). Accessed 9 Oct. 2018.

This rejuvenated my interest in model building and I began buying more and more kits once I finished school. Jumping forward a number of years, I realized that I had accumulated several hundred plastic model kits. I had been stopping at hobby stores regularly and purchased whatever caught my attention or was a good deal. My shopping trips most definitely outpaced my ability to build the models. They filled case after case and took up lots of room in the crawlspace and on shelves in the basement. About this time in my life, the cost of plastic more then doubled and this led to a price tag of $80 or more on a nice kit of a 1:72 jet from a quality Japanese manufacturer. Even the kits based off of worn out moulds[8] that were inexpensive were now priced at $40 or more. Obviously, many hundreds of kits represented a non-trivial amount of money invested. At the same time I was developing a critical eye in an attempt to improve my results. This led me to a loss of confidence in my abilities and I became afraid of making a costly mistake. I did not want to mess up an expensive kit and ruin it due to just a single misstep.

When I realized this I recalled the scenery that my grandfather had constructed out of cardstock for his model railroad…. This caused me to put my hands of ham and fingers of butter against the keyboard and search for information on paper models. I quickly found the Paper Modelers Forum[9] which held a wealth of resources, fellow enthusiasts, files[10] of model plans, tips, tricks, and a large group of others interested in the paper model hobby. I quickly began downloading every model I could find because your stash[11] can never be large enough. I also saw that it was possible to produce a finished model made of paper that looked just as good or better than one made of plastic. Paper models usually have colorings, markings, and detail printed onto the parts prior to assembly. This is in contrast to plastic models where they require painting as part of the construction process.

It also quickly became apparent that the number of different paper models available was far greater than that of plastic kits. The investment required for a plastic kit to be produced involves $10,000+ worth of tooling in order to produce the parts. At the same time, for a paper model, the equivalent was a decent printer and a ream[12] of card stock. Recouping the investment to press out a plastic model requires selling enough kits to make that money back… and if you pick an obscure subject with a niche set of customers it seems less likely you will be able to pull that off. As a result, uncommon or obscure models often do not get created in plastic. Since the investment to design a paper model was mostly measured in time and skill set, this opens up the possibilities to a huge breadth of subjects. This drove my desire to learn how to design my own paper model kits.

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[8] Mould (n.): A vessel used to contain a liquid material that will later harden. It is used to impart shape and detail into the exterior of the material injected into it.
[9] "Forums - Paper Modelers." http://www.papermodelers.com/forum/. Accessed 9 Oct. 2018.
[10] "What is PDF? Adobe Portable Document Format | Adobe Acrobat DC." https://acrobat.adobe.com/us/en/acrobat/about-adobe-pdf.html. Accessed 9 Oct. 2018.
[11] Model stash (n.): A collection of models that have been acquired but not yet built.
[12] Ream (n.): A bundle of paper consisting (usually) of 500 pages.

As I started building paper models and later designing them, I ended up tracking down techniques to improve my results. I have been collecting these techniques and concluded that it would be time to compile them all together into a single place. Thus, I am writing this book. It is also forcing me to think about how I both build and design a model. Many of the things I do to construct a model are no longer consciously considered at the time. I hope this book can be of help to people just starting the hobby, those that wish to advance their skill set, and those that want to try their hand at designing models.

My background is in engineering, IT process design, process management, and continual service improvement. The thought processes that draws me to that kind of work can be directly applied to model design and construction. I will not claim that I am a master at executing all of the techniques that appear later in this book, but I do try to consider their lessons as I am building or designing a model. The techniques lend themselves to new approaches and solutions to the problem of constructing an impressive and astounding model.

When we get to the section on how to design models, I will not advocate for a specific set of software[13] to be used. Each person has a slightly different set of needs and preferences which will drive the selection of a specific set of tools. I also will not try to explain how to use the software based tools, as they change and are updated so frequently that this book would be quickly out of date. Each application has its own set of functionality, forums, guides, and resources on how to use it best. I will talk about some concepts that are important from both the perspectives of accuracy and efficiency.

Above is the USS Sulaco[14], designed by Jan Rukr. This model is nearly six feet long and the studio model can be seen in the movie Aliens.

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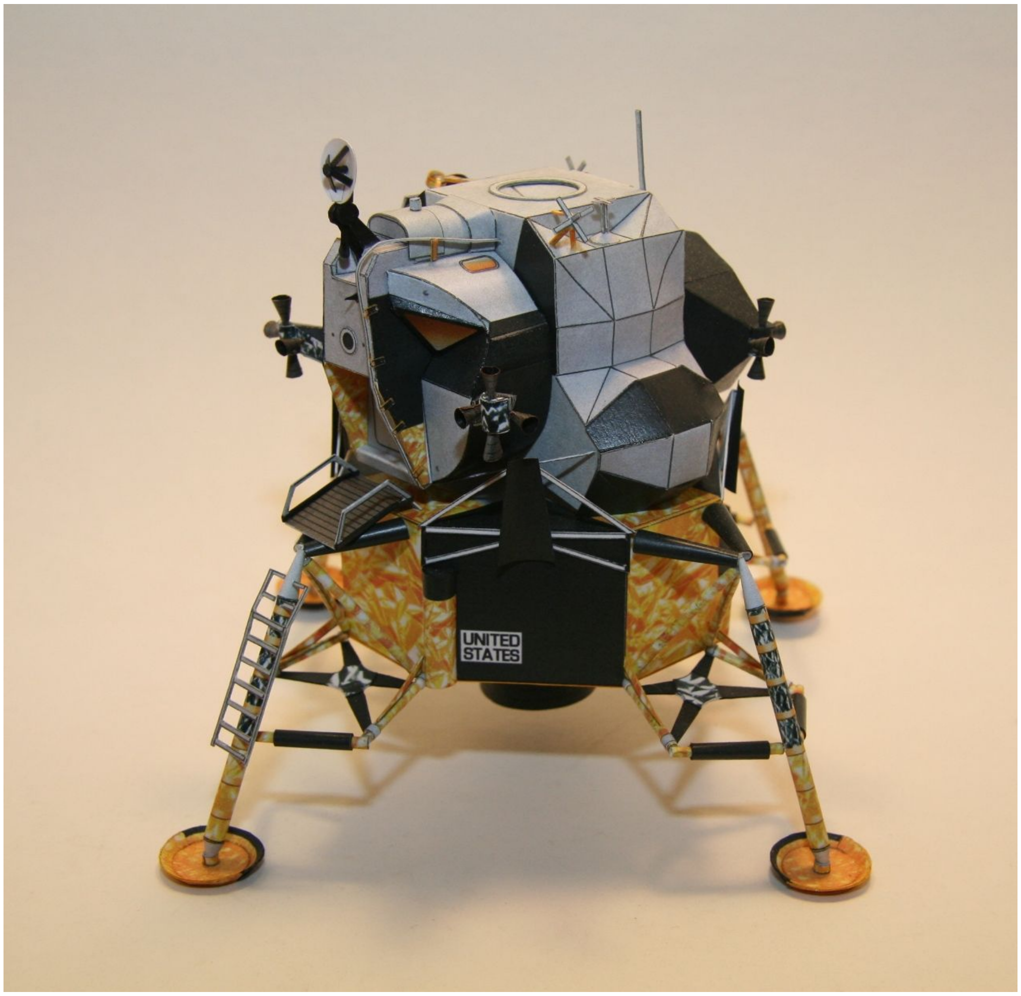
[13]Software (n.): The programs and other operating information used by a computer.
[14] "USS Sulaco | Xenopedia | FANDOM powered by Wikia." http://avp.wikia.com/wiki/USS_Sulaco. Accessed 10 Oct. 2018.

Below is a 1/48 LEM (Lunar Excursion Module).



History

What is paper modeling and where did it come from?

Paper modeling is also referred to as card modeling. It is a subset of a larger grouping called papercraft[15]. Papercraft includes any kind of art or construction that uses paper, cardstock, or cardboard as its primary medium. Beyond paper models, papercraft includes other artistic disciplines such as paper mache, decoupage[16], scrapbooking, origami, paper airplanes, and the like.

Early paper models first appeared in toy catalogs from France in the early 1800's. Even beyond toys, early hot air balloons were made from parchment paper by the Montgolfier brothers at the same time. What we think of today as paper models first appeared in the early 1900's. Even the Wright brothers constructed some of their design from paper to test and evaluate their viability in their home built wind tunnel. In the 1930's Jack Northrop utilized paper airplane models to do basic tests of new airframe and wing designs. The production of paper models increased significantly during World War II because paper was available and was not rationed like other materials (plastic, metal, etc). As paper models flourished the kits available covered subjects such as buildings and architecture, ships, airplanes, vehicles, and trains. Though, as time has gone on and plastic models became more widely available, the distribution of paper models has decreased.

In the later portion of the 20th century, Poland became one of the largest bastions of paper models and still has a large number of commercial paper model publishers today. At this time, paper models were just about the only type of model available in Poland. These kits were designed well, but the paper and printing quality lagged behind significantly as compared western European and American standards. In 1989 Poland changed dramatically as the country transitioned to a democracy. As a result of this, the maturity of printing technology advanced very quickly and paper quality reached that of Western standards.

Starting just after 2000, paper modeling had a great resurgence of interest and distribution. This was primarily due to the combination of inexpensive CAD tools to design models, inexpensive color inkjet printers, and the ability to easily distribute kits via the internet. This made it possible for independents and hobbyists to create their own kits and allow the world to acquire them. Previously, paper model designs were traditionally produced and distributed by publishing companies. This then shifted to a situation where control was held by individuals who could develop and distribute their own paper model kits on the internet. Some companies

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[15] Papercraft (n.): Any creative art form that uses paper as the medium. It includes paper models, origami, and paper mache.

[16] "Decoupage - Wikipedia." https://en.wikipedia.org/wiki/Decoupage. Accessed 17 Oct. 2018.

outside of the model industry began making kits available over the internet and used these as marketing efforts (usually for manufacturers of paper or printers).

While the overall interest in paper models in 2018 has decreased from 2010 levels, there are still numerous individuals and independents designing and releasing new models regularly, including the author of this book. In recent years, it has not been uncommon for fans of video games to extract the CAD models of objects from their favorite game and turn those into paper model designs.

A model of an M2A2 Bradley.

A 7.5ft tall, 1/48 Saturn V.

Basics of Building

This section will focus on the basic tools and techniques needed to construct a paper model. I will include a moderate amount of explanation around each of these topics. Some of them will be expanded upon in the advanced building section along with the addition of more complex topics.

Within each of the topics for the basics I will give you a line or two with the very short version of what you need to know if you have never made a paper model and then I will expand from there.

Choosing Your First Model

I've never made a paper model. - Start off with a simple model and progress to more complex ones as your skills develop.

You have decided you want to build a paper model. Great! Like with many endeavours, the skills that are used require practice in order for you to become proficient with them. You would not expect a new piano player to sit down and pound out Beethoven's Fifth symphony[17]. Similarly, it would be a disappointing experience to start with a very complex model only to become frustrated and annoyed by it. Because of this, I would suggest that you begin with a fairly simple model initially and then progress onto more involved designs over time.

Some models, such as warships and large spacecraft, can take months and months of work to complete. If you were to start with one of these kits as your very first model, I suspect most people would quickly become discouraged, frustrated, and angry… and likely give up the hobby. There is no point in making yourself miserable, so choose your first few models based upon your ability and interests. I would recommend a simple rocket model (NASA vehicles are mostly made of simple shapes) or a Cubee type figure as your initial project. Both of these are made of basic shapes and usually lean towards the simpler side of things with a modest number of parts.

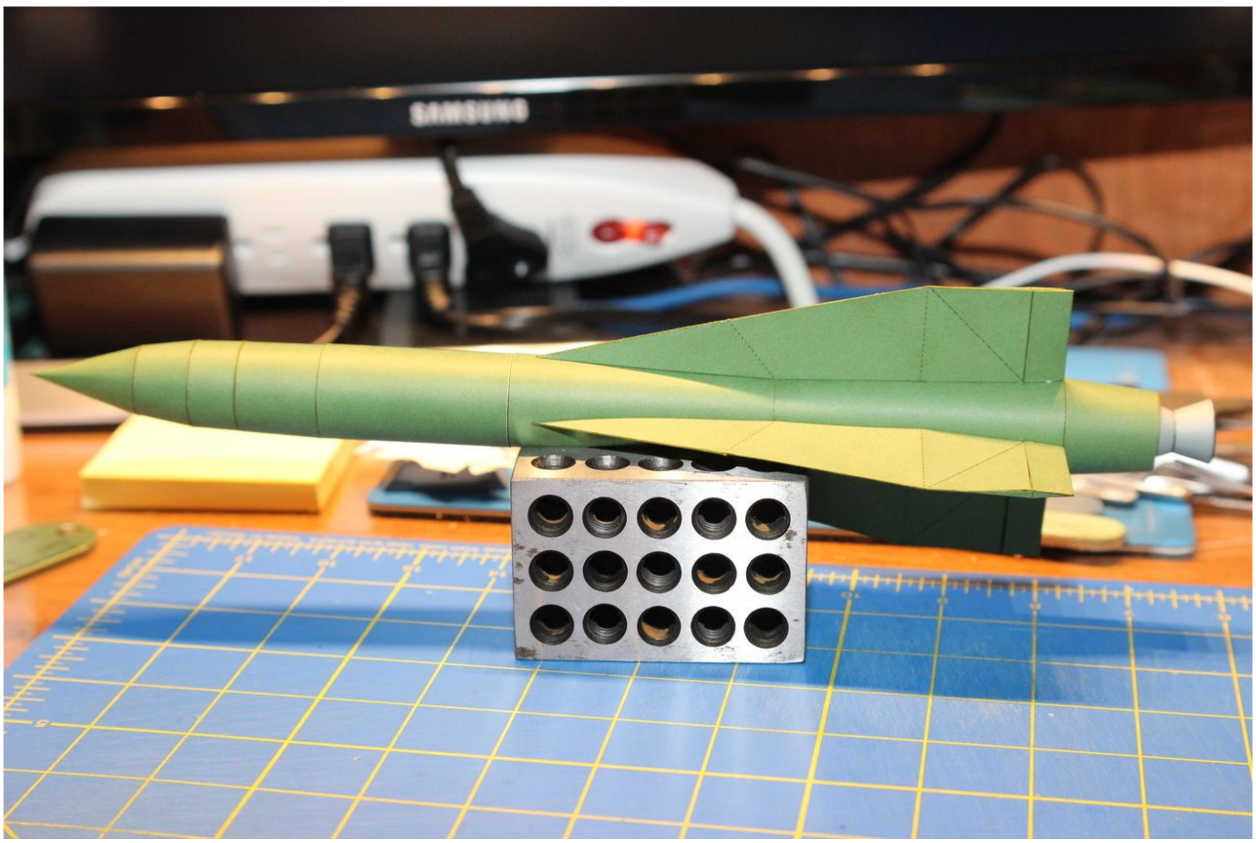
A rough approximation of difficulty can be made by looking at how many pages of parts and how many parts there are. If there are a dozen or so parts spread over one or two pages, that model is likely relatively simple. Some designers will indicate up front (usually on the title page) what level of difficulty they consider that particular kit to be. There are difficulty scales that run from 1-3, 1-4, 1-5, and 1-10. There are others that rely upon words to indicate the complexity by using phrases such as "very difficult" and "easy".

[17] "Symphony No. 5 (Beethoven) - Wikipedia." https://en.wikipedia.org/wiki/Symphony_No._5_(Beethoven). Accessed 9 Oct. 2018.

Whatever model you choose to build, it does not have to be perfect in the end. One of the great things about paper models that you print yourself, is that if you do not like how a part or subsection comes out you can print another copy and try a different way of building it again.

Beyond your very first model and developing your skills… what next? There are models of animals, ships, tanks, cars, trucks, airplanes, spaceships, science fiction vehicles, weapons, architecture, and figurines. Choose whatever model captures your attention. If a model does not interest you then there is little point in building it for fun… because it will not be fun. Pick models of subjects that you enjoy.

Many paper models have a handful of markings that tell you where and how to fold a part and how thick it should be laminated. I will cover these in more detail later on.



A simple Hawk missile[18].

[18] "MIM-23 Hawk - Wikipedia." https://en.wikipedia.org/wiki/MIM-23_Hawk. Accessed 3 Apr. 2019.

Tools

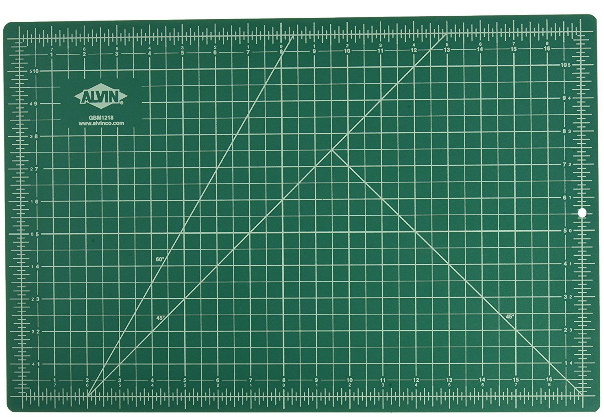
There are a handful of tools that are necessary to make a presentable model. While you could construct a kit without some of these, the result might not live up to your expectations. These needed tools should not cost too much money and should last you a good amount of time. When I moved from making plastic models to paper models, I had nearly all the tools I needed lying around already. For more advanced techniques there are other specialized and involved tools, but they are not necessary to jump into the hobby.

Cutting mat

I've never made a paper model. - Get a cutting mat from the hobby or art store that is 12x18 inches and is labeled as "self healing".

A cutting mat[19] is a definite "must have" for paper models. It allows you to have a stable work surface and will prevent your cutting tools from rapidly going dull. Mats will also prevent you from getting yelled at for destroying a nice wood table. Mats such as these come in various sizes from 6x6 inches (15x15 cm) up to ones that can cover an entire workbench.

I tend to use the ones that are 12x18 inches (30x45cm). This size is big enough to slice up any part that will fit on a normal size piece of cardstock and small enough that the price is reasonable. While many mats come with angle and measurement markings on them, I have found little use in those features. The important quality is that the mat is of the self healing variety. It should be ⅛ inch thick (2 mm), made of medium hard rubberized plastic, and preferably double sided. The rubber/plastic nature of the surface will allow the mat to absorb slices and cuts without getting cut to ribbons itself and prevent your cutting tools from rapidly going dull. Being double sided also allows you to flip it over to the backside once you have worn out the first side.



Cutting mats do wear out and eventually a "self healing" mat will not longer "self heal". This is when you know it is time to turn the mat around or flip it over to the unused side (or get a new one). This degradation occurs over time as you make cuts on the mat, but even under heavy usage a mat will last months or years. I find that I replace my mat every year or two with quite heavy use.

[19] Cutting mat (n.): A plastic mat is a material that you cut other objects on. It is designed to resist significant damage when materials are cut and a blade runs across the mat.

Once a mat has broken down past the point where you should be cutting on it, they can still be of use for holding completed parts or painting parts on them. For a mat like the one in the image above, if you are starting to get green flakes or green dust coming off of it after cutting, then it is definitely time to replace it.

Periodically, I will wipe my mat down with a damp cloth. This helps pull up any glue that may have dribbled onto it and wipe away any paper dust and building debris. I have seen a number of debates on the topic, as there are some people that occasionally add moisture to the mat with the notion that it helps prolong its ability to heal. Be sure that there is no moisture on the surface of the mat before using it to cut up parts. It should be thoroughly dry to the touch. A drop of water on a piece of paper printed with an inkjet can ruin it and make the printing run.

Scissors

I've never made a paper model before. - From the hobby or art store get a set of titanium or non-stick scissors with comfortable handles. Aim for a set that is either 6 or 8 inches long.

Scissors[20] will be used less than you would expect, but they will still be useful. Primarily, you will use them for cutting out large curves and separating sections of a page of parts to carve up with razor blades later on.

I recommend a pair that have non-stick blades and that will stay sharp a good long while. This means they will either be titanium coated or carbon steel with a coating. I will suggest a pair in the six to eight inch length range with comfortable grips. Do not overtax your scissors with hard or abrasive materials. If you try to cut something like thin tin sheets or sandpaper with scissors, you will quickly tear up the blades and they will no longer be suitable for paper. Similarly, use wire cutters for wire, as cutting wire with scissors will destroy them.

Again, you will be using these mostly for large scale curving cuts as opposed to small detail work.

For smaller parts you may want to have a tiny set of scissors, like those that would be used for trimming thread in needlework or cuticle scissors.

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[20] Scissors (n.): An instrument used for cutting cloth, paper, and other thin material, consisting of two blades laid one on top of the other and fastened in the middle so as to allow them to be opened and closed by a thumb and finger inserted through rings on the end of their handles.

Cutting blades

I’ve never made a paper model before. - Buy a set of chisel blades that are ½ inch wide (#10 blade) and a large handle to hold it. Also buy a few #11 blades and a thinner handle for them. Blades will eventually get dull and you will need to replace them.

There are a few different types of blades that could be useful to start out with, but only two are really needed initially. The first you will want to have is a chisel blade[21]. These can come in widths from .25 to .5 inches. I tend to use the .5 inch model more than any other cutting tool . You will want to have a large handle for it as that makes it easier to get a good grip on it.

I use the #18 style blades on a large red handle like the one below.

The chisel blade will be used for cutting out corners and small detail pieces. This is my go-to blade for anything that is not a long straight cut.

The second type of blade you will need is for long straight cuts. For this you can use any number of options. Any of the following will work: single sided razor blade, scalpel[22], and angled carving blades. Each of these needs a proper mount or handle so you can safely grip them.

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[21] Chisel blade (n.): A straight edged blade that is placed perpendicular to the material to be cut. As opposed to drawing the blade across a page, it is used to sheer vertically through the paper.
[22] Scalpel (n.): A knife with a small, sharp, sometimes detachable blade, as used by a surgeon.

Again, a comfortable handle with a textured grip is important for proper control. There are a number of options that fit this need and you can use whichever you feel comfortable with. Blades that are thicker (like single sided razor blades or carpet blades) can have more force applied to them to cut through paper, while thinner ones will buckle or break under that same pressure (scalpels). Thinner blades tend to be lighter and also give you more control. This is better for working with finer detail.

Also, do not be concerned with cutting through a thicker piece of cardstock in a single pass. You may need to take multiple passes to cleanly cut through it. Trying to put more pressure on the blade to go through thicker material will result in tearing, rough edges, and potentially breaking the blade. You could also cause the blade to jump or slip and hurt yourself badly.

With all blades, they will become dull over time. Paper and cardstock are some of the most abusive materials you can cut with a metal blade. Due to the fibrous nature of the material, a blade can be dulled within a few cuts, totaling just a few feet, under the worst conditions. You will need replacement blades eventually… and likely sooner rather than later.

Using a dull blade is not a good idea. It can lead to tearing the material instead of cutting through it. It certainly contributes to an increased risk of injury. [Author's note: This is said from experience.]

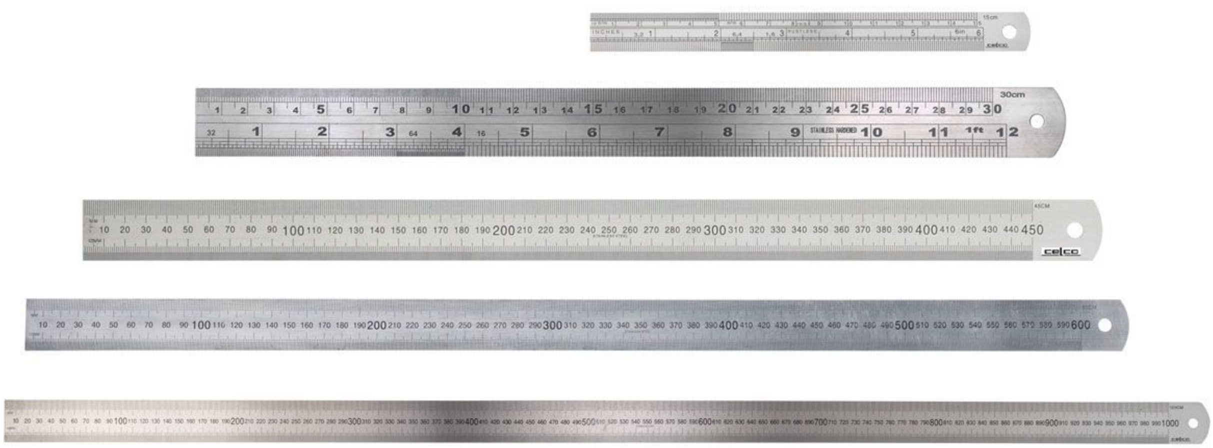
That being said, you will eventually cut yourself… sooner or later. Make sure to have some kind of bandage around just in case you need it. A dull blade and a bit of exhaustion led me to visit the Emergency Room in 2017 where I needed six stitches and several weeks of healing to put my finger back together. I had cut the side of my index finger and it was 60% severed along a 1 inch cut. Please[23] do not follow my example here. A year later I still have a noticeable loss of tactile sensation in my finger. I am intentionally not including an image of it here. After coming home from the ER, my work area looked like a crime scene.

[23] Finger injury (n.): Ow ow ow ow. Don't do it.

Straight edge

I've never built a paper model before. - Buy a metal ruler that is 12-15 inches long and does not have a heavy coating of paint on it.

You will need a straight edge[24] to guide your blade for long linear cuts. The straight edge will also be used as a guide for scoring parts. Get a metal ruler, as wood or plastic ones will just not work. Non-metallic straight edges will give you problems because your blade will cut into them causing them to bow and preventing you from making straight cuts in the future. I would recommend something around the 15 inch length, as this will allow you to make the longest possible cut on a piece of letter or A4 sized paper and a second straight edge in the 6 inch range for smaller work.



*images are not to scale.

It has taken many years (nearly a decade), but I have successfully worn out a metal ruler. After many 10s of thousands of cuts I began to notice a slight curve that has been formed by the razor blade rubbing against the ruler's edge. At that point it is time to replace it. I have and use multiple metal rulers that range in size from 6 to 24 inches.

[24] Straight edge (n.): Any device capable of being utilized as a guide that has a perfectly straight edge for long straight cuts.

Scoring tools

I have never build a paper model before. - Make a scoring tool out of a #11 blade that has been dulled or filed round. Alternatively, an embossing or scribing tool like in the picture below can be found at the local art store.

Later on we will get into how to score paper, but you will need a scoring tool[25] to make it possible.

Scoring allows you to make a clean fold along a piece of cardstock. It creases the page so there is a structural “break” for the fold to run along.

These types of tools are often re-purposed from other uses. I use an angled hobby blade that had become quite dull, which I then further rounded off with the application of a file. Other people use ballpoint pens that no longer have any ink, the back of a razor blade, or the tip of a thin knitting needle. The purpose of this tool is to make a linear crease and selectively compress the paper. This causes a weak spot that allows the paper to fold easily. You do not want a sharp blade for this tool as it will slice through the part as opposed to crease it.

It will take some practice to figure out how much pressure you need to apply with a scoring tool. If you apply too little, your folds will not be crisp. If you apply too much, you can go through the paper or it will split when you fold it. The paper thickness, grain, scoring tools, and the surface you are scoring on will determine how much force is required.

[25] Scoring tool (n.): An implement for creasing material.

This is a dulled #11 blade used as a scoring tool. The rainbow effect in the metal is from heating the blade (to soften it) and filing, so it loses its sharp edge.

Dowel and pad

I have never made a paper model before. - Get a foam mouse pad and some inexpensive dowels for curling and rolling parts.

A common operation in building paper models is to roll a part such that a curve is imparted upon it. In woodworking, this would be done by steaming a board and clamping it to a form, then letting the board cool to retain the shape of the curve. Parts are rolled for situations where you need them to be cylindrical in shape or that involve any kind of curve. To do this involves dowels[26] and potentially a pad to roll the parts on. I have a number of different sized wood dowels and metal rods that I can wrap parts around. Some people will use their hands to shape the part around the dowel and others will use their pants leg and yet others use a foam pad (mouse pad). My preference is to use a mouse pad as the base on my desk, as this provides a stable and consistent surface to roll parts upon.

For the mouse pad, I recommend a thicker foamier style pad at least ⅛ inch thick. The thicker it is the easier it will be to achieve a tight curve on the part you are shaping.

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[26] Dowel (n.): A cylindrical piece of wood or metal tubing.

Paper

I have never built a paper model before. - Buy a package of 60-67lb cardstock from the office supply store.

Not all paper is created equal, and saying merely that a model is made of paper is to simplify the situation to the point of being misleading. Several factors go into the varieties of paper you might use… size, weight, thickness, finish, and grain. The main ones you will concern yourself with, and that have many choices, are size and weight/thickness. If you are buying a pre-printed model then you have no choice in any of these details. For a pre-printed model you will use whatever the publisher printed the kit on to. These details only come into play when you are printing a model yourself.

To get the easy items out of the way, the finish[27] will either be matte or glossy. Glossy paper is usually sold as paper for printing photographs. But most of the paper you will come across is matte (non-glossy). The other simple detail is grain[28]. This refers to how fine and tightly packed together the individual fibers are within the piece of paper. This will vary from weight to weight and brand to brand of paper. You will not have a choice of grain other than to switch paper weights or manufacturers. The grain determines how smooth the texture of the paper is and how much ink (either from an inkjet printer or a pen or marker) will bleed. The larger the grain the rougher the paper will feel and the greater the bleed of the ink. The finer the grain the smoother it will be and that will cause less bleeding of ink.

For size, there are two main standards of measurement… metric and imperial. Generally, you will have access to paper in one set of standards or the other, but not both. This will depend upon the country you are in.

Imperial measurement standards will result in 8.5x11 inch paper (letter size), 8.5x14 inch (legal size), and 11x17 inch (ledger size). You will find the greatest selection of weights and thicknesses for 8.5x11 inch pieces of paper.

Metric paper measurements are A4 (210x297 mm), A3 (297x420 mm), and A2 (420x594 mm). These are the closest equivalent to the imperial sizes, but are not identical to their imperial counterparts.

Primarily, you will buy whatever size is available in your region. Beyond that, the weight of the paper will be the specification that will concern you the most. Thinner and lighter paper will crease more cleanly, hold more detail, and look crisper. Thicker and heavier paper will offer more strength and rigidity to your model, but will cause ink to bleed more. There are multiple

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[27] Finish (n.): A description of how shiny or dull a particular surface is on an object.
[28] Grain (n.): The longitudinal arrangement or pattern of fibers in wood, paper, etc.

ways for the paper weight to be identified, but the two main ones are metric (measured in grams per square meter) and bond ledger (the weight of a 500 sheet ream of the material 17x22 inches across).

Basic printer or copier paper is 20 lb or 75gsm and moderate card stock is 67lb or 260gsm. Paper in the US can commonly be found in the range from super thin (18lb) up to very thick (120lb) with multiple weights in between. Beyond 120 lb stock, the material is not what you would think of as “paper”. At that point it more resembles poster board, chipboard, or cardboard.

A list of all the currently used weight standards and conversions between them can be found here: http://www.paper-paper.com/weight.html

Overall though, the higher the weight rating, the heavier and thicker the paper will be. There will also be slight variations in thickness from manufacturer to manufacturer.

Printing

I have never built a paper model before. - *Use a color inkjet printer if you have one at home or pay for some pages to be printed on cardstock at the local office supply store.*

If you are building a pre-printed kit, then this section will not pertain to you. But if you are printing a paper model yourself there are a few key items to keep in mind. While some models will look good in just black and white, most will require some kind of color. As a result, a color printer is nearly a must have. The next question becomes whether it is an inkjet printer[29] or laser printer[30].

Laser printers are good in that the colors will be sharp, clear, and as vibrant as the toner in the cartridges. The downside is that unless you have a relatively high end laser printer with a very hot fuser[31] (the part that causes the toner to melt into the paper and adhere), the printing can flake off of thicker paper when you are working with the parts. You can imagine that it would not be ideal to spend a bunch of time on a model and have the toner flake off the page as you are folding and manipulating the pieces. A very hot fuser will do a better job of causing the toner adhere to heavier pieces of card stock. The higher end fusers can usually be found in larger laser printers, such as those used by large businesses or high end copy centers. These are more industrial types of laser printers and not likely one you would have at home. Hotter fusers are needed for cardstock because the paper is much thicker. It is akin to trying to iron a shirt which has a towel on top of it. You can make progress on the shirt that way if the iron is hot enough, but applying the heat directly to the shirt would be much easier.

Inkjet printers do not have the issue of the ink flaking off of the page as you manipulate the parts. They have the opposite effect where the wet ink from the printer can bleed through the fibers in the page. The colors are often not as crisp as compared with a laser printer. But an inkjet printer is much less expensive to buy and maintain.

With either type of printer, you will need to make sure it can handle the weight of paper you are working with. Not all printers are capable of working with cardstock (60lb and heavier). With all that being said, for a couple hundred dollars you can find a nice inkjet printer that can handle cardstock where a laser printer with a fuser capable of getting very hot will cost many thousands of dollars or more.

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[29] Inkjet printer (n.): A printer in which the characters are formed by minute jets of ink.

[30] Laser printer (n.): A printer producing good-quality printed material by using a laser to form a pattern of electrostatically charged dots on a light-sensitive drum, which attract toner (or dry ink powder). The toner is transferred to a piece of paper and fixed by a heating process.

[31] Fuser (n.): Component of a laser printer that heats the toner causing it to adhere to the page.

When printing, most applications default to some kind of automatic scaling. This will shrink the content of the page down to whatever the printer can handle putting onto a piece of paper. This includes such details as adding borders and margins. This scaling will vary from printer to printer and from page to page, depending upon how much whitespace is on the page in the file. If your model is comprised of 10 different pages worth of parts, they could all end up at a slightly different scale than each other. If this happens, it will only make the whole effort confusing and parts will not fit together properly. Thusly, it is recommended that this feature “Fit to Page” be turned off (print at 100% normal size).

If the content of the file you are trying to print does not fit on your combination of paper and printer with zero scaling, then you would want to manually set the scaling factor to less than 100% so that everything prints out at the same scale. This usually ends up being 98% or 96% or something else just under 100%. If a file for a model was laid out for your size paper, then often times just turning off “Fit to Page” will be enough to provide good results. The specific scaling is generally needed when a file is laid out for A4 paper is being printed on letter size paper or a letter size design is printed on A4 paper.

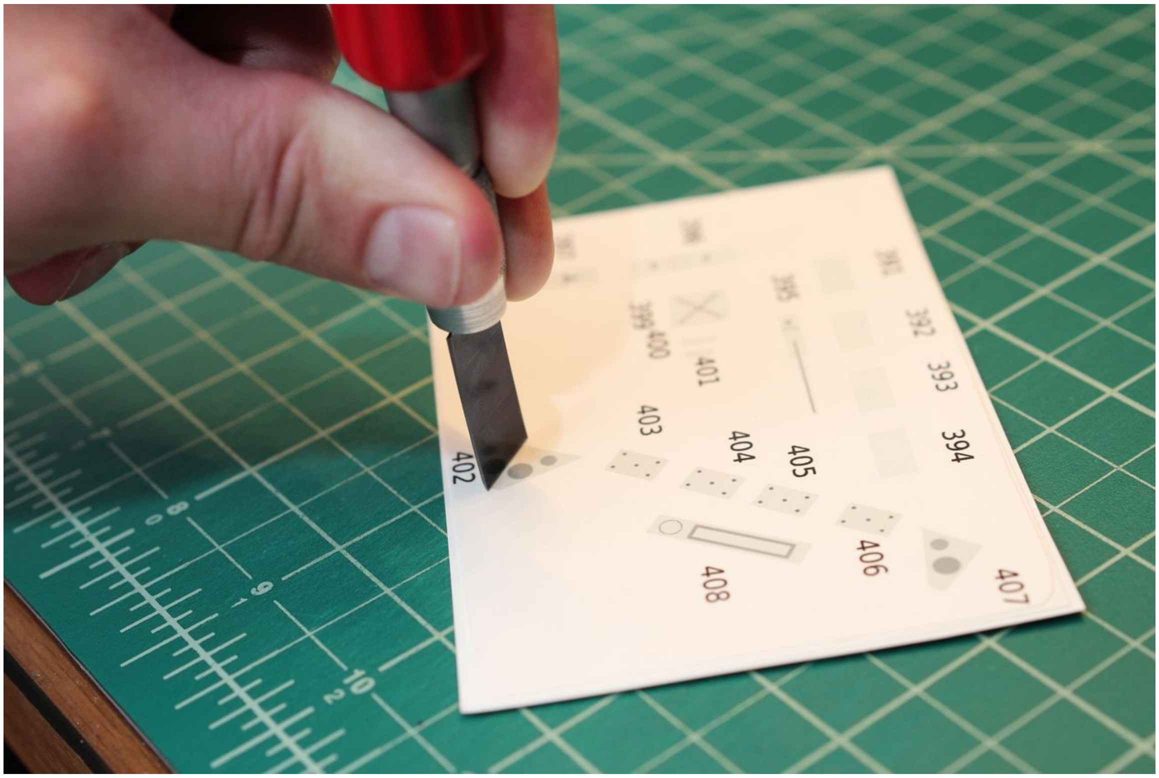
Cutting

I have never built a paper model before. - Hold your metal straight edge along the line you wish to cut and draw your blade along its edge. Use multiple passes if needed.

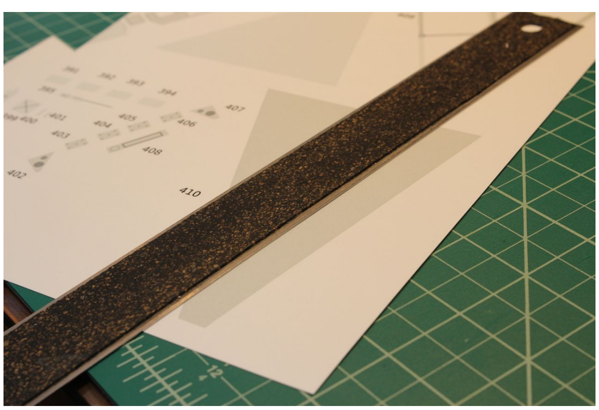
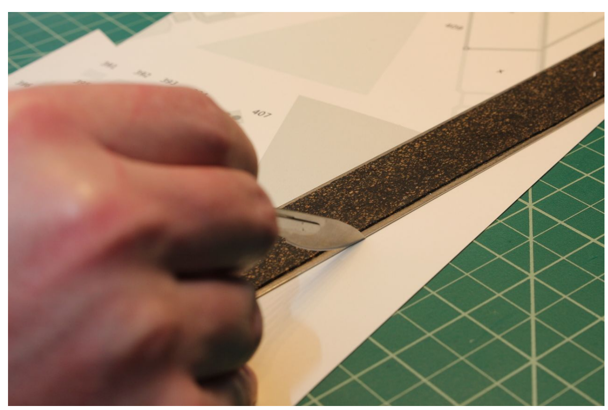
Cutting through a piece of paper sounds like it would be pretty straightforward to do. It is both as simple as you would imagine and also horribly complicated. The complicated parts I will include later on in the advanced section of this book. From the basic standpoint, there are three main ways you will be cutting the paper.

Scissors - You will use scissors to cut along curved lines and to separate one set of parts from others on the page. Resist the urge to use the scissors to cut out the straight edges of parts. Even with as steady a hand as you think you have, the methods below will offer a far better result.

Chisel Blade - You will use a chisel blade to cut out corners, small parts, and small straight edges on parts. Hold the chisel blade upright to your cutting surface (perpendicular) and apply a downward force through the paper into the cutting mat below.



Drawn Blades[32] - This group is made up of any blade you hold at an angle and pull across the paper. Implements such as hobby blades, box cutters, razor blades, and scalpels fall into this category. With a steady hand you can cut out nearly any shape with a drawn blade. For those of us who do not have that control any longer, you can generate better results by using a metal straight edge as a guard and slicing down the side with the blade. This is the best way to cut a straight line.

[32] Drawn blade (n.): Any blade that you hold at an angle and pull across the materials you are trying to cut.

Scoring

I have never built a paper model before. - Hold your metal straight edge along the line you wish to score and draw your scoring tool along its edge with moderate pressure.

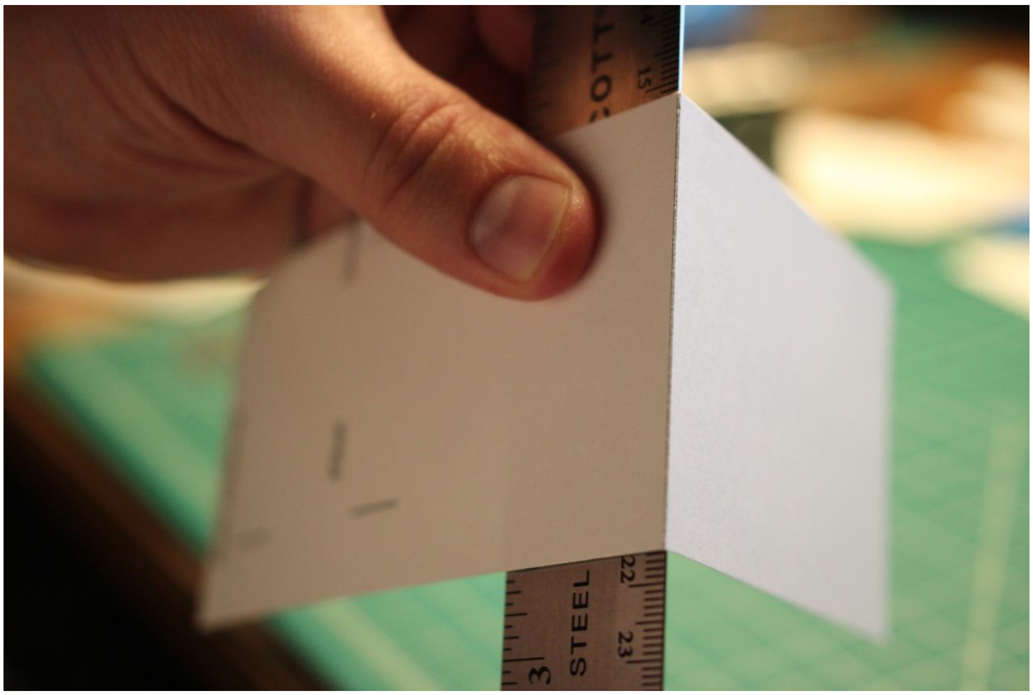
Many parts of a model will require a fold in them at some point. If you have ever tried to put a fold in a specific place on a piece of cardstock without assistance… by hand… you know that it is difficult to get that fold where you want it and difficult to make it clean and crisp. Scoring[33] will take care of this type of situation for you. Using your metal straight edge and scoring tool, you will draw the tool across the line to be folded. The purpose is not to cut through the paper with the scoring tool, but instead to crease or compress the paper in a very specific place. This weakens the paper along the score line and allows you to fold it cleanly.

[33] Score (v.): To impart a crease or weak line across a piece of paper. This allows for a clean fold to be created across the scored line.

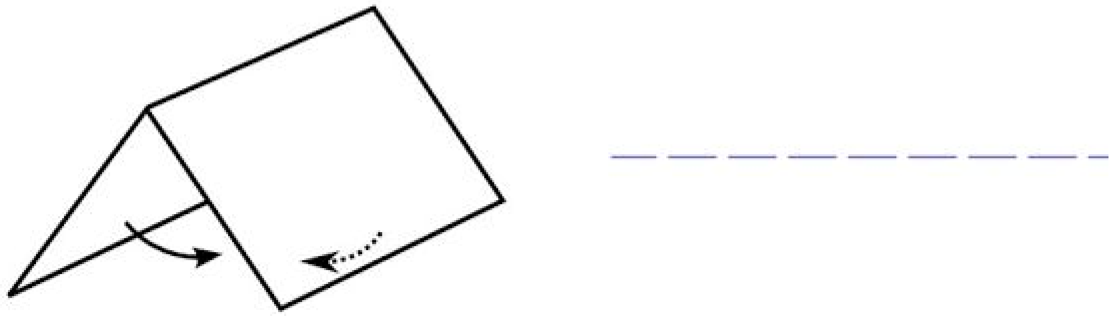
Folding

I have never built a paper model before. - There are some common markings on models indicating how to make the fold. Dotted lines with a constant size dash indicate you are to make a mountain fold. Dotted lines with long and short dashes indicate you are to make a valley fold. Score along these lines so they are easier to manipulate.

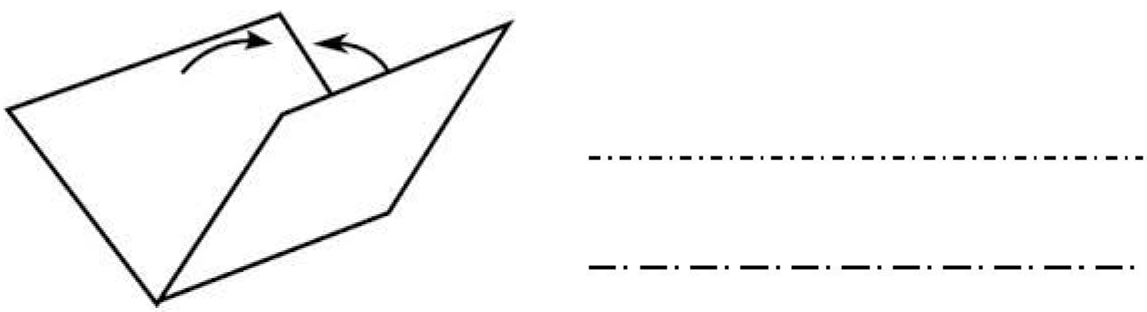
If a fold line is scored properly, you can usually fold it without issue using your fingers. For longer fold lines you may need to use the edge of a desk or straight edge as a support to complete the fold. In a metal shop, this would be the equivalent of using a press brake.



There are two types of fold indicators commonly used in paper models. The first is an evenly spaced dashed line. That evenly spaced dashed line represents a mountain fold[34].



The other type of marking is alternating long and short dashed line and it indicates the need to make a valley fold[35].



These lines may appear in various colors and contrasts on the model parts in an attempt to make them blend into the finished work. In a perfect world the fold lines will be clear enough to identify and allow you to score them, but faint enough that they do not detract from the finished model. In some situations the designer will make the fold lines in whitespace outside of the part on the printed page. This gives you the same indication for where to score and fold, but completely eliminates any markings on the printed part.

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[34] Mountain fold (n.): A fold where the fold line appears like that of a mountain peak, where the fold line is pointing up.

[35] Valley fold (n.): A fold where the fold line appears as if it is a valley between two mountains, where the fold crease points down.

Rolling

I have never made a paper model before. - Put the part, concave side up, on the mousepad and roll over it with a dowel like you were rolling out cookie dough.

Another important technique, which will be used for shaping cylinders, is rolling[36]. Rolling is used to form cylinders, tubes, and curved surfaces of various types.

Using your mouse pad and a dowel, roll the part between the two until the curve begins to form. Using progressively smaller dowels and increased pressure you can form the part into a tighter and tighter curve.

[36] Rolling (v.): To impart a curve to a piece of paper such as to create a tube or cylinder.

Glue

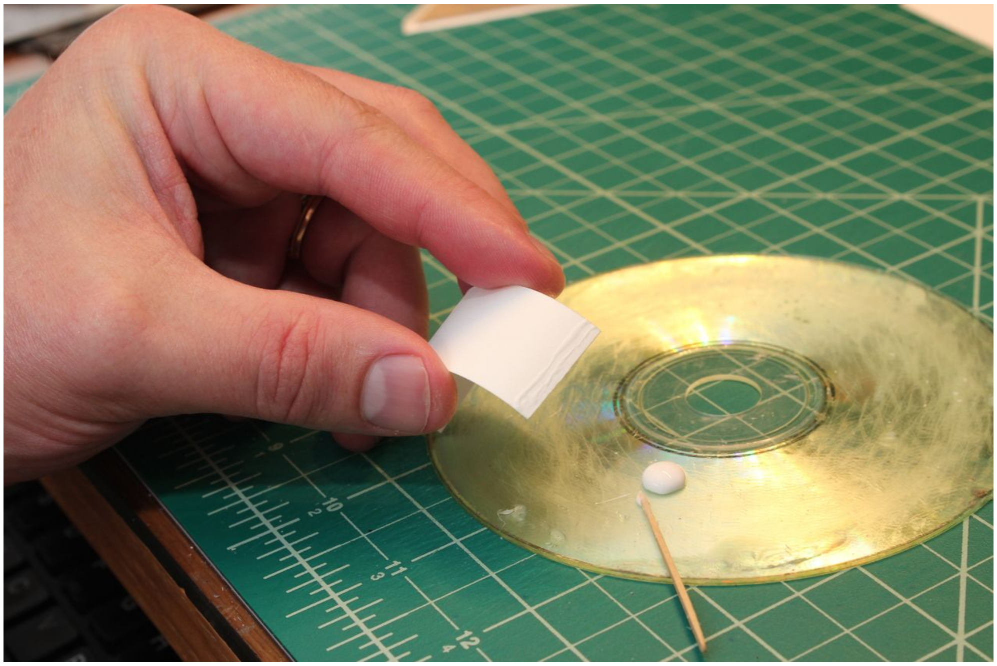
I have never made a paper model before. - Buy a bottle of Aleene's tacky glue from the local craft store. Dispense a blob of glue from the bottle onto a piece of cardstock or an old piece of plastic and use a toothpick to apply it to the seam on your model.

Fundamentally, glue[37] needs a surface on a part that it can bind to. With paper, as a fibrous material, it has lots of texture and microscopic nooks and crannies. This is perfect for glue to properly adhere.

How much glue should I use? The short answer here is "enough". But this does not tell you much. You want to use enough glue to securely bond the parts together and no more. That is to say, use as little as you can where you still get the structural integrity and strength you desire. Applying too much glue (over applying) can lead to unsightly smears, smudges, and blobs on the outside of your creation. Using too little glue (under applying) will lead to weak joints and potential separation of parts later on.

Resist the urge to use the tip on the glue bottle to apply it. The bottles themselves are not precise applicators and will not give you nearly the control that you desire. Instead, deposit a blob of glue on a piece of scrap material and use a toothpick or straightened paperclip to apply the glue to your model parts. This will give you a much greater level of control and precision. I utilize an old CD as a glue pallet because they are abundant, worthless, and have enough weight to stay on my desk when using a toothpick to gather glue.

[37] Glue (n.): An adhesive used to fix two objects together.



One of the most common questions for new paper model builders is what kind of glue to use. The super short answer is to use whichever one works for you. That answer also tends not to include very much information though. A slightly longer answer is to start with a water based PVA white glue[38] which will dry clear. These come from brands such as Elmers, Aleene's, and UHU.

Personally, I use almost extensively Aleene's tacky glue. It is quite strong once it dries and when applied contains less moisture than most other brands. If you have too much moisture in the glue it can cause parts to warp and deform. As a rule, you do not want your parts to take on strange curves and bubbles as you are working with them.

Another type of glue I often use are large generic glue sticks from the local office supply store. These are ideal for when you need to laminate a part to make it thicker or have large surfaces to adhere together.

If additional detail needs to be added to a model, such as with wire or railings, CA glue[39] (super glue) is the ideal choice for those items. CA comes in varieties that range from very thin to very thick consistencies. They also come in various drying times from just a few seconds to many minutes. For long drying varieties a bottle of CA accelerator is also a good addition to the drawer of supplies.

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[38] PVA glue (n.): A water based glue made with polyvinyl acetate.
[39] CA glue (n.): A glue made of cyanoacrylate. Also known as super glue.

Each builder will find methods and uses for various types of glue, so having a few varieties available can be very useful for non-trivial projects.

Markings

Various types of instructional markings can be found in model kits. Some indicate a cut, fold, or another type of action. Here is a brief list of the most common markings you might find and what they mean. If there are other markings, they should be noted in the model's instructions and can vary drastically from one publisher to another. Since the largest concentration of commercial paper models comes from Poland, I am including a few Polish terms which you may encounter. For the dotted lines, you may need to use your discerning eye to separate instructions for folds from surface detail printed on the part.

- Solidly spaced dotted line — — — — — — — — — - mountain fold
- Long and short dotted line —·—·—·—·—·—·—·—·—·—· - valley fold
- Thin outline - generally means to cut the line
- X - remove the blank space for a cut-out within the face of a part
- * - laminate to .25mm, will be clarified in the instructions
- ** - laminate to .5mm, will be clarified in the instructions
- *** - laminate to 1mm, will be clarified in the instructions
- L., l., lewa - Polish shorthand for left
- P., p., prawa - Polish shorthand for right
- Kleic - Polish for glue
- Cz, czesci - Polish for parts
- Krawedz - Polish for edge
- Odcinac - Polish for cut off
- W., w., wreg - Polish for frame or former

Scales

The vast majority of the time, models are not the same size as the object they are trying to represent. They are usually smaller than the item in real life. This reduction in size is defined by the scale[40] of the model. This is expressed as a ratio with either a colon or slash, such as 1/48, 1:144, 1/87, etc.

These numbers represent how much smaller the model is over the real life object. A model in a scale of 1/48 will be one 48th the size of the real item. If we are talking about an airplane with a wingspan of 24ft and the model is in 1/48 scale, then the model's wingspan will be half a foot. The scale tells you how much to divide the original measurements by to get the resulting model size. The larger the number in the scale, the smaller the model will be compared with the original object.

There are other mechanisms for specifying a model's scale as well. One of these is used when referring to model railroad components. Here is a list of the common railroad scales and their equivalents.

- G scale - 1:25
- O scale - 1:48
- S scale - 1:64
- HO scale (half O) - 1:87j
- N scale - 1:160
- Z scale - 1:220

A third common way for models to have their scale described is their height. Common variants are 10mm, 15mm, 25mm, 28mm, and others. This measurement represents how tall a miniature figurine is. These notations are most commonly used for tabletop wargaming figurines. Since a 28mm figurine of a soldier (roughly 6ft tall) and a 28mm figurine of a tank (roughly 12ft tall) are both 28mm tall, there is only approximate relationships between this notation of scale and others. Having all of the figurines the same height allows for compatibility with any wargaming system designed for that size.

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[40] Scale (n.): the relative size or extent of something

Advanced Building Techniques

In this section I will cover some of the previous topics with additional detail and delve into several new ones.

The hardest technique to learn is patience, because we all want to see the finished product as fast as possible. Take your time and test fit[41] your parts before committing to a course of action. Slow down, take your time, and the finished result will be better than if you had rushed through it.

Many concepts from other forms of model building can and do apply to the construction of paper models. But there are a few ideas and concepts that apply only to paper due to the properties paper has as a construction medium.

Environmental Concerns

There are some obvious concerns with moisture and paper models. Water will be absorbed by the paper and start to degrade [read: turn into mush]. Because of this we will want to keep finished models in low moisture conditions and out of direct sunlight. Using acid free paper and ink will extend the life of a finished model, and this can be helped even further by using a fixative spray from an art store.

Without using acid-free materials or a fixative, solely keeping the model in a dry place will allow it to last a couple of decades. The main sign of age will be yellowing of the paper which is caused by the breakdown of the paper from exposure to sunlight.

But up front, before you have finished the model, there are a number of things you can do that will make the building process go smoother.

For those of us that excel at sweating, the moisture build up in your hands can smudge ink and cause parts to warp. The best solutions here are to lower the moisture content of the air (dehumidifier or air conditioning) so that any moisture on your hands evaporates quickly. The next option to deal with clammy hands is to rub a very small amount of antiperspirant on your hands. This will prevent your body from sweating as much through your palms and fingers.

If you live in a dusty environment, you will want to limit the airborne contaminants as much as your can with an air filter or fan. Dust and grit in glue joints will weaken them and a buildup of

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[41] Test fit (v.): The act of testing a part in a larger section of a model. This involves aligning seams, matching textures, and verifying the proper shape and orientation without permanently affixing it.

dust on a model is no fun at all. Trying to dust a model ship covered in railings and antennas can easily result in parts getting ripped off.

Keep food and beverages away from your work area. Even a little drop of oil from food can ruin many hours of dedicated work. Similarly, I have knocked over mugs of tea[42] which sluiced across my desk and doused models I had spent more than a hundred hours on. After that occurred I did not have the heart to attempt to build that model again. The drowned half-completed model ended up in the rubbish bin.

From an obvious safety perspective, keep all of your cutting tools out of the reach of children and away from pets.

Do I even need to mention how bad drinking and very sharp tools can go together? No, I did not think so. [Author's note: Swilling a martini[43].]

The fixative[44] I mentioned above can also be used to treat freshly printed inkjet pages. It will help prevent your fingers from smearing any of the ink as you work with the parts. The downside to fixative is that it will mute the colors that have been printed onto the page.

To that same end, several companies make finger gloves (which jokingly are referred to as finger booties). They are similar to rubber gloves but they only cover a single finger each. These can definitely limit the amount of moisture conveyed by your fingers.

Lighting is another aspect that can make your life much easier or much more difficult. Having enough light in your work area is important for eliminating shadows. With an absence of shadows seeing the lines to be cut or scored becomes much simpler. If you have insufficient light with shadows being cast, it can be difficult to see the score line that runs across a dark part or to even see the cut lines. Having good lighting is also important later on when you decide to take photos of your creations.

[42] Tea (n.): A hot drink made by infusing the dried crushed leaves of the tea plant in water. The best drink ever excluding martinis.

[43] Martini (n.): A cocktail made from gin or vodka and dry vermouth, typically garnished with an olive. The best beverage ever (if you omit the olive).

[44] Fixative (n.): A chemical application used to preserve or stabilize markings on paper prior to construction.

Tools

Clamping tools

Often times we need to apply some pressure to parts while glue dries. And when you have fists consisting of ham and fingers made of butter, mechanical assistance becomes a great benefit. Some of my most used tools are medium sized self-closing forceps[45] and hemostats[46]. Both of these can be found at military surplus stores or online. They are available both with pointed and rounded tips and with or without serrated jaws. The pointed tip varieties of clamping tools are good for getting pressure applied deep in a corner of a part. The rounded tips apply a more even distribution of force to hold two parts together. The one downside to hemostats is that they usually have serrated jaws. Those serrated teeth can impart unwanted marks upon your parts. A way to ameliorate the effects of teeth is to either file the jaws smooth or use thin pieces of cardboard between the teeth and the parts of your model.

Be warned though that hemostats are not meant to have their jaws spread apart with thick material when locked in place. They are designed to lock completely closed. As a result, they can break if too much force is applied to them. A method to avoid this unfortunate situation is to bend one of the handles on the hemostat to prevent over tensioning the lock and stressing the pivot pin.

Beyond hemostats and forceps, there are a good number of clamping tools that can be used. A few other items that are readily available and inexpensive in the home are clothes pins, hair clips, and pliers. Pliers also have serrated teeth and can impart teeth marks into parts like hemostats mentioned above. You can use the same trick of inserting thin pieces of cardboard to protect the part from the teeth on a set of pliers.

I would not recommend using rubber bands, as they do not stop applying pressure once the paper relaxes into your desired shape. This can lead to the unfortunate event where a rolled part is crushed under the force of the bands. Depending upon the makeup of the rubber used in the rubber bands, oils from the bands can be drawn out and will stain your parts.

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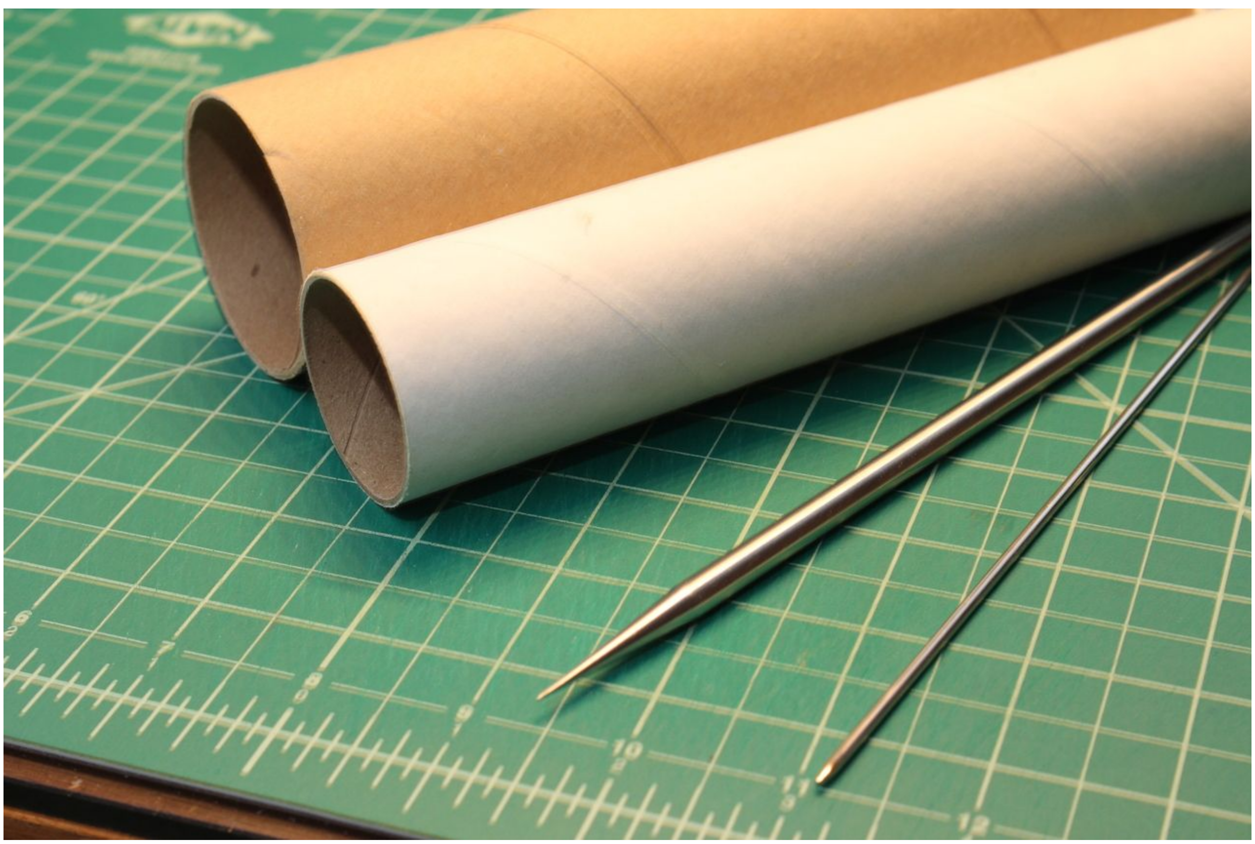
[45] Forceps (n.): A pair of pincers or tweezers used in surgery or in a laboratory.
[46] Hemostat (n.): An instrument for preventing the flow of blood from an open blood vessel by compression of the vessel.

Tubes and rods

I have a selection of multiple dowels and tubes that I use for rolling parts. These help give the part a curve that would not be possible to reproduce with other mechanisms.

I also use the cardboard core from paper towels to form parts. You will find that once you roll a part it desires to flatten out again afterwards. After rolling, there are still residual forces and tension in the paper. Letting a part sit for a time in the desired shape allows those residual forces to dissipate. I have found that if I roll the part, put it inside another cylinder with a diameter smaller than that of the finished part, and let it sit for a few hours reduces the uncurling effect. This leads to the paper relaxing into the curved shape. When the part stays in the proper shape it is much easier to glue a cylindrical part to others.

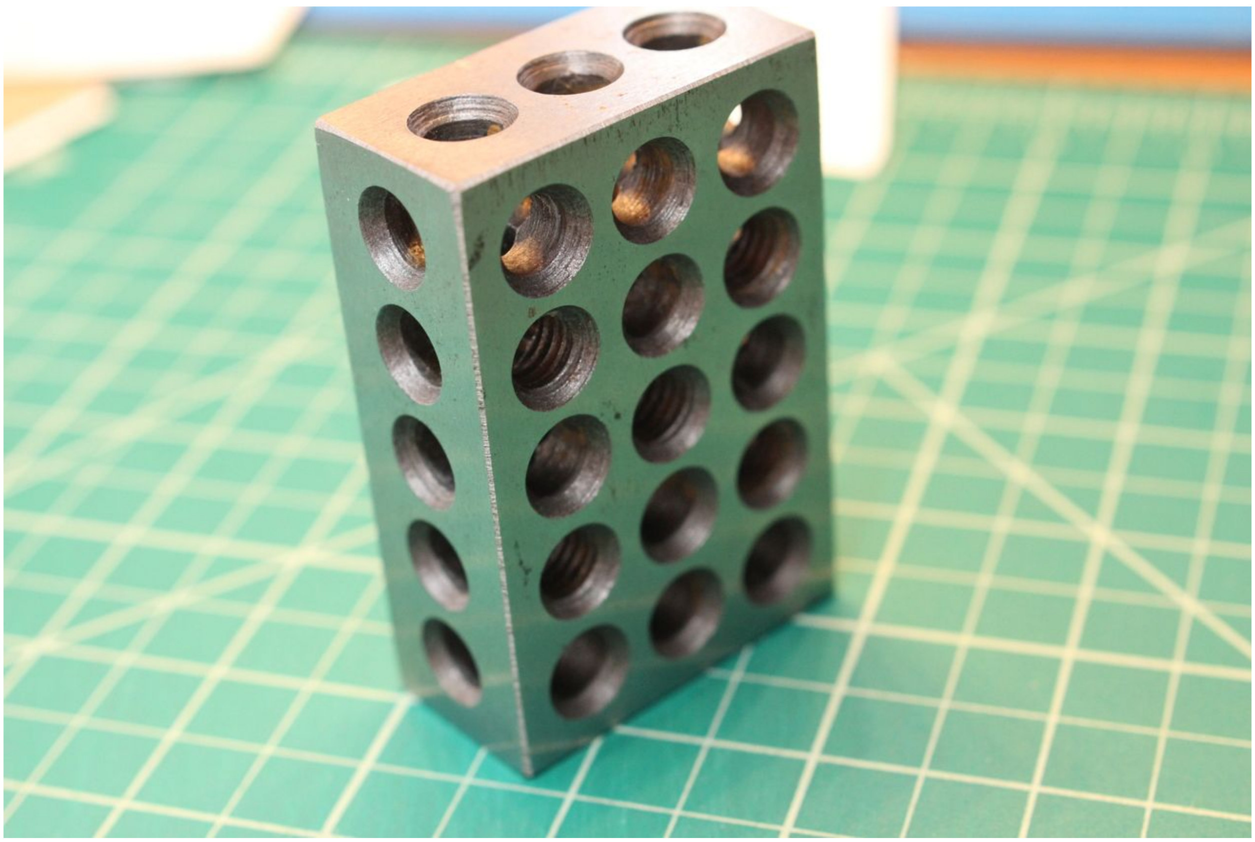
In addition, knitting needles are good for rolling as they are stiff (metal, often steel or aluminum) and of a relatively small diameter. I have some that go all the way down to 1.5mm in diameter.



Weights

When you laminate parts, to make them thicker and stronger, significant amounts of glue are required. With that much moisture applied to the page, the paper has a tendency to curl along one axis. This is where weights come into play to keep the part flat and to apply compression to the parts made of multiple layers. You can use nearly anything that is clean and flat for your weights.

I use a series of 1-2-3 blocks[47] I got from a machinist's shop. They are very flat and since they are made of steel they weigh a good bit themselves. For larger parts I have two pieces of wood with a flat glossy finish and then heavier weights on top of them. I can slide my parts between the two pieces of wood and let the 25 pounds of weight compress the parts together.



[47] 1-2-3 block (n.): A block of steel, commonly used in metal machine shops, that has holes drilled through it in each direction. They measure 1x2x3 inches in size.

Brayers

Historically, brayers[48] are handheld rollers used to break up and evenly spread ink in printing presses. But in model building we will use it for a different yet similar purpose (spreading glue between parts). While applying downward pressure on the dry side of a part, the brayer is run along a glue seam or a laminated part to ensure that there is good contact between the two layers of paper. It also allows the glue to flow, to a degree, between the layers of the lamination.

For laminated parts I use the brayer to make sure the layers are attached to each other then put the page under some weights to ensure it dries flat.

You only really need one brayer in your toolset. A 3 inch to 4 inch wide model will be sufficient for just about any situation you encounter.

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[48] Brayer (n.): A rubber roller used to press two layers of a lamination together.

Circle cutters

One of the more difficult shapes to cut out cleanly is an ordinary circle. It can be done with a set of scissors if you have a very steady and consistent hand, but it is not easy. As an aid, there are specific tools designed to assist in cutting circles. These tools are often made up of a center pin that you put in the middle of the circle and a blade that can be locked into place at various radii. Like a compass[49], you rotate the circle cutter around the center point to cut out the circle. The problem with these devices is that they will either work brilliantly for your situation or they will not work at all. They also assume you know the exact center of the circle initially.

One variety of circle cutter positions the blade in set increments from the center point of the circle. This is all well and good if your circle exactly matches one of the sizes that this type of cutter can handle. If it is not an exact match, then you are out of luck.

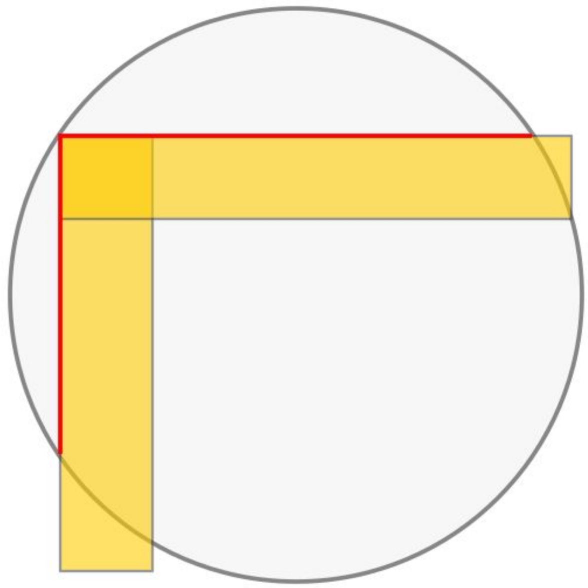
The second set, as mentioned initially, have a continuously variable radius for the blade. These give you more options and they behave like a drafting compass. With a variable radius cutter though, there is only so small of a radius that can be achieved due to the structure of the arms. If you wish to cut a circle smaller than that, this tool will not help with that situation.

[49] Compass (n.): An instrument for drawing circles and arcs and measuring distances between points, consisting of two arms linked by a movable joint, one arm ending in a point and the other usually carrying a pencil or pen.

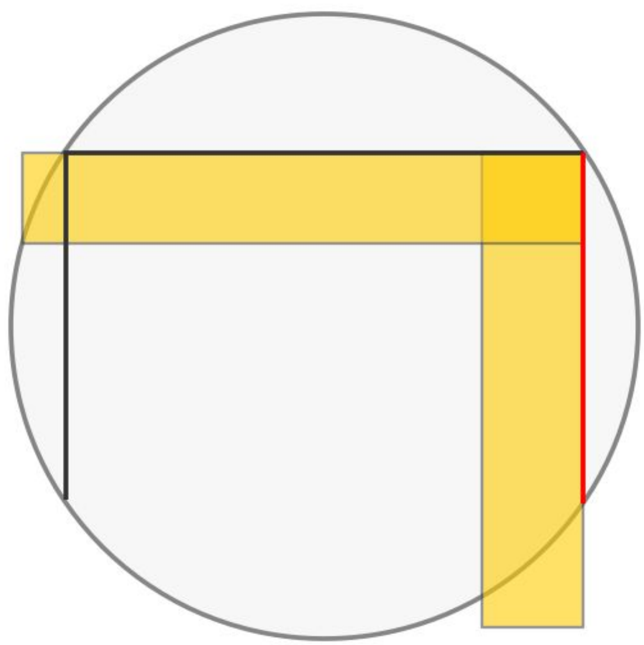
With both of these you have to know the exact center point of the circle and often times you do not have that information. If it is not marked on the part, then you need to determine the center of the circle yourself. One way is to use a center finder, which is a set of concentric circles, with a common center point, that is printed on clear plastic film. This allows you to lay it over top your part and approximate the center with a good degree of accuracy.

Another good way to find the center of a circle is to use a small carpenter square and apply some lessons from geometry class.

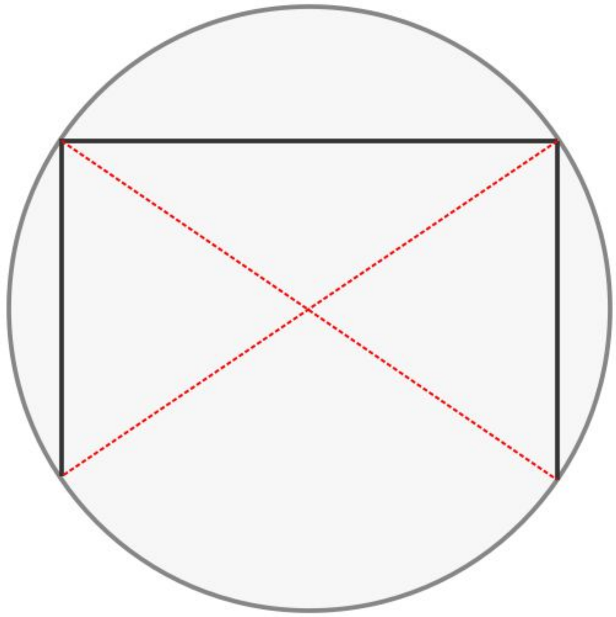
Step 1: Put your square inside the circle and mark the lines in red.



Step 2: Flip over your square and mark the opposite side (red line).



Step 3: Connect the opposite corners of the lines you have drawn and where they cross is the center of the circle.



There are multiple methods to determine the center of a circle, but this is the method I prefer.

These methods will work if you have a perfect circle, but if the part you are trying to cut out is only a partial circle or is a more complicated curve, such as an oval or french curve, then none of these mechanisms or tools will help. The only option at that point is to use a good pair of scissors and a steady hand.

Punches

Punches[50] are another set of tools to work with circles. These handle much smaller circles than are possible using the circle cutters discussed previously. There are both solid and hollow punch varieties, which allow you to knock clean holes into parts (or extract small clean circles for other needs). A downside of these are that they come in specific sizes and if you need a circle in between two sizes, then you are out of luck again.

A drawback I have encountered with these is that they struggle to cut through just a single sheet of cardstock, but work well with multiple pages stacked together. I will place another piece of cardstock underneath the one I am try to cut and punch through both at once. This adds enough rigidity to the cardstock for the punch to go cleanly through the material.

In general, you put the cutting edge of the punch against the spot of the paper you want to cut and hit it with a hammer to impact sufficient cutting force.

[50] Punch (n.): A device or machine for making holes in materials such as paper, leather, metal, and plaster.

Draw plates

Draw plates[51] are used to thin down cylindrical material. This touches upon the topic of using non-paper materials within a model. Outside of model building draw plates are used to stretch and thin wire, often for jewelry. Within the model building world, outside of thinning out wire, you can use this to make very fine dowels of wood out of toothpicks.

You start by running the toothpick through the plate in the hole one size smaller than it freely fits through. You run it through this hole several times, then progress down one size and run it through that hole several times. As you keep doing this the edges of the toothpick or dowel start to get shaved off a little at a time. Keep doing this down to the diameter you desire and you now have a round sliver that can be an antenna, fishing rod, or any other thin object for your model. Doing this with toothpicks or dowels allows the result to be significantly stronger than if it was made solely of a thin strip of paper. The downside is that the shaved toothpick now requires either painting or some other form of colorization to fit with the rest of your model.

[51] Draw plate (n.): A draw plate is type of die consisting of a steel plate with one or more holes through which wire is drawn to make it thinner.

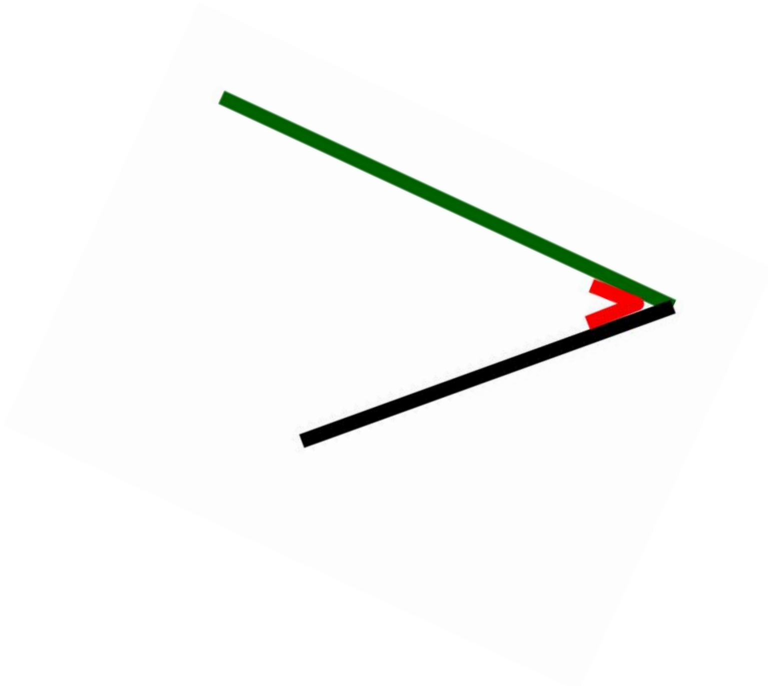
Files and sanding sticks

Another type of tool you will likely want in your collection of implements is a set of files[52] and sanding sticks. Sanding sticks are foam core strips with sandpaper on the outside. Traditionally, these are used for filing fingernails in beauty shops. For us, they can be used for making minor modifications to parts or for evening out seams. I would recommend a set of jeweler's files and a handful of sanding sticks in various grits. Jeweler's files are made of hardened steel, are thin, and have fine serrations on them.

If you do use these on the outside of your model, you will likely need to touch up any area where you disrupt the printed markings. The touchup can be done with any number of paints or art supplies, which will be covered in a later section.

Sanding sticks can also be used to bevel the edges of paper to enable the proper shape of wing trailing edges and airplane fillets. Cutting parts with a blade or scissors often leaves a square edge and you may need to sand the corner off of those edges for certain applications.

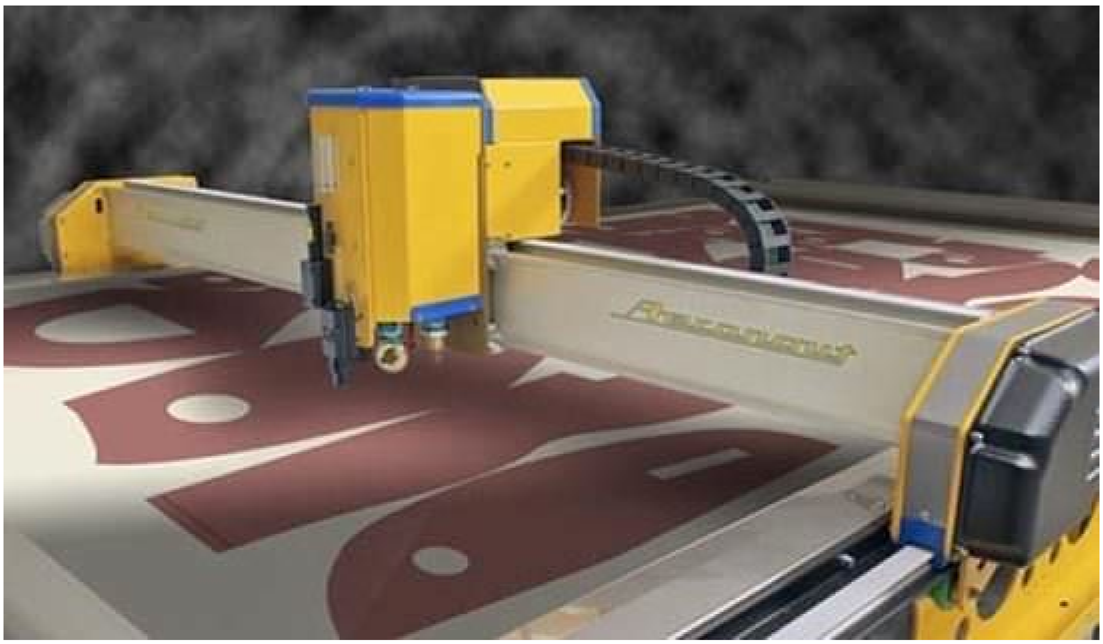
[52] File (n.): A tool with a roughened surface or surfaces, typically of steel, used for smoothing or shaping a hard material.



If we imagine the right side of this image is the trailing edge of the wing, the area where the green and black lines meet would be sanded to remove the inside corner of the edge. They could then meet without a visible edge seam from the paper.

CNC cutters

Computer Numerical Controlled cutters (CNC[53] Cutters) have been around for a number of years, but are only now becoming affordable for home use in the late 20-teens. These devices are connected to a computer and can cut out shapes and parts in cardstock (and other types of material). There is so much detail that entire books can be written on the topic. CNC tool sets and methods of controlling them are skill sets in and of themselves and is beyond the scope of this book.



In general, for paper model building, the cutting implement is either a blade or laser mounted on a toolhead that is capable of traversing across the material in both the X and Y axis. Larger CNC cutters for wood and soft metal will use either a high speed rotary tool or high output laser to perform the cuts.

The upside of using a CNC cutter is that it will perform the same actions every single time, which is good if you need a number of parts all cut out the same way. But I have found that if I am making just one model of something I can do it by hand quicker than it would take to set up, prepare, configure, and program the CNC device to do… and I need to have the hand dexterity anyway for the rest of the construction.

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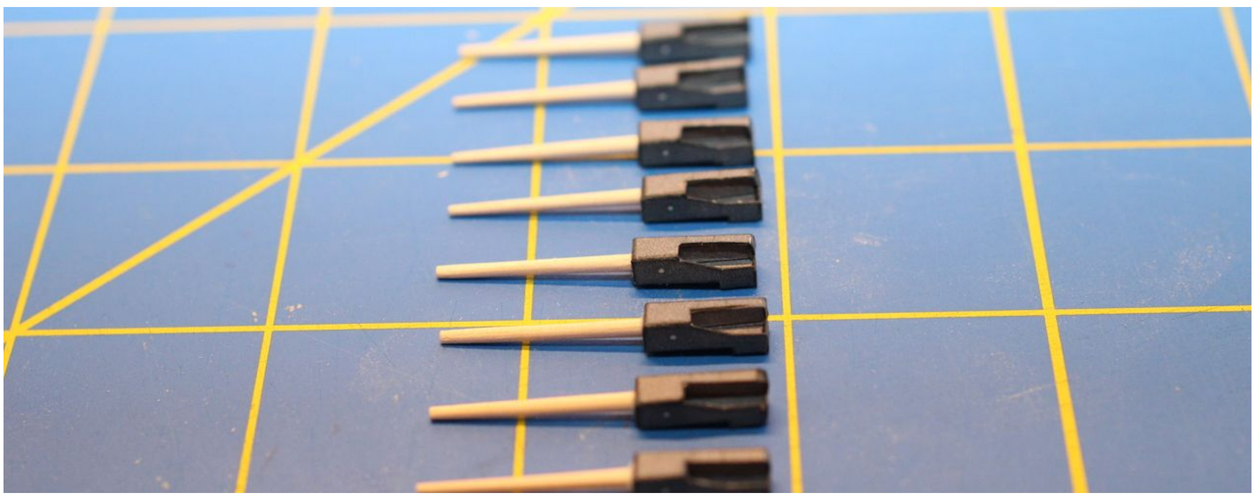
[53] "Numerical control - Wikipedia." https://en.wikipedia.org/wiki/Numerical_control. Accessed 3 Dec. 2018.

Rotary tool

A rotary tool is another good addition to the toolbox. They can definitely be used for their usual intended purposes (sanding, cutting, drilling, grinding). But in addition, if you are making small parts out of wood dowels or toothpicks, you can use a rotary tool as a miniature lathe. Put the dowel into the chuck and let the tool spin it. Then you can use jeweler's files to cut into it and shape it.

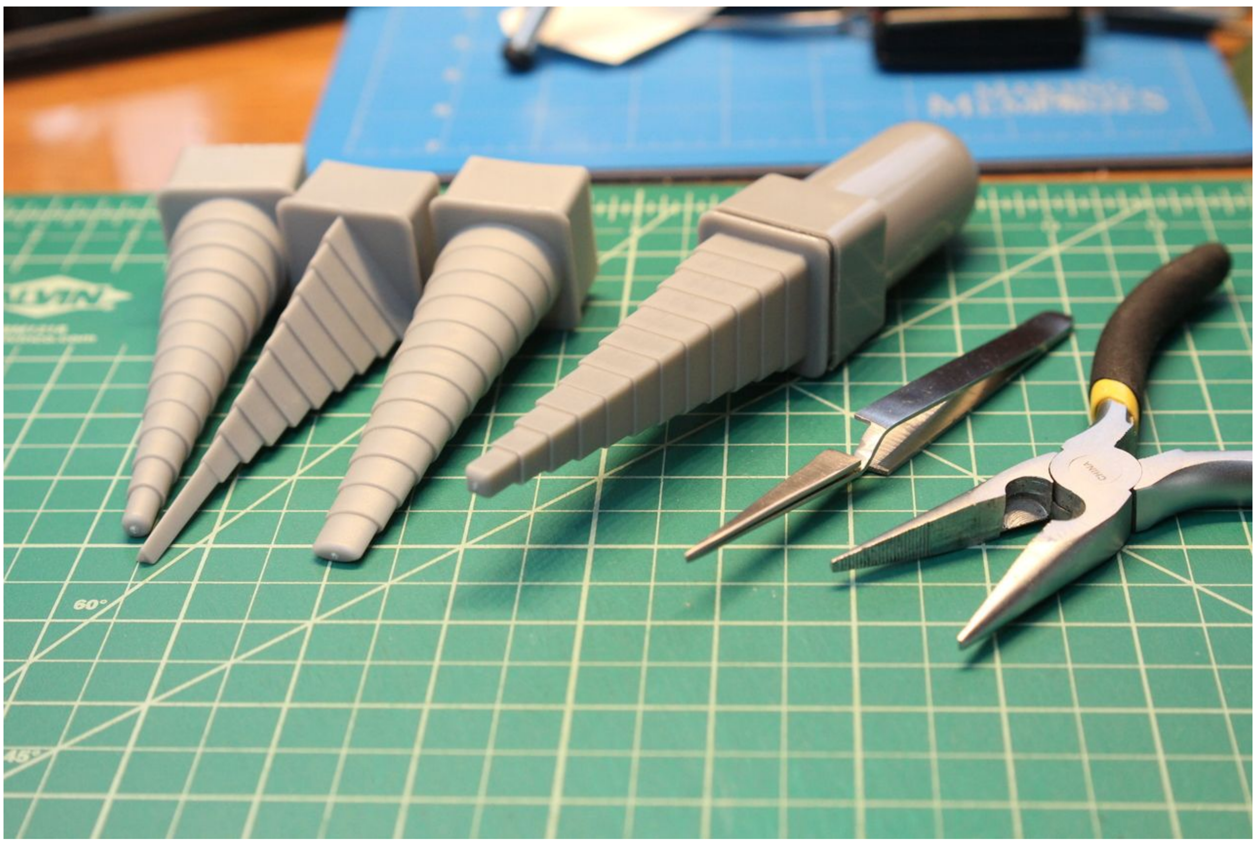
This technique was used to shape the barrels on the secondary guns on the USS San Francisco[54] I built. After shaping the barrels and gluing them to the breach assembly, they were painted.



[54] "USS San Francisco (CA-38) - Wikipedia." https://en.wikipedia.org/wiki/USS_San_Francisco_(CA-38). Accessed 10 Oct. 2018.

Mandrels

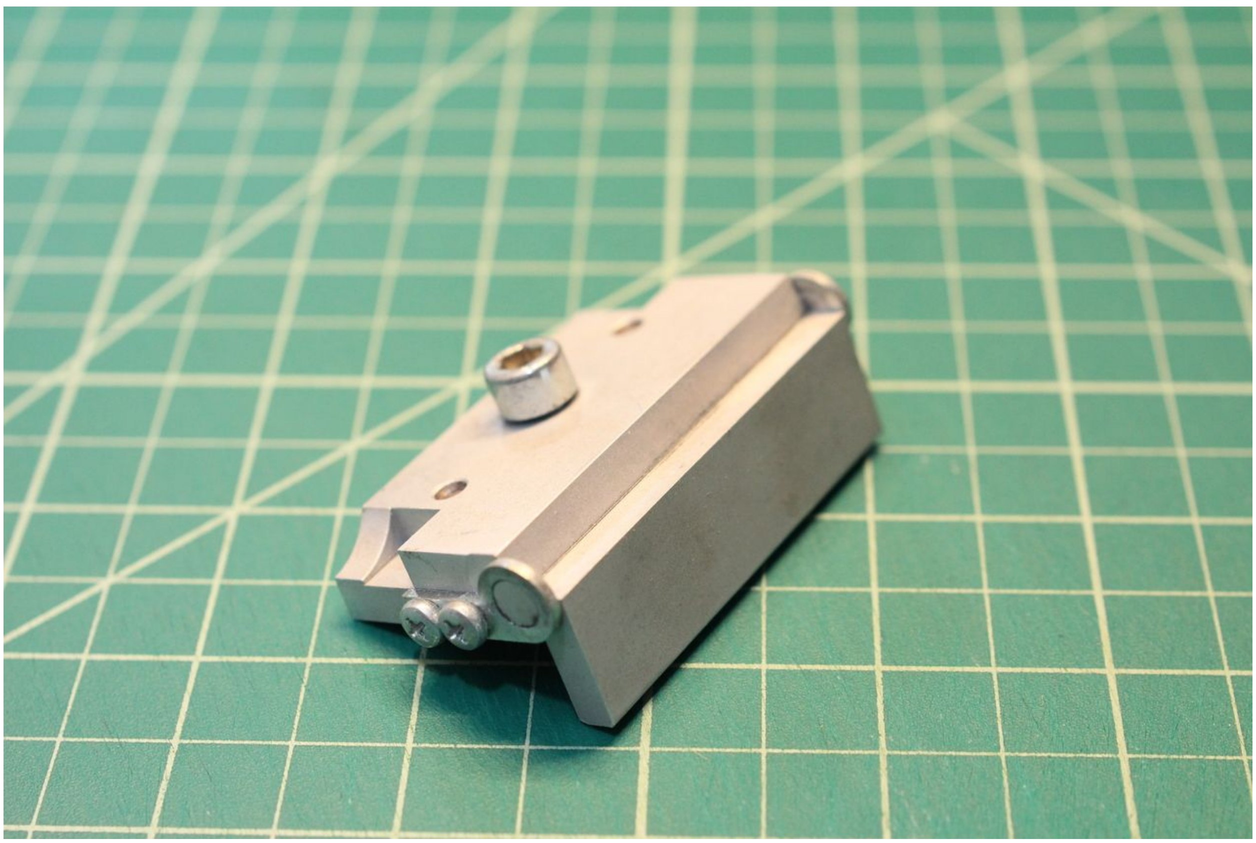
Mandrels[55] can easily be used to shape both paper parts and segments of wire. Their primary craft implementation is for shaping wire for use in jewelry making. But there is nothing that says we cannot use it in paper model construction. This is not a type of tool that is by any means required to create a good looking model. Similar functions can be done with heavy forceps or pliers.



[55] Mandrel (n.): A tool used to shape wire or another material.

Photo Etch Benders

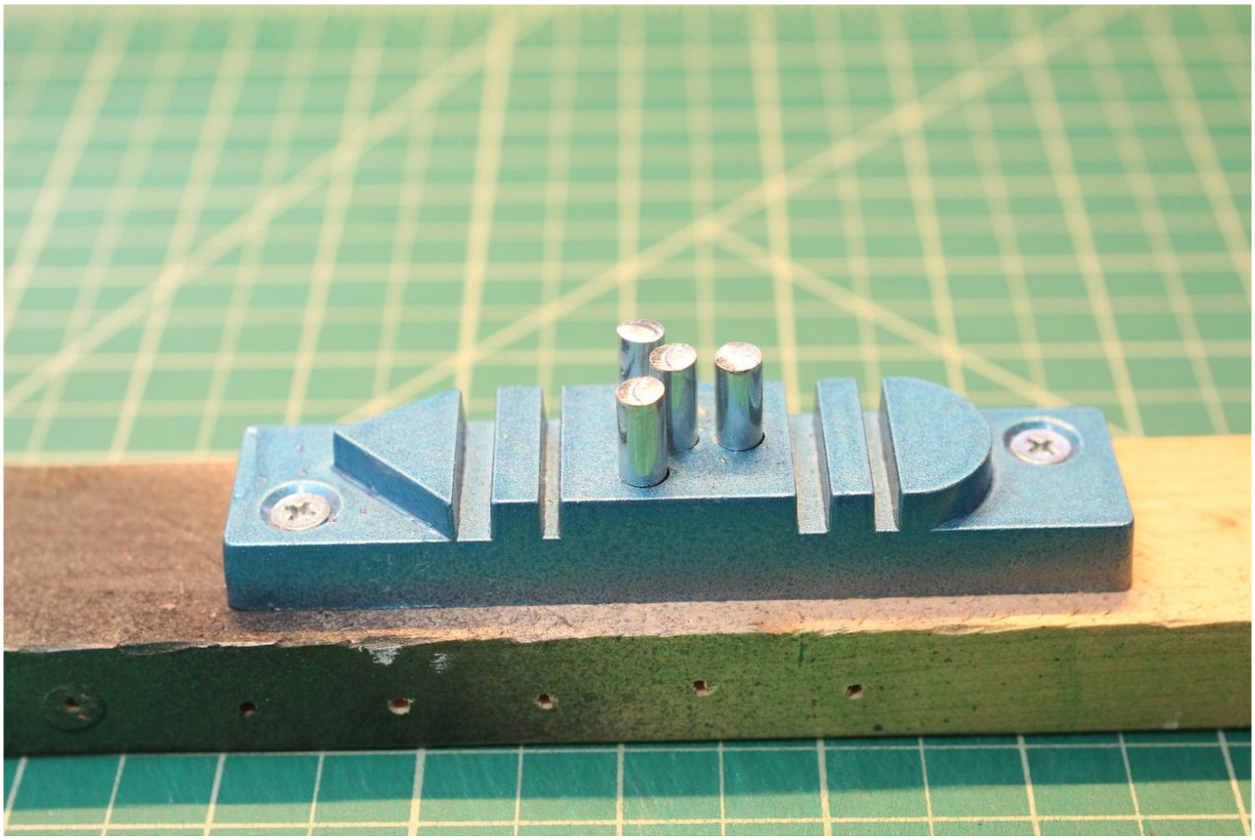
Photo etch[56] benders are designed to manipulate photo etched (PE) pieces of brass. These are very thin pieces of brass that have been shaped into very detailed components. They are used for details that are often very difficult to replicate in paper or plastic for a model. But bending brass, even thin brass, is not easy to do without assistance. PE benders give you a way to clamp a piece and apply a very specific bend to it. If you are familiar with a press brake from a metal shop, this provides the same functionality for miniature parts. And again, there is nothing that says you cannot use one of these tools to put very crisp folds into very small and difficult to handle paper parts.



[56] Photo etched brass (n.): Thin brass that has been prepared with a film, exposed to UV light, and etched with acid. This produces very fine details in the resulting part.

Wire Bending Jigs

At the hobby store there are several selections of wire bending jigs[57]. Usually, these are meant for making jewelry, but they can be useful for shaping wire details for our models. They are usually made up of some kind of base with various slots and shapes. In addition, there are pins that can be setup in various holes that enable you to form complex shapes.



[57] Jig (n.): A device that holds a piece of work and guides the tools operating on it.

Art supplies

If you wander into an art supply store or the art section of a hobby store, nearly everything you see can be used in one manner or another when making a paper model. This is not to suggest that you should load up on all the art supplies. Instead of acquiring everything, I would encourage you to find out what methods work for your situation and which ones you can do well, then purchase the supplies to have on hand to execute those techniques. There is no point in purchasing a load of oil based paints if you are never going to utilize a technique that requires them.

From the art store there are all kinds of things that may be useful to you.

Supplies

- Leather punches - for cutting small circles
- Paint brushes - for applying detail and weathering
- Blending sticks - for smudging and blending pastels or pencil marks
- Erasers - removing pencil markings
- Markers - for applying detail and edge coloring
- Colored pencils - for applying detail and edge coloring
- Pastel chalks - for applying detail
- Brayers - for laminating parts
- Glue - for sticking things together
- Cutting mats - to protect yourself and your work surface from damage
- Blades - for cutting
- Wire and ribbon - for adding detail
- Thread - for adding details that look like thin wires
- Pins - for adding details that look like stanchions
- Knitting needles - for rolling parts
- Sanding sticks - for sanding down rough edges
- And lots more

Beyond the art supply section, items such as razor blades, carpenter’s squares, and dowels can be found in bulk at the hardware store. Toothpicks, bamboo skewers, and other similar items can be found at the grocery store. Office supply stores will have the best selection of cardstock, metal straight edges, drafting pencils and bulk glue sticks. Do not be afraid to look outside of an art department to find the supplies you need.

Pencil

While this section is labeled “Pencil”, that word alone too is a vast of a simplification. One of the most important tools I have on my desk is a nice mechanical pencil. I use it to mark part numbers on the back side of those parts and to record the measurements for an internal lamination (to make the part stronger). It is also incredibly useful for making notes on the parts sheet as a whole or marking the ends of fold lines that are obscured by the straight edge.

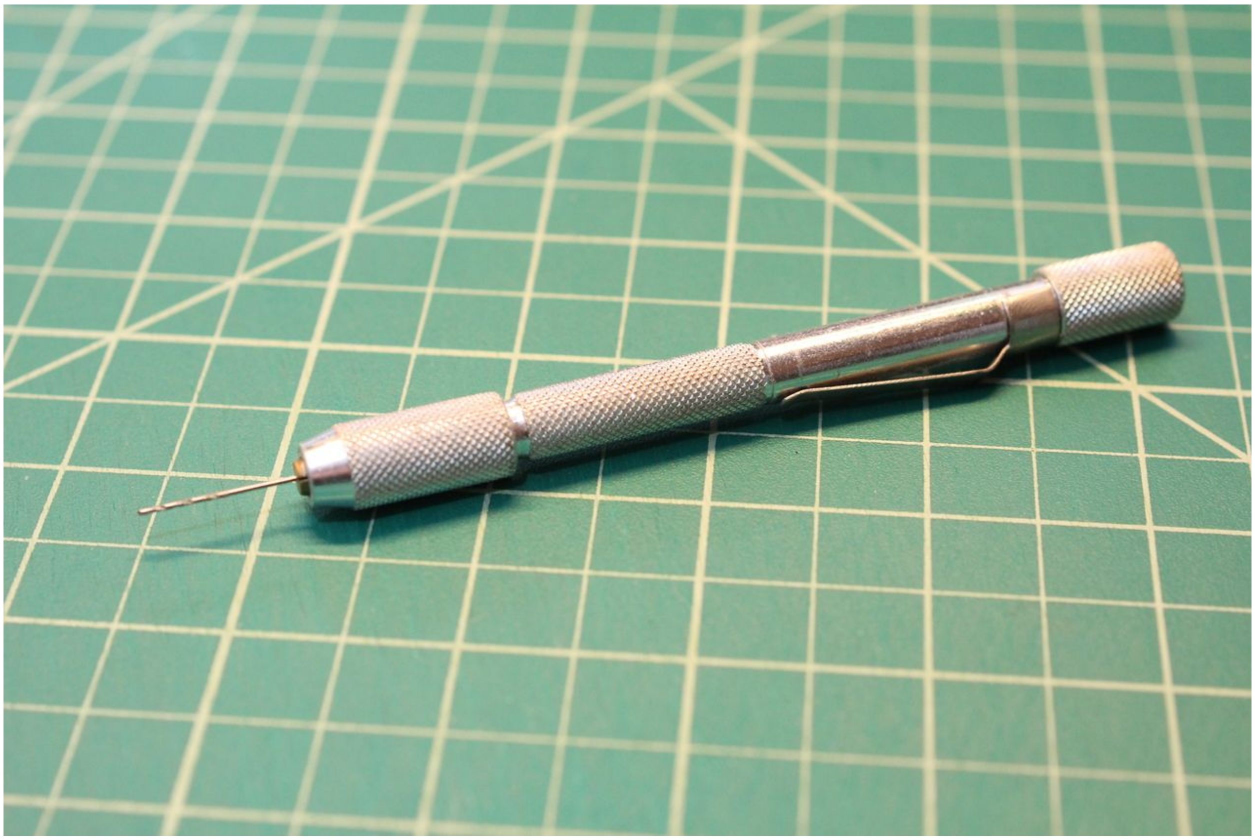
I will recommend a pencil over a pen. I make this recommendation because with a pencil you can erase the marks and make very faint lines as needed. In addition, pencil marks will not break down over time and discolor paper, like many inks will.

This may sound incredibly simplistic, but a nice pencil helps keep you organized and on task. I find it to be the single most important tool I have on my desk. Preferences differ, so if a normal #2 pencil works for you, then use it. Any pencil is better at keeping you organized than no pencil at all.

My preferences lead me towards a precise, high quality, heavy, narrow tipped, drafting pencil. It is one that I ***want*** to write with. The model that fits my needs the best is a Rotring 600 with a .5mm lead aperture. The downside is that this pencil is expensive as compared to just about any other writing pencil you will find. But the upside to a $17 pencil is that I look forward to using it and it is a pleasure to hold.

Pin Vise

A pin vise is a small clamping tool used to hold a small drill bit. As you would expect with a miniature drill, you use it to make very small holes in parts. A pin vise will often come with a selection of small drill bits and one or two collets to hold them.



Paint, Brushes and Airbrushes

An airbrush and compressor are the most expensive tools that will be mentioned in this book. But let me state that they are by no means required. Plenty of model builders can pull off amazing paint jobs using small jars of paint and traditional artists' brushes. I might pull out my airbrush for a paper model once a year… if that.

Eventually you will have something for one of your models that needs to be touched up. This could be a seam that you needed to fill and sand or some wire work that needs to be painted to match the rest of the model or some weathering detail you wish to apply.

There are many books written on airbrushing already, so I wont get into the details of how to use them. Just know that as a minimum to use an airbrush you will need an air compressor, hose, airbrush (with all of its requisite parts), paint, and a thinner for your variety of paint. Lots more parts can be utilized and airbrushes in themselves can become very complex.

Fundamentally, a flow of air enters the airbrush (usually from the bottom) and the trigger controls the airflow (single action) or controls both the airflow and the amount of paint (double action) applied. The air going through the brush will aerosolize the paint and spray it out of the nozzle onto your target. The flow of air and flow of paint determines the spray pattern (along with the needles and nozzles you use).

In terms of paint, there are multiple carrier mediums such as oil (enamel), acrylic, water, ink and gouache. Not all of these can be painted on top of each other. Since oil doesn’t mix with water, you cannot apply water or acrylic based paint layers on top of an underlying enamel. If you layer acrylic on top of enamel the water based top layer won’t adhere properly to the underlying oil layer.

You will likely want a selection of art paint brushes in various sizes and shapes (usually focusing on the smaller end of the spectrum). Natural fiber (horse hair) paint brushes hold up well to oil and alkyd based paints due to their natural oils. Synthetic (nylon) brushes work well with acrylics and water based paints. Natural fiber brushes will be damaged over time if used with acrylics based paints.

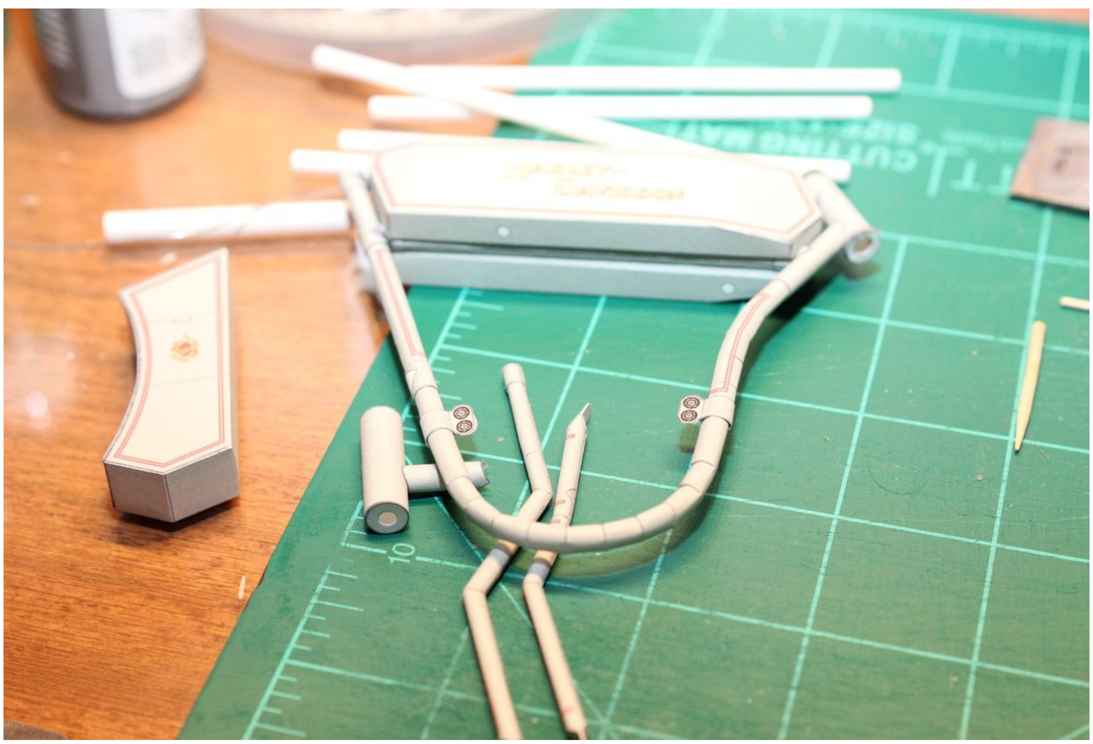
Make your own tools and jigs

There will be models that you will construct that require you to have a large degree of precision and accuracy in your construction, or you will be in a scenario where you are repeating the same task numerous times. These are situations where a custom tool or a jig[58] is an ideal solution. I encourage you to make whatever tools you need to get the results you desire. Tools can be as simple as a stick or as involved as a motorized winder and bobbin to make miniature hose reels.

I will use the example I built a few years ago of a 1:6 1910 Harley Davidson Model 6. For this build I needed both a custom tool and a jig to successfully complete it.

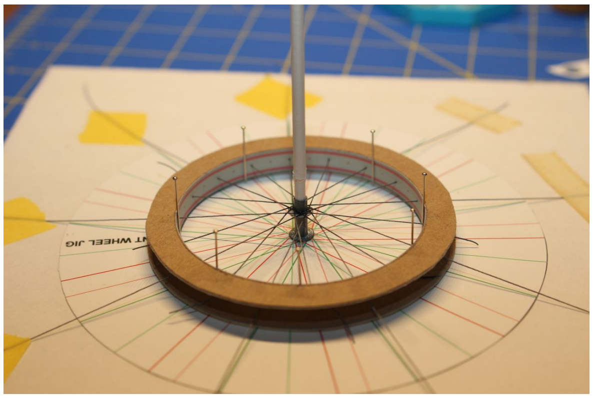
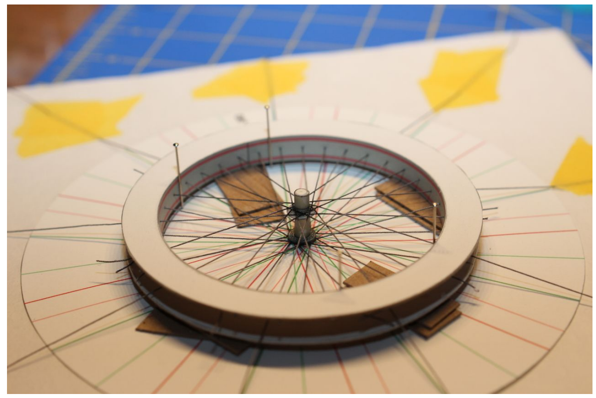
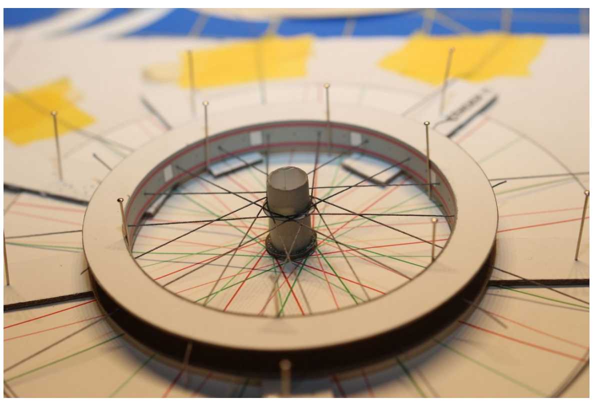
The custom tool was very simple. It consisted of a brass rod that the frame tube was formed around. Since this portion of the frame is curved in multiple directions I used the brass tube inside the part to act as a cutting surface. With a scalpel I cut all the slits into the part so that the end shape matched that of the motorcycle's frame.

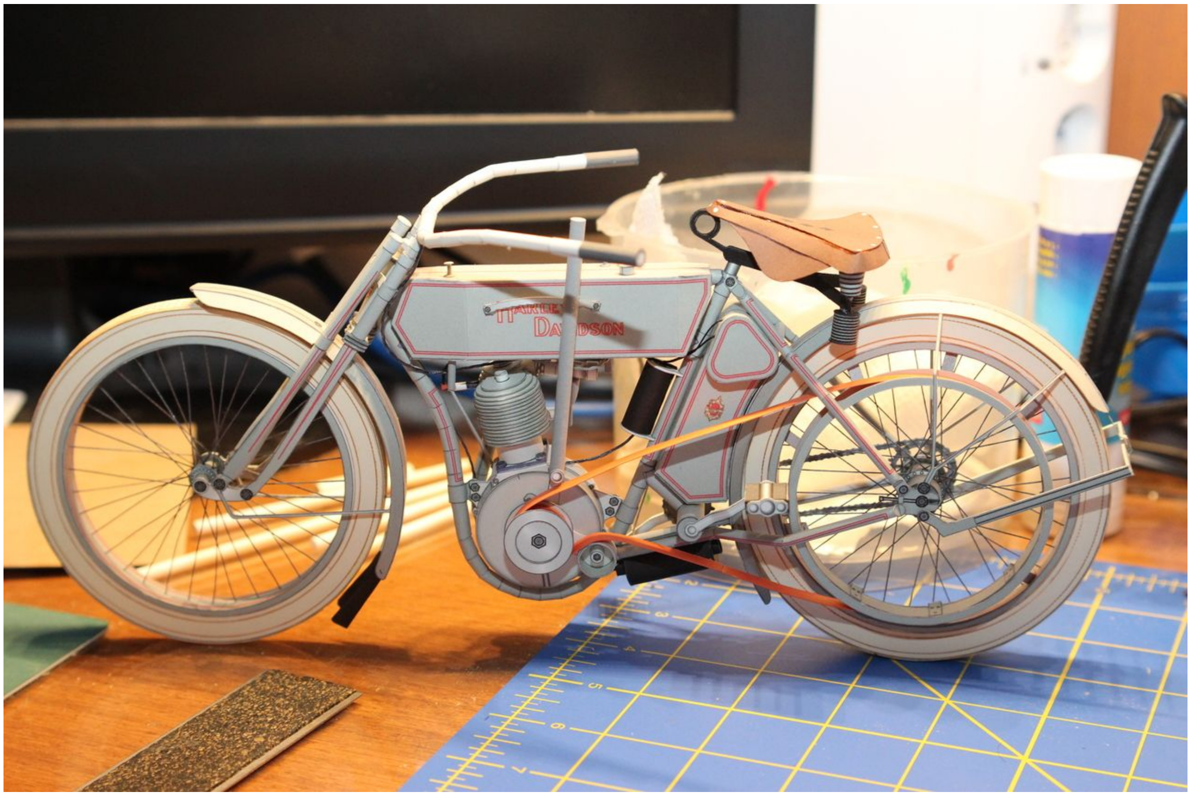
[58] Jig (n.): A device that holds a piece of work and guides the tools operating on it.



Once all of the slits had been cut in the frame, I inserted a similarly sized thin spring inside the tube. If I recall correctly, the spring came from an old ballpoint pen. This allowed me to bend the tube at each of the cut slits without crushing the part. The spring acted as an internal reinforcement during the manipulations. Afterwards the spring was slid out of the part. The other tubes you see in the 2nd image above went through the same manipulations.

For the wheels on this model the designer kindly provided plans to construct a jig for each of the front and rear wheels (they are not identical). This was used for forming the wheels and running the spokes. For a component such as this, a jig is nearly a necessity.

Here you can see the fine results that emerged from using the jig.

Sealing

Sealing is a technique whereby a fixative is applied to the model either before construction or upon completion. Is it one of those efforts that builders swear by or ignore completely. I have not found a lot of middle ground while talking with other builders about sealants.

Applying a fixative to a model once it is complete is the obvious application. It will add a layer of protection to the completed work to protect it.

The other use is to spray pages of parts (uncut, unscored, unfolded, fresh out of the printer) with the fixative. The upsides of doing it before construction is that it will allow you to more easily wipe up excess glue, it will resist moisture damage from your fingers, and the ink will not transfer off of the page. The downside to applying the fixative before construction is that edge coloring the parts can become a bit more difficult, as the parts may resist your attempts to apply pigment. It will also make it more difficult to paint or color if you intend to apply detail after assembly.

The last option is not to use it at all. You will not get any of the benefits, but you also will not have any of the downsides.

If you do decide to apply a fixative, put on a thin even layer, let dry, and apply again. Avoid causing any drips or runs as they will ruin the page of parts. Avoid heavy coats of sealant. Spray the sealant evenly over the page, like you would with a can of spray paint. The liquids that are aerosolized by the can are enough to wet the paper and cause it to curl. Weigh down the edges of the paper while it is drying to prevent unwanted curling and warping.

Upsides:

- It will increase resistance to moisture.
- It will prevent the ink from transferring off the paper onto you or other parts.
- It will prevent the printed details from smudging with handling.

Downsides:

- It will mute and dull the colors of any page it is applied to (both inkjet and laser).
- It is slightly more difficult to get glue to “grab” the material.
    - This only really applies when you are attaching small details, such as an antenna that is mounted on a panel. In this situation, there is only a very small contact point between the antenna and paper and with a fixative involved that glue joint will be weaker.

Things it will not do:

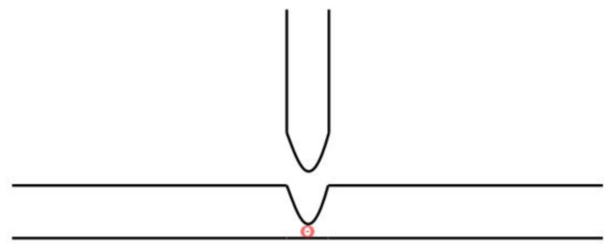
- It will not prevent the paper from aging or make it “acid free”.

- It will not prevent the ink from aging or reduce its acidity.
- It will not cause toner from a laser printer to become more firmly affixed to the paper if you have a weak fuser.

With all of these details in play, I never apply a sealant to my paper models. The main downside, in my mind, is washing out the colors that have been freshly printed on the page. A fixative makes it very difficult to produce a build with sharp, vibrant colors. When printing a model with bright colors it is difficult to anticipate just how much they will be muted by a fixative and correct for it ahead of time. Since I manage how sweaty my fingers get and I do not intend for the model to be handled at all once completed…. I do not bother with a fixative and use one only in extremely rare situations. As a result, I find that the benefits do not make it worth my effort or worth the loss of color.

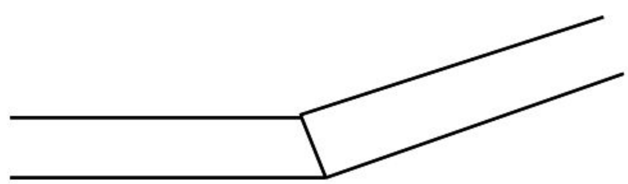
Scoring the Backside

When we score a piece of paper or cardstock, we are looking to create a weak spot so that the piece can be easily folded. This gives us a sharp fold line and prevents the paper fibers from fraying.

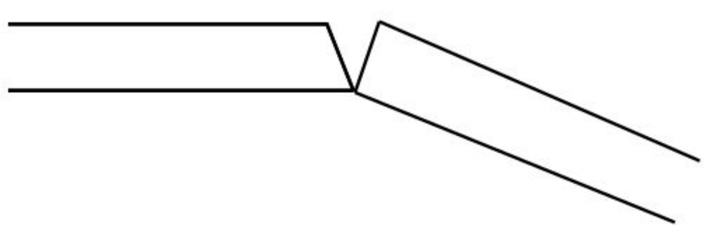


In the image above pretend we are looking at the paper edge on, and the rounded edge of our scoring tool has just been drawn across the page. The weak spot is now located at the red circle. If you tried to fold this page now, structurally it would fail and fold along the line at the bottom of the channel created by the scoring tool.

If we are looking to make a valley fold, with our printing on the top of the paper, this is ideal and gives us a clean result. The printed surface on top of the part now has no break in it after being folded.

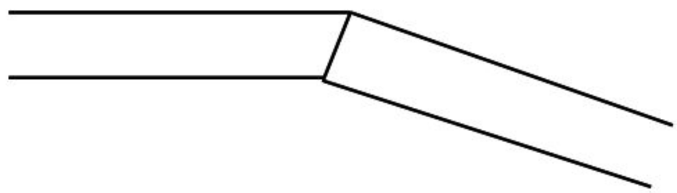


This is all great, except for the situation where we want to make a mountain fold. If we do the same thing we get this result.



In this case we now have a large gap between the printed surfaces on the top of the page. This can often be seen as a white line on folds in a finished model. Since a valley fold is just a mountain fold upside down, what if we score the part upside down? We would get something like this.

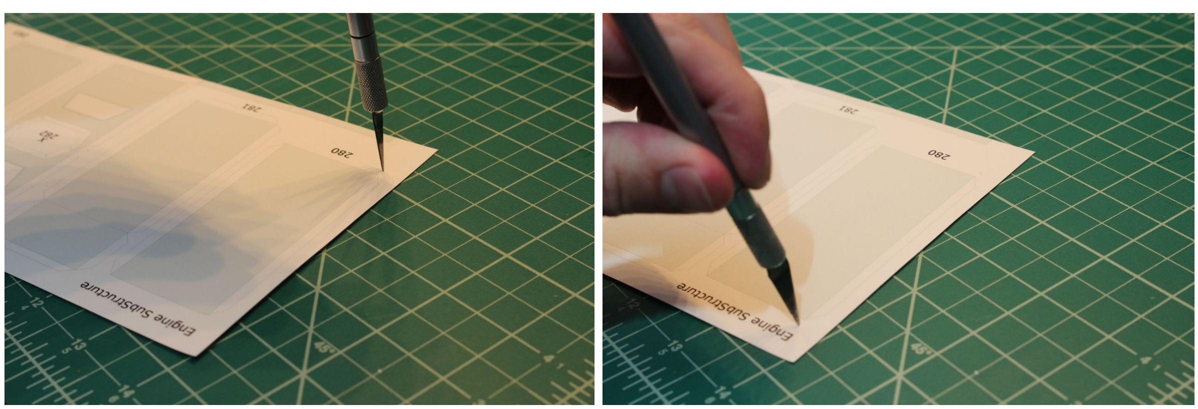
And after folding this, we end up with a more desirable result once folded.



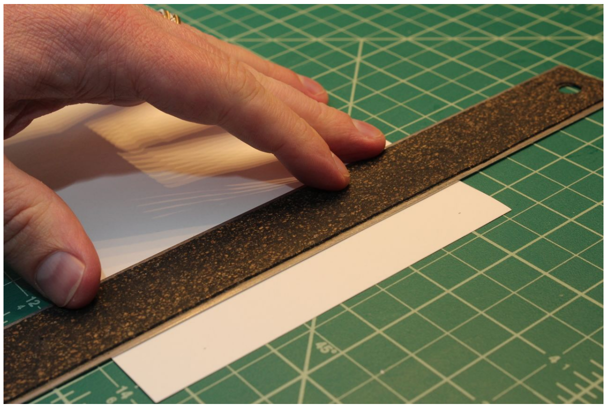
Now we have continuous ink coverage on the printed side of the part where the markings reside.

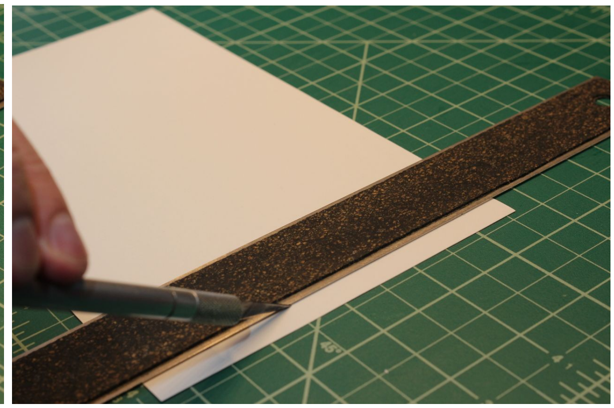
So we now know that we need to score the underside of a fold line when we want to make a clean mountain fold. How do we go about doing this since the printed fold line is on the top of the part?

One of the many ways is to use thin sewing pins (or any other thin pointed tool) to mark the ends of the fold line outside of the part, flip it over, and score between the two pin holes. You then have a score line on the backside of the part. This the only predictable way I have found so far to accomplish scoring on the underside of the part.

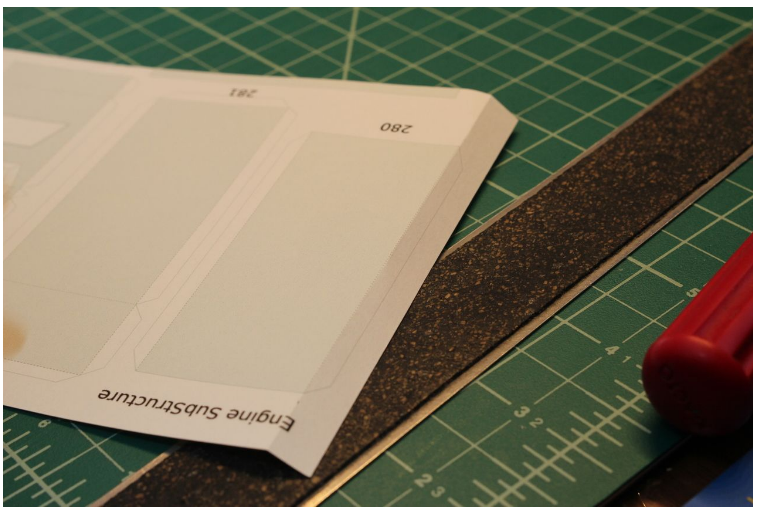


With a sharp object, mark either end of the fold line.





Next flip the part over and make a score line between both pin pricks.



Flip back over and you can make a clean mountain fold.

Slicing and Cutting

When we take a closer look at the details of paper being cut, we quickly have to acknowledge that paper is a three dimensional object. Up until now, excluding the scoring section previously, we have been making the assumption that paper has a zero thickness. That is to say that we have been talking as if it only has two dimensionals. At this point in the discussion we need to acknowledge the fact that paper has a small, but non-zero, thickness. The issues below only become more pronounced as you start working with thicker materials. The thicker the paper the more these concepts need to be taken into account. This also holds true for laminated parts, which will be covered later in this book.

Unfortunately, paper and card stock are some of the most unforgiving materials as it relates to blades and knives. In just a very short amount of time, paper can quickly dull a blade due to the structure of the wood pulp fibers in the page. This effect will vary from one weight and brand of paper to another. Unfortunately, blades can be dulled to the point of uselessness in as little as a couple feet worth of slicing.

Once a blade has become dull you will end up applying more pressure to it. This increases your chances of cutting yourself and tearing your material. A dull blade will also lead to more damage to your material and require multiple passes to separate a part from the page. In order to keep everything functioning well, replace or sharpen a blade once you notice that it has become dull.

Blade thickness

The thickness of the blade directly factors into how much material needs to be displaced as you make a cut. You can similarly think of it as a boat moving through water. The wider the boat hull, the more water has to be pushed out of its way to make forward progress (and this takes more energy). With a thinner boat hull you need to move less water to the side.

In the diagrams above, the blade on the left is significantly thinner than the one on the right. The thinner blade has significantly less material to move around in order to successfully cut the paper. This makes it easier to execute a slice and yields a situation where you have less drag on the blade as it moves through the paper. A downside though is that thinner blades have less metal at their cutting edge, so they do have a tendency to go dull more quickly than thick blades. A thinner blade is also easier to damage or chip for the same reason.

If we assume that our printed part is on the top of the paper in the diagram above, after slicing we now have a white edge at a slight angle from where the blade cut through the paper. As you can see, the white edge from the slice is larger in the example with the wider blade. This could create a larger seam that we would need to hide when we glue the parts together in the future.

“Knowing that, I should just use the thinnest blade I can find. Right?”

The answer to that is both yes and no. A thin blade will bend and break with much less force than a thicker blade. Thicker blades are considerably stronger and more structurally sound. For example, scalpel blades are very thin, but quite bendable; single sided razor blades are twice as thick and very difficult to bend.

Since you can apply more pressure to a thicker blade, you can make a deeper cut as compared with a thin blade. If the thickness of your paper is small enough that you can cut through it with a thinner blade in a single pass, then that is the way to go. If you cannot make it through the paper in a single pass with a thin blade, you may be able to do so with a thicker blade (because you can put more pressure on it). If you cannot make it through the material in a single pass with a thicker blade then you are relegated to making multiple passes either way… but you will have fewer passes with a thicker blade.

If you are working on a small detailed cut, the thin blade will give you more agility and flexibility to complete that task. It is a trade off between precision and detail vs. power and strength.

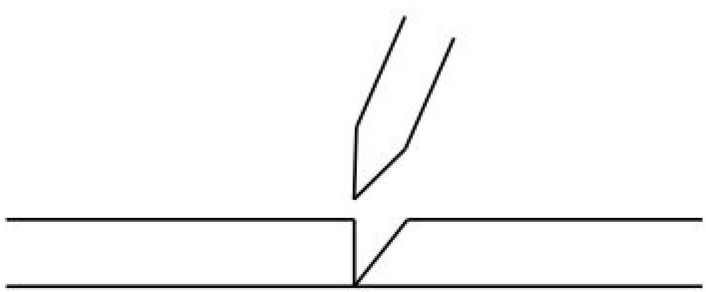
On my desk I regularly have scalpels (very thin and fragile blades), single sided razor blades (relatively thick and strong blades), and a large box cutter (the locomotive of hobby blades). If the cut I am making can be done with a scalpel, I will use that. For thicker paper or laminated parts, I use the razor blade. For chipboard formers I will cut them out with the box cutter.

Blade edges

Beyond the thickness, some blades are sharpened and angled on both sides and others are only sharpened on one side.

As you can see in the diagram above, a blade that is sharpened on both sides creates a ‘V’ shaped slice in the paper. The blade that is sharpened on just one side leaves one piece (left side) with a square shoulder and the piece on the right with an angled edge. Blades with a single sharpened side are known as chisel blades as they resemble their larger relatives from a woodworking shop. Chisel blades are not usually drawn across paper, but instead are plunged down at a right angle to the part. If our desired part is on the left of the blade in each of these illustrations, then the chisel blade on the right creates the minimum possible white edge and results in the smallest edge to prepare and hide later on.

Blade angle



If we were to lean a double sided blade at an angle, we can create a similar effect as that of a chisel blade. As seen here, the left side of the paper has a clean, square shoulder on it and the piece on the right has an accentuated bevel on it.

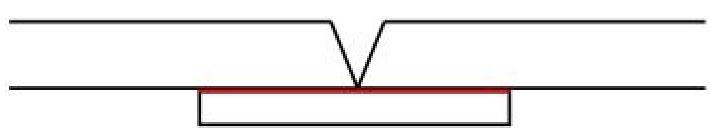
If we continue to lean both types of blades over even further, we can undercut our piece on the left side of the paper. See the diagram above for an illustration of undercutting.

Leaning the blade over in the other direction causes a similar effect. Our desired part (on the left side of the paper in each illustration above) is then beveled. There are situations where you may want to either undercut or bevel a part before attaching it to others. This depends entirely upon the angle at which the parts come together.

Why edges matter

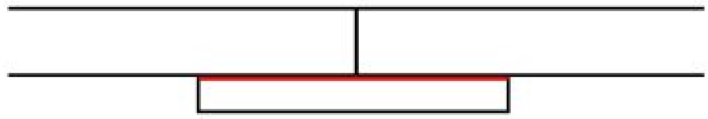
Seeing all of this, you might ask: “Why do I care about any of this?”

Let us take the example of gluing two parts together with a strip of paper supporting the joint from underneath.



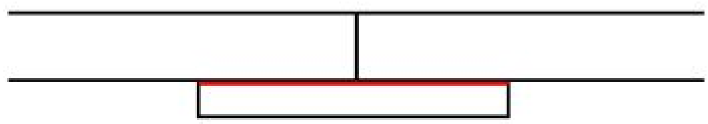
In the diagram above, we have two parts with a backing strip underneath and the glue is applied in the red area. If we simply sliced the parts and created beveled edges we have a result with a ‘V’ seam between the two parts. If our parts are printed on the topside and are not entirely white, we will now have a white seam visible in the middle of the part’s texture. In order to make that white seam less visible we now need to color it (I will cover edge coloring later on in this book.) and try to steer the eye away from both the difference in color and texture of the seam.

Instead, what if we can remove that ‘V’ shaped groove from the equation?

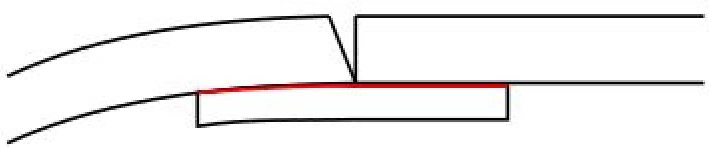


If we use either a chisel blade or lean our double sided blade at an angle, then we have square shoulders on the two parts and a much smaller seam. Pulling the eye away from a small seam in this example is much easier to do than hiding the large ‘V’ shaped seam and results in a much cleaner looking build.

Now let us take another example. Let us begin with square shoulders with two flat parts like we had before.

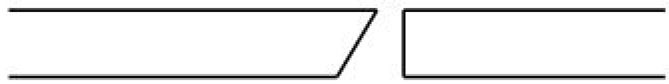


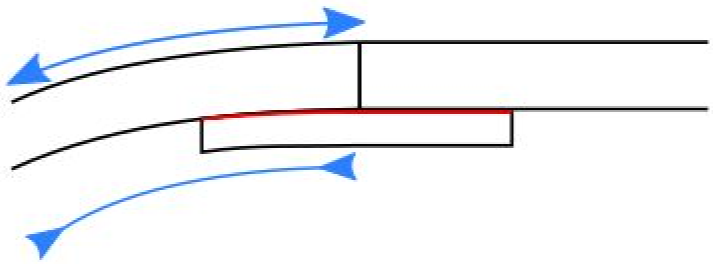
Things line up nicely here, as everything is square and we have a tight, clean seam. But what if one or both of the parts needs to be curved to fit the model?



Those same square shoulders are now deformed when one of the parts is curved. The act of rolling the part causes the outer side of the part to be put under tension and the inner side of the part under compression. These in combination cause our square edge to become beveled at the joint.

One way around this is to compensate for the deformation in the edge by undercutting the part to be curved. If we do this and then roll the part on the left, its edge becomes square once again.





Now our edges are square again. I noted the lines of compression and tension in the diagram above in blue. This also acknowledges the reality that paper has a non-zero thickness. While most of the time we can mostly ignore that non-zero thickness, this is a situation where we should take it into account and that will yield a better result.

Burnishing

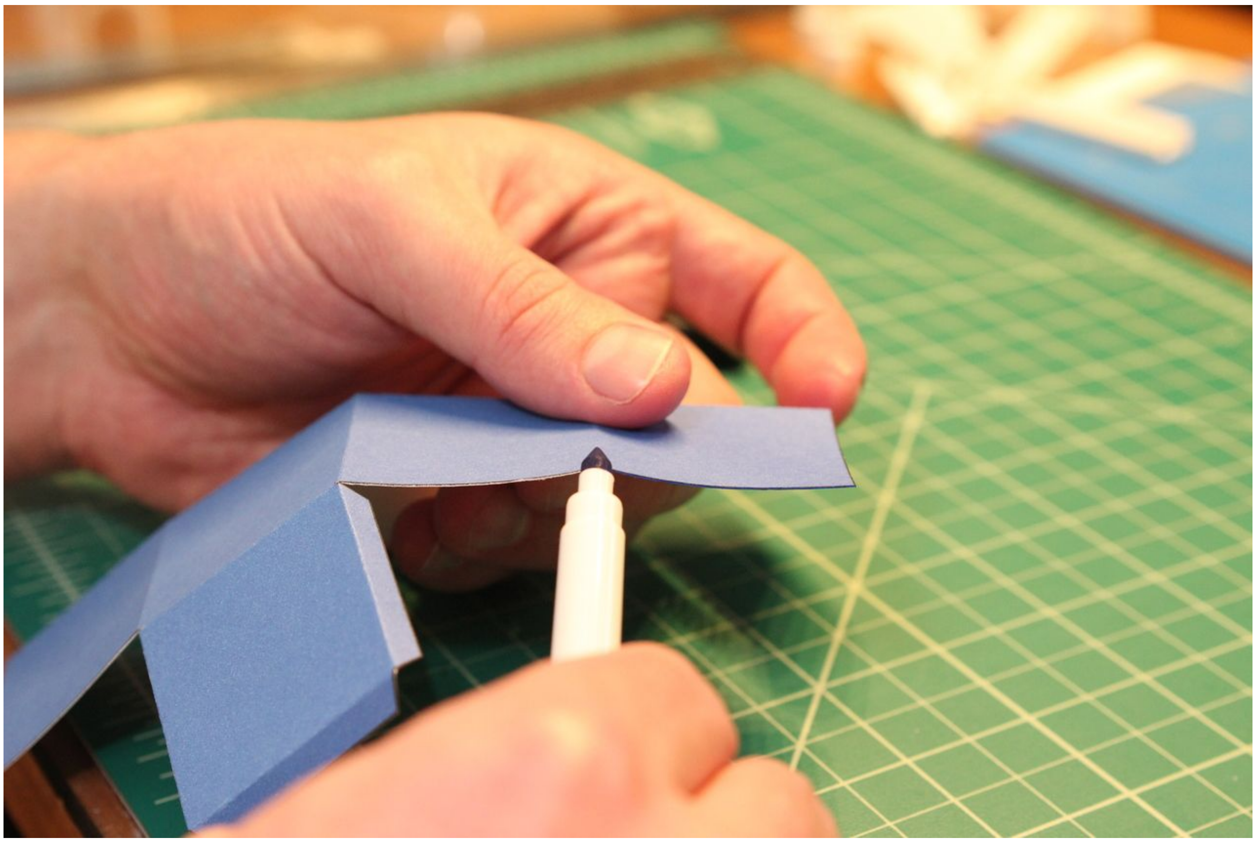
Beyond basic curves, we can use a technique called burnishing [59]to help match two parts together along a seam. Once a part is glued together, the edges where two parts can be rubbed from the inside on a pad like in the image above. The burnishing can be done with the fingers or will any rounded tool (like the near end of the rod rolling a cylinder above). There are specific tools that are designed for burnishing and shaping seams.

The purpose is to smooth the joint where two parts come together and to make the transition across a seam smoother.

[59] Burnishing (v.): Deformation of a seam to smooth the texture of a transition from one surface to another.

Edge Coloring

Edge coloring[60] is another technique that can help make a model look more real, and less toy-like. It entails using markers, ink, pencils, paint, or another artistic pigment to color the edge of the part. When we cut a part out of cardstock, that thin non-zero thickness of the paper's edge appears as a white line. This is great if you are building a model that is naturally white, but if you are building a colored model those white lines distract from the overall creation.



Edge coloring can be as simple as running a marker down the edge of a part to cover up that white line. Warning though, inks and so forth can bleed into the printed face of the part. I have a large selection of art markers, colored pencils, crayons, and paint that I use to cover up the white edges. If you can match the color or have a single shade lighter than the printed face of the part, that is ideal. Through trial and error, I found that the contrast between the part's printed face and the white edge is what makes it stand out. Even if you do not have the exact color, one that is close but bridges the contrast gap will go a long way.

Here is the blue cube with the edges colored a similar shade of blue.

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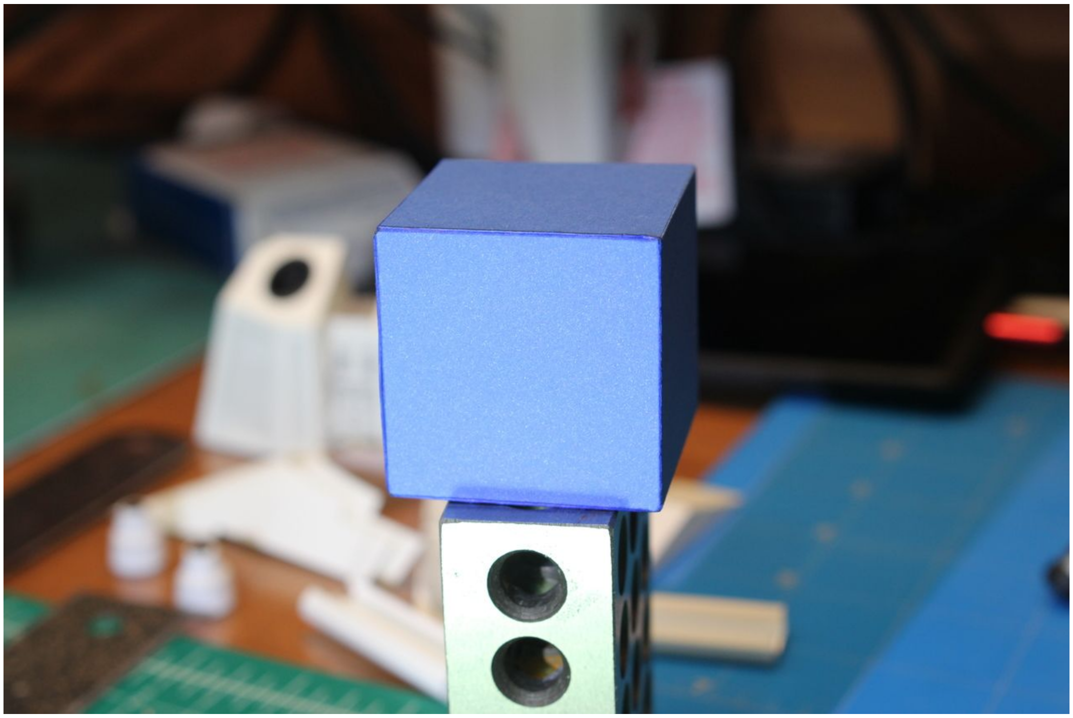
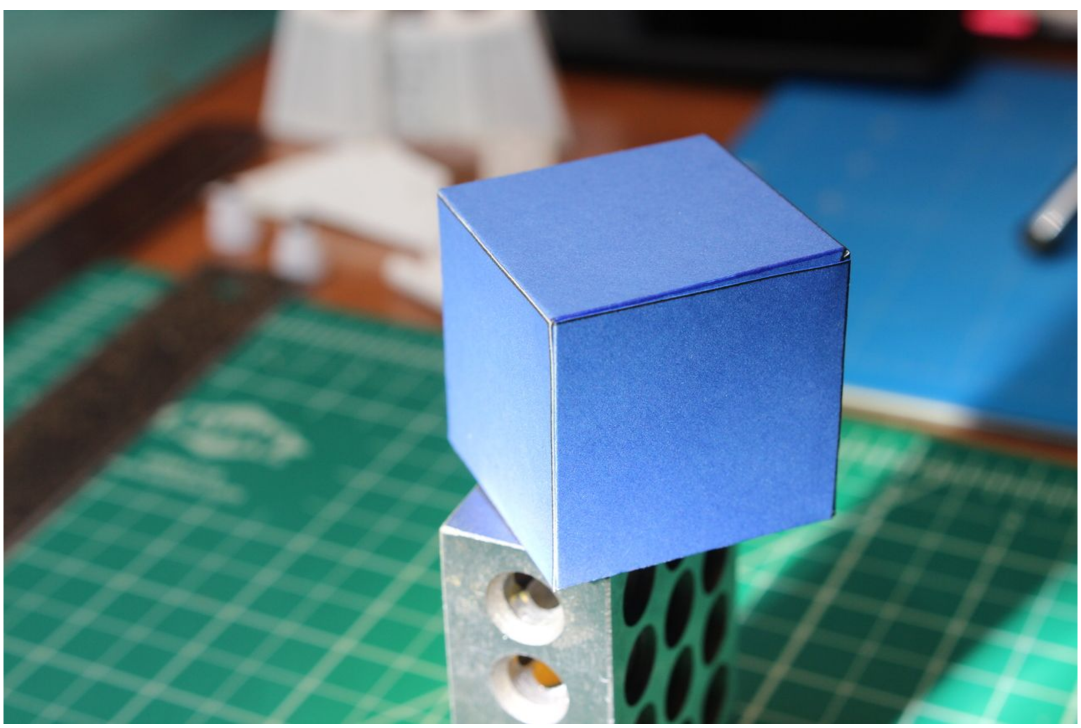
[60] Edge coloring (v.): Applying pigment or ink to the exposed white edge of a part, that white edge being exposed after cutting the part out of the remainder of the piece of cardstock.



Here is the opposite side of that same cube which has not gone through an edge coloring process. You can clearly see how the left face of the cube appears to be outlined in white due to the lack of edge coloring.



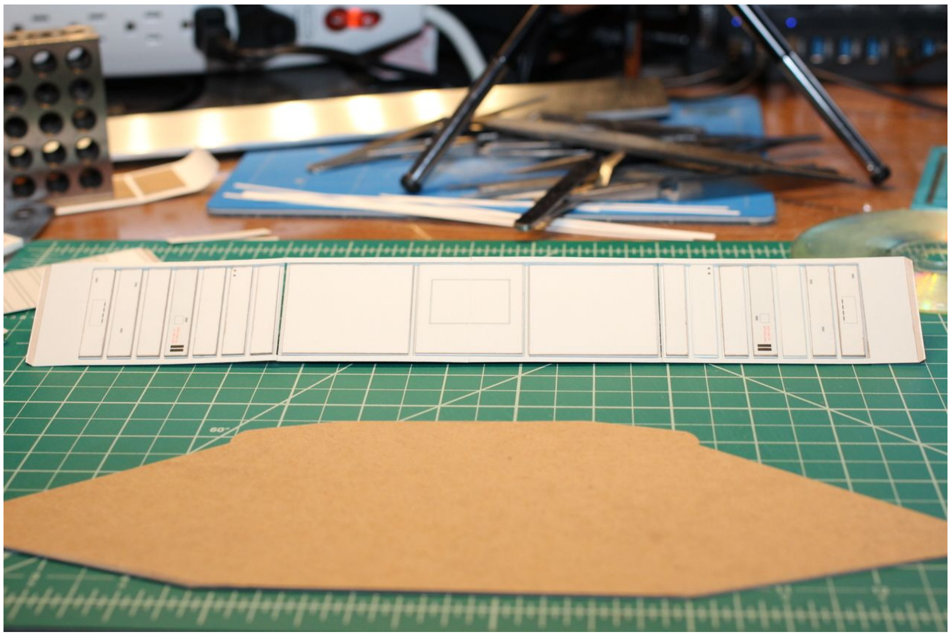
Nearly any art supplies will work for edge coloring. I prefer alcohol based markers/pens, but your preference may vary. I try not to use oil based pigments as the oil medium can bleed into the part over several hours. I also shy away from water based markers or paint because they will be quickly wicked into the paper. From the perspective of paint, I use acrylic paints from the craft store as they come in thousands of colors and shades.

Materials

- Paint (water, cellulose, acrylic, oil, enamels)
- Ink
- Markers (water based, alcohol based)
- Pastels (chalk and oil based)
- Chalks
- Colored pencils
- Watercolor pencils

Laminating

Laminating[61] parts can be used to accomplish several effects. Two of these can be seen in the image below.



Firstly, we can laminate a part to increase its thickness to offer some visual relief. The panels in the strip above have been laminated to .5mm and this causes them to stand up off of the backing part they are glued to. We could accomplish a similar effect without laminating by running a .5 mm thick strip of paper all the way around the outside edge of the panel. But, it is far easier to laminate the part and cut it out without worrying about a very thin and structurally weak strip being wrapped around it.

The second reason is to add structural integrity. This can be seen in the lamination of chipboard[62] to the bulkhead in the bottom of the image. This offers a significant amount of structural rigidity as compared with a single piece of cardstock. Chipboard is often used for structural components on the interior of a model. It is approximately .5 mm thick and offers an easy and inexpensive way to make a component much stronger. If you do not easily have access to chipboard you can also use the cardboard from cereal boxes in its place, even though it is slightly thinner and slightly less rigid.

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[61] Laminating (v.): The technique/process of manufacturing a material in multiple layers, so that the composite material achieves improved strength, stability, appearance, or other properties.
[62] Chipboard (n.): A thin variety of cardboard.

For laminations that will be seen edge on, I will use 67 lb or 110 lb card stock and then edge color the part to match appropriately. In general, thicknesses up to 2 mm can be achieved with layers of cardstock. Beyond 2 mm thick, using another model part to put an edge wall on a component is a better bet.

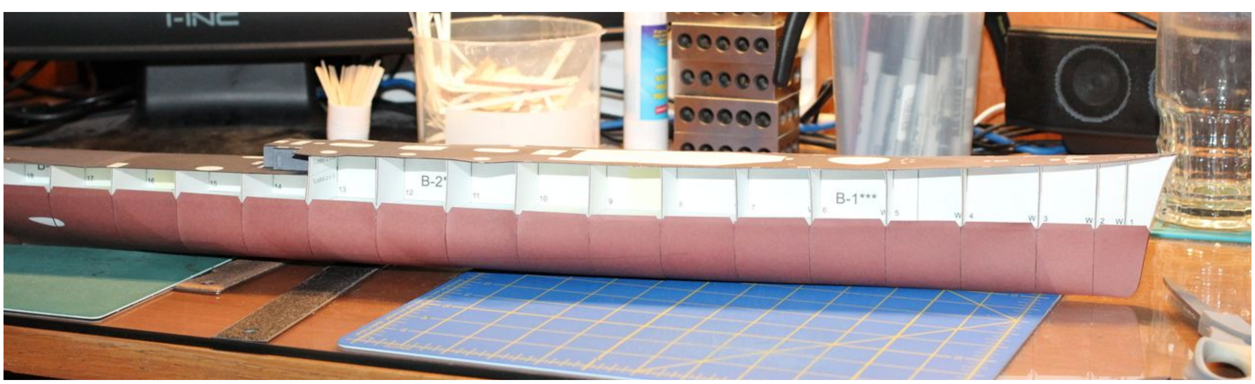
To glue the laminations I recommend a heavy duty glue stick applied liberally with the part then put into a press and allowed to dry. Other builders have very good luck with spray adhesives to make the procedure go faster.

In larger models it is not uncommon to have internal formers[63] that help shape the section from the inside. You would see these parts in models for ship hulls and the bodies of aircraft, for example. The common way to indicate part thicknesses is by either explicitly stating it: "Laminate to .5 mm". The other way is by using asterisks: *. A single asterisk usually indicates to laminate a part to .25 mm. Two asterisks means to laminate to .5 mm. Three asterisks means to laminate to 1 mm.

- * = .25mm
- ** = .5mm
- *** = 1mm

The model instructions should explain what they mean by the number of asterisks as the convention is not entirely universal.

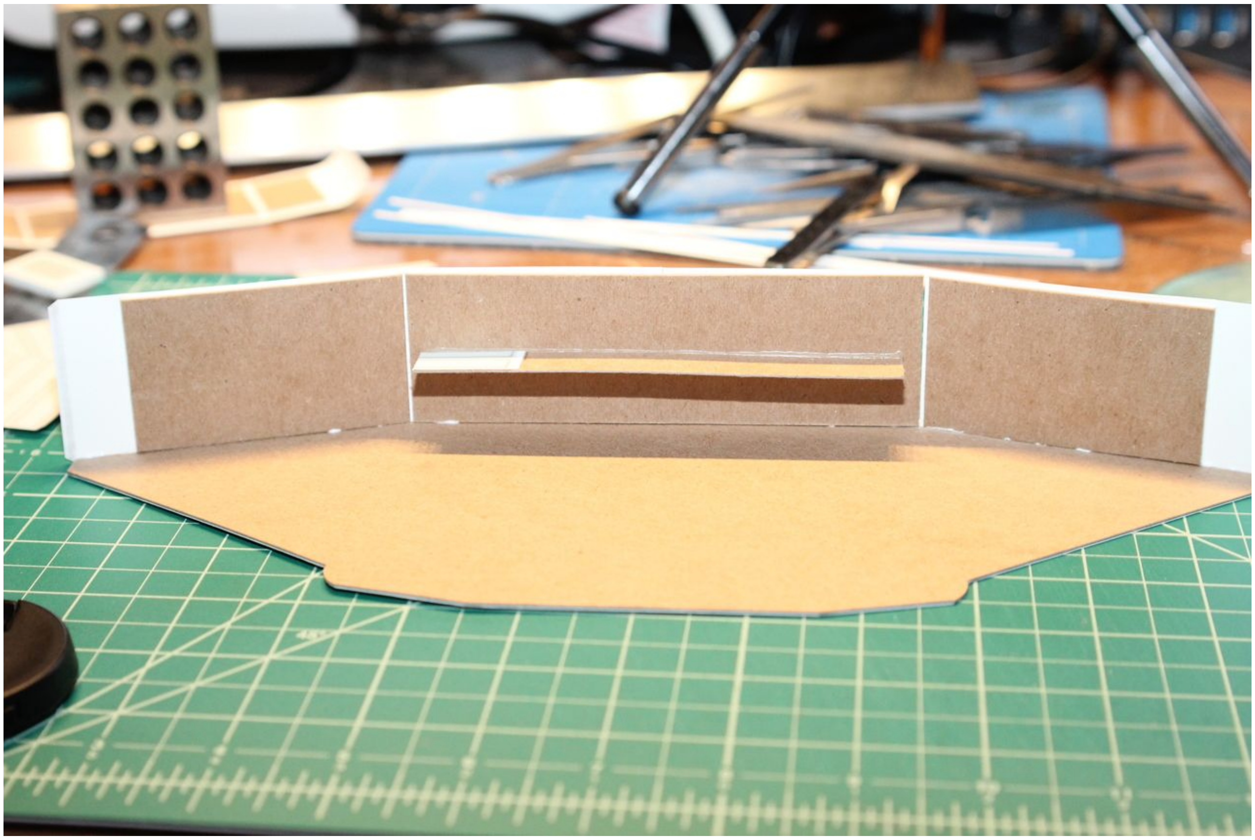
You can see this in the image below for the hull of a ship. The skin of the hull is wrapped around the formers.



The third main use of lamination is as a rib to keep a part from curling. A large part, even if it is laminated to chipboard, will still tend to curl to a degree. In order to keep the part flat you can use a rib of laminated material (chipboard or cardstock) glued on its edge to the back of the part. This helps counteract the curl of the part.

[63] Former (n.): A structure that is used inside a section of a model to help shape the externally seen surface.

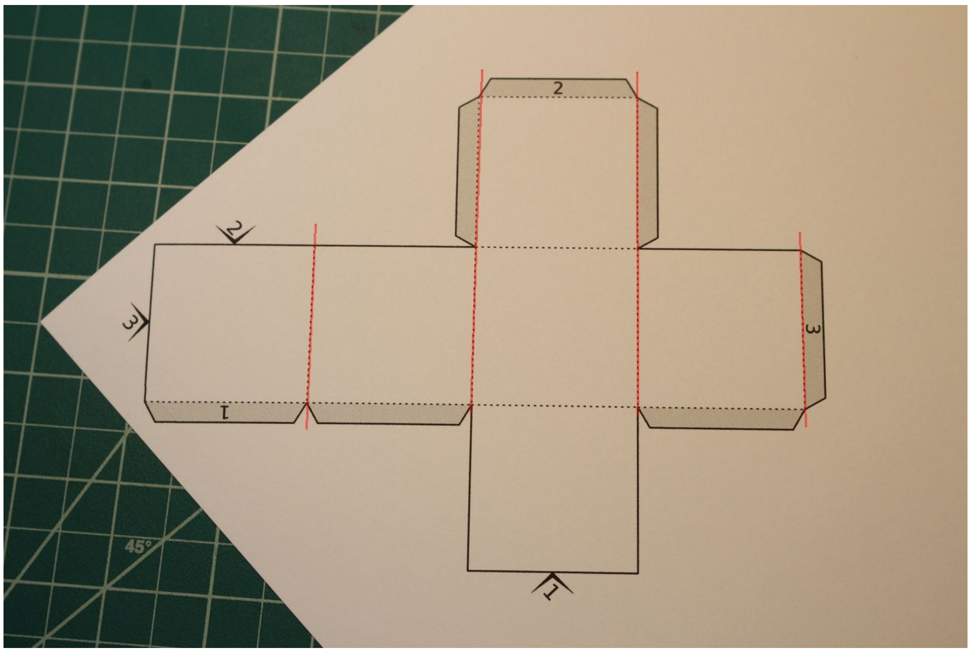
You can see this in the image below.



Even if the rib curls, its long edge is still flat and aligned in two dimensions. That is to say the long edge on the rib is flat in two of the three dimensions, and applying that edge to the back of the main part forces the attached surface to remain flat.

Building Square Structures

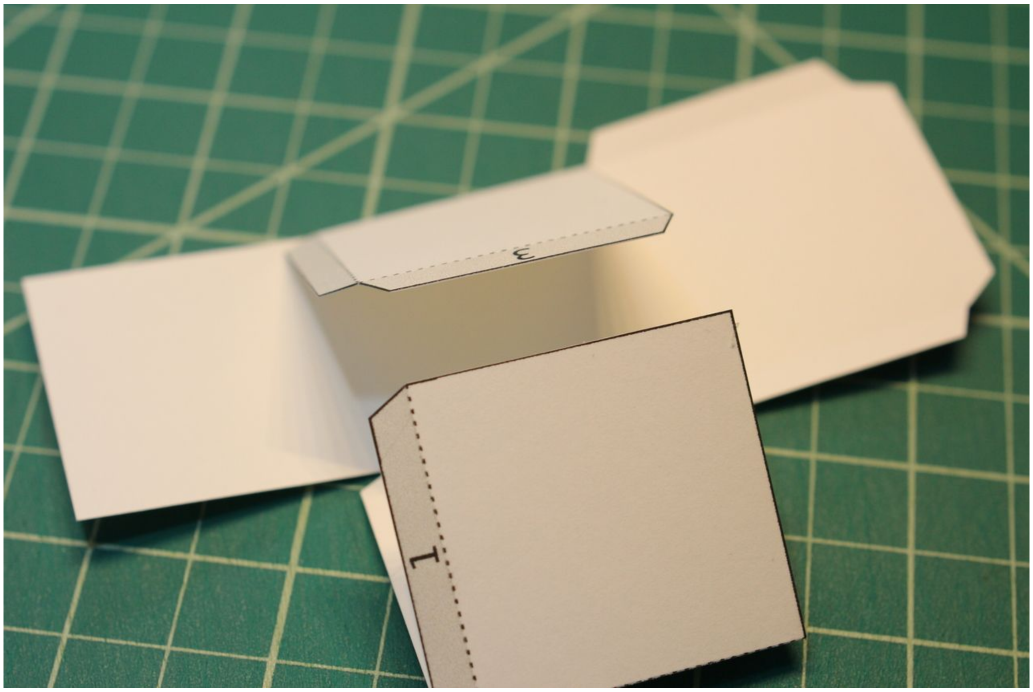
A challenge when building beams in paper is that it is far too easy for them to be warped after they are glued together. I will use the cube below as an example.



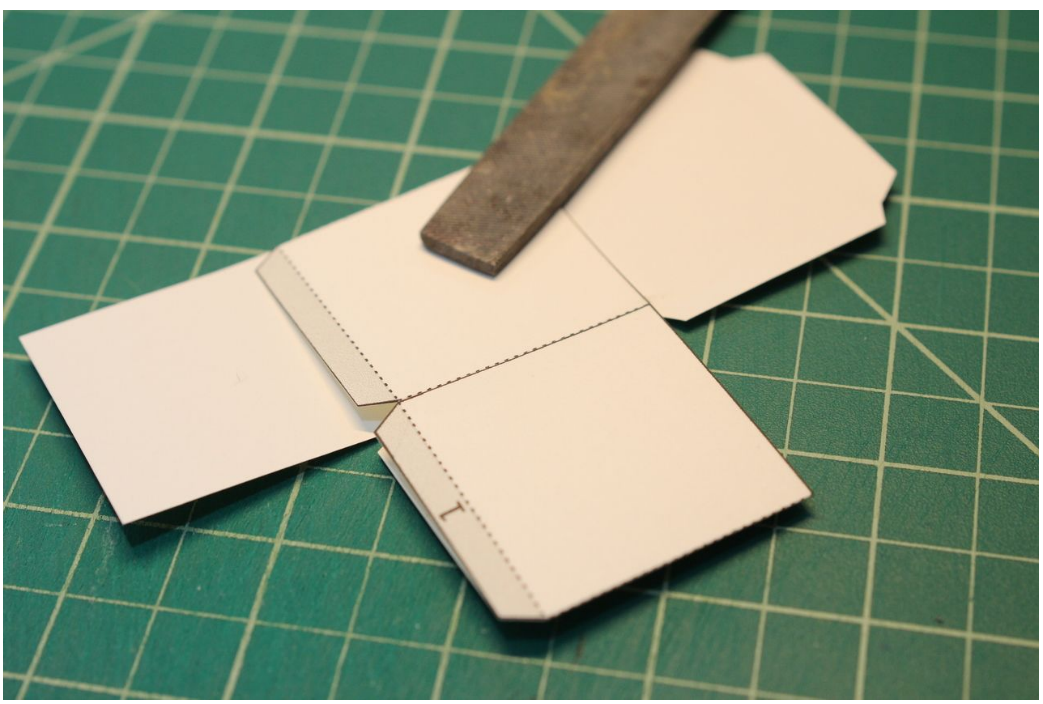
In this image, each of the red lines needs to be scored exactly parallel to each other for the result to be square. If one or more of these lines is not parallel to the others, there will be a twist imparted upon the finished structure. If we stretch a cube in one dimension it becomes a rectangular prism and a twist there would be even more apparent over significant lengths.

One way around this is to force two of the red lines to be parallel and then force the other two to do the same.

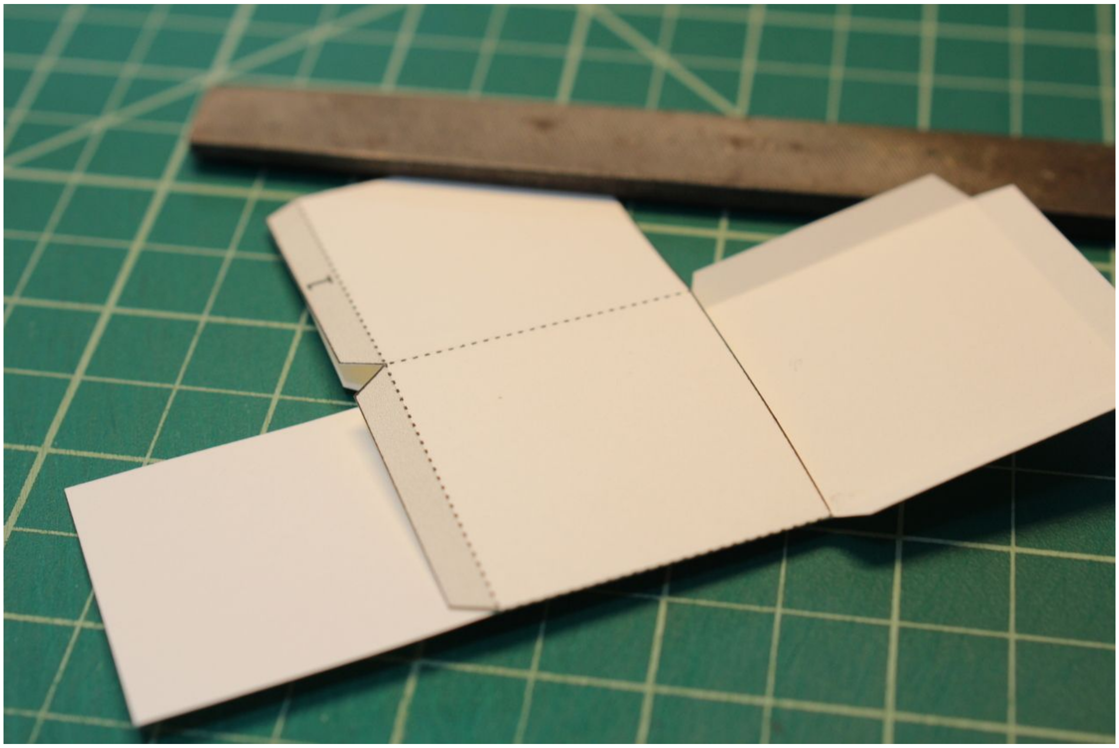
Start by scoring the cube, cutting out the cube, and folding the square on either end completely over. You will get something like this.



Then align and glue the seam. This will force the two edges that have been folded to have parallel creases.



Then pick up the square with the 1 on it and fold across the other two creases. Apply pressure to the new two folds and this should get all four score lines to be parallel (or very close to parallel).

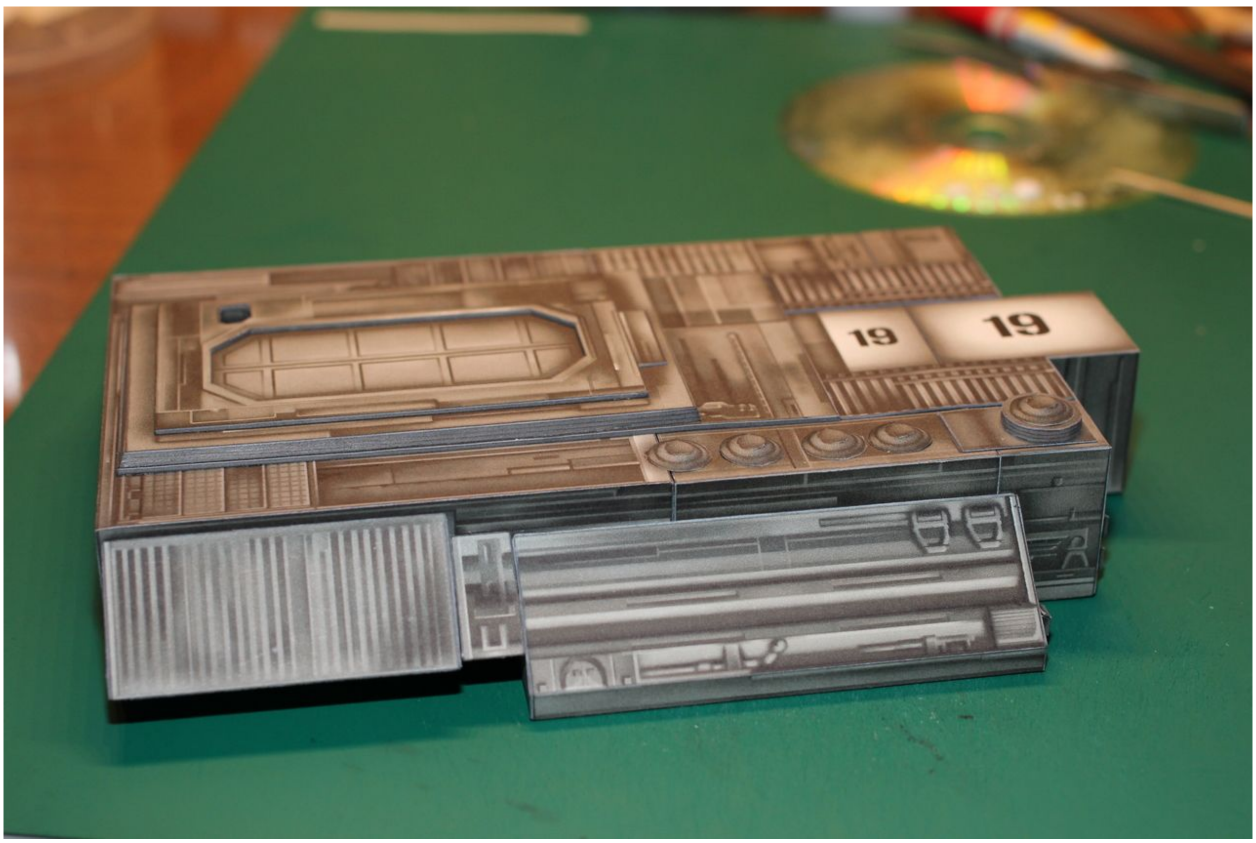


Now complete the cube as you normally would. This mechanism does not work in every situation, but it does help to align the four score lines in red and gives you a better chance at keeping all the angles square.

Panel Layering

Panel Layering is another technique that is similar to laminating. When building a model, you can have large flat surfaces which have a significant amount of printing and coloring on them. The downside to a scenario like this is that the large flat plane does not have any 3D relief on it. The visual realism can be lost when you have a large flat surface such as this with nothing to break it up. Adding 3D paneling to it adds a layer of visual texture and dimension and makes it more visually interesting.

If we take this section of a model as an example…



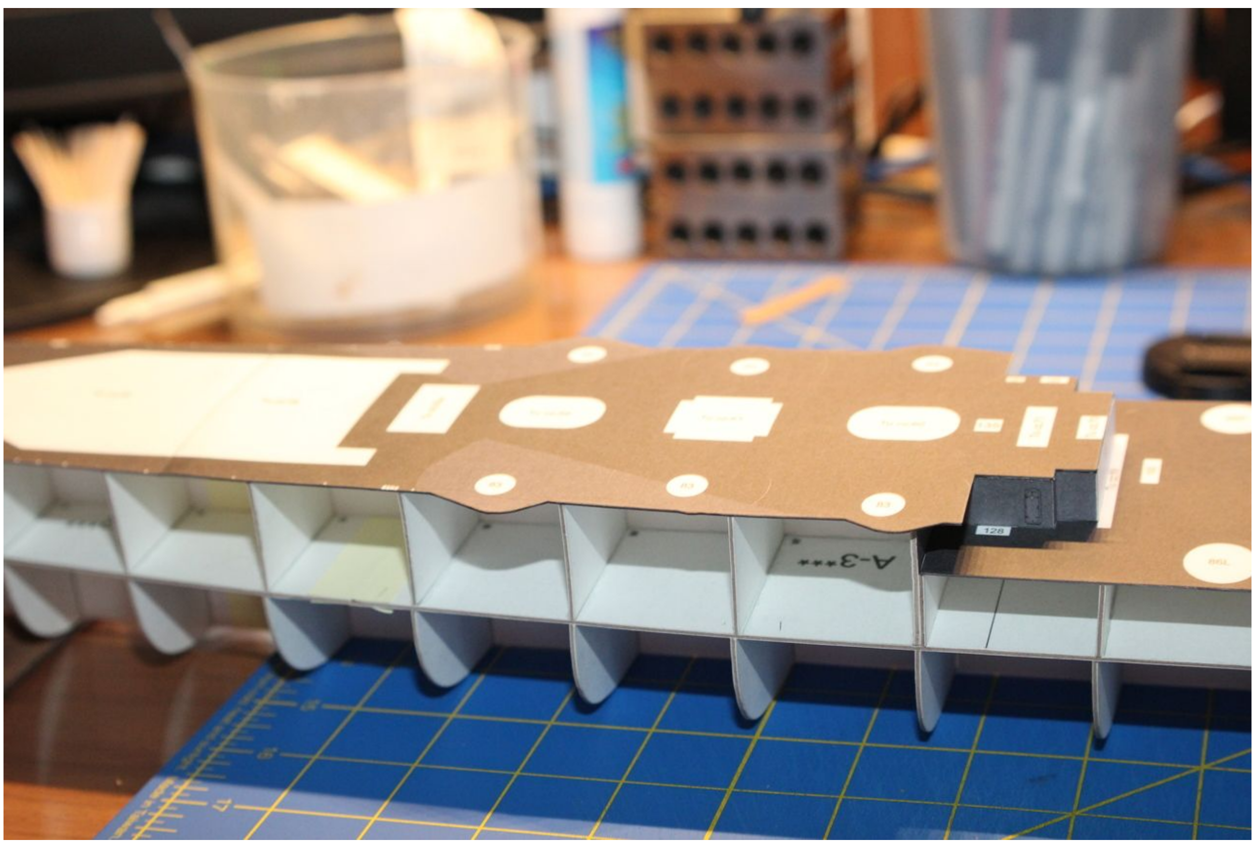
While there definitely are 3D components to this, there are still a lot of large flat surfaces. To panel layer this, I would print off a second copy of the parts and cut them up along the edges of the printed panel and texture lines. These can then be glued on top of the parts in the image above. Specifically, I might cut out the grates which are just above and below the numbers 19 and build them up by one or two thicknesses of card stock. The cross beams on the octagonal airlock door would be similarly built up to add more visual relief to the result. The trapezoidal “handle” shapes on the top right corner of the triangular prism facing the camera would be other details to build up.

Boat Hulls

Boat hulls can be one of the trickier structures to build effectively. They have a uniquely complex and repeating structure to them. I will describe the methods, and its subsequent steps, I use to construct hulls.

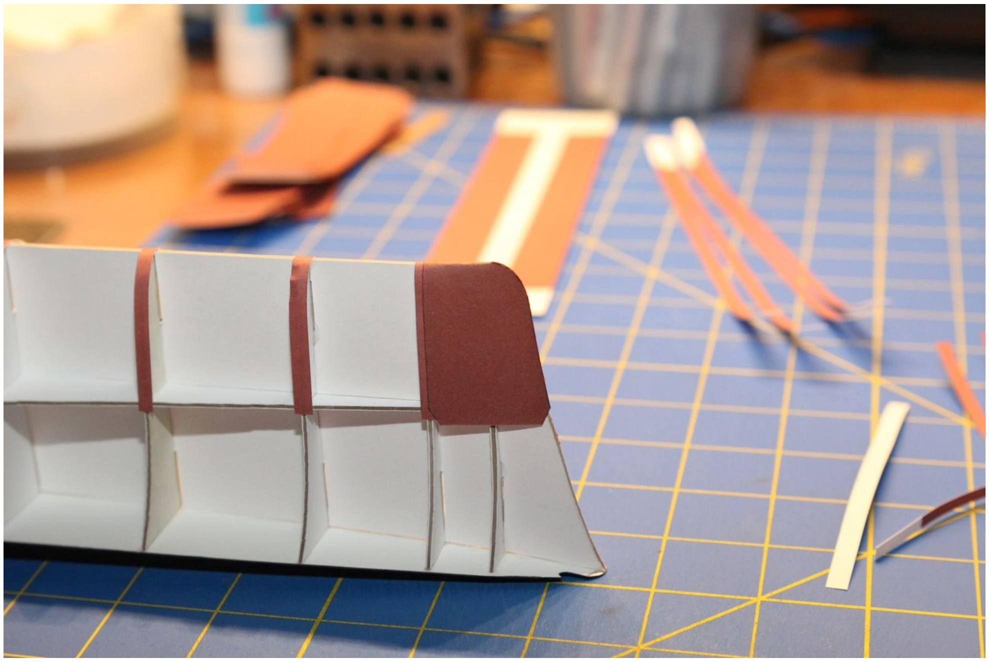
Start by laminating all of the hull formers to the thickness specified by the designer. This will add rigidity and strength to the skeleton under the hull plates. Even laminated, formers can curl, so put the pages of parts in a press of some kind and allow them to thoroughly dry. After they are dry, label them if they are not already identified and cut them out.

If formers wish to curl, I will cut out right angle triangles that have been laminated to .5 mm chipboard in order to align all of the corners. I will join the large horizontal former pieces to create a single segment to use as the start of the hull.

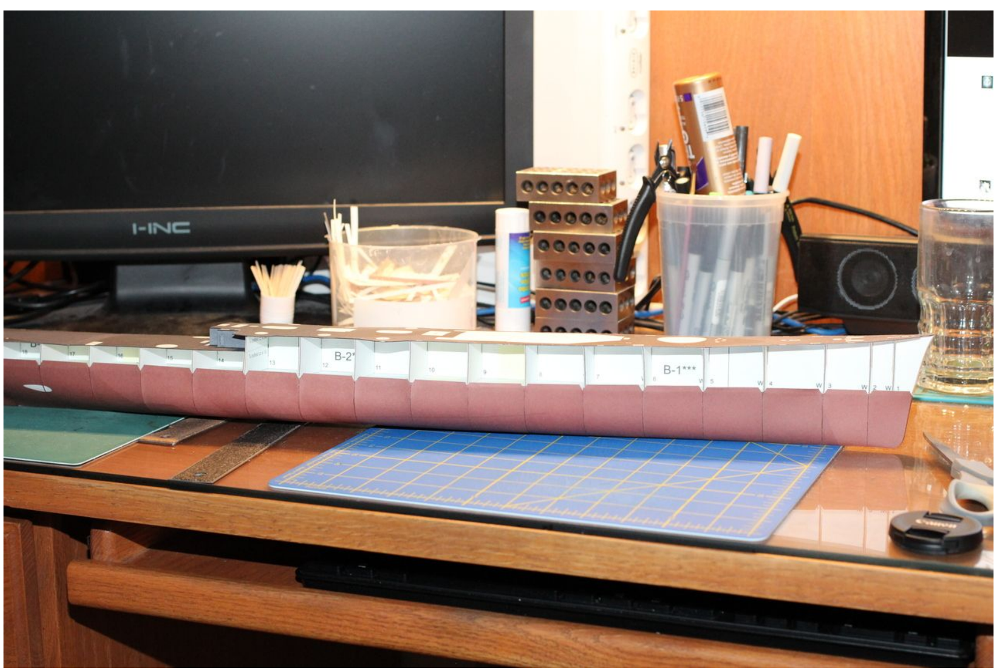


From here, all of the vertical formers are glued into place. I will use the right angle triangles here to force square corners if needed. Then glue the topmost deck (after having lamainted it per the instructions) to the hull's skeleton.

From here I glue on ⅛ to ¼ inch strips to the edge of the formers. These should be the same color as the hull parts to help hide the seams.

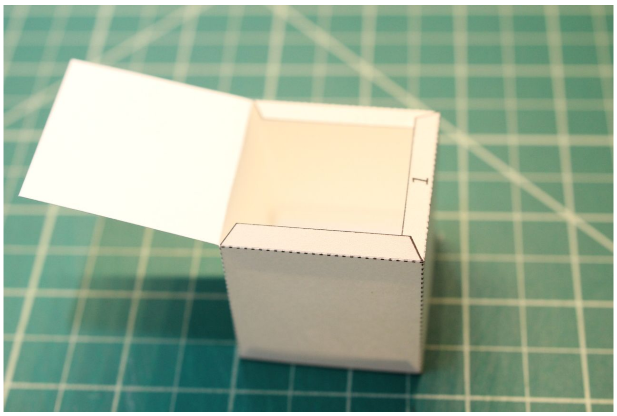


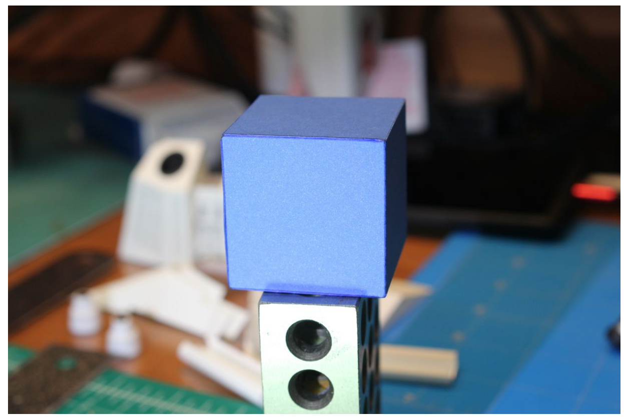
Once those strips are in place, begin gluing the hull panels on. Start at the bottom of the hull at the bow and work towards the stern of the ship. Then move up one layer of hull paneling and work from the bow to stern again.



Glue Tabs vs. Strips

Glue tabs are an efficient mechanism to facilitate gluing parts and edges together. They are a quick technique to use so that parts go together easily for the builder.





The downside to them is that the procedure of scoring and folding the glue tab causes the paper to be crushed and made slightly rounded along that score line. This can be hidden most of the time by using edge coloring, as we have seen before. While glue tabs make construction go quicker, they show more of their weaknesses as the angle of a joint becomes more acute or if we need a joint to appear very crisp.

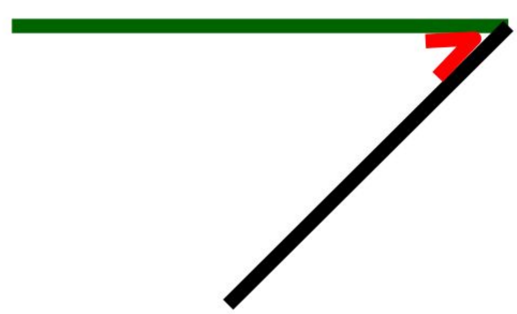
If we look at the joint between two parts that utilize a glue tab there is a slight fraying and rounding on the corner that has the glue tab.

As you can see here (looking edge on), the black part has a glue tab which forms a slightly rounded corner from the fold. That rounded edge is exposed and requires some kind of clean up (such as edge coloring) to hide it, but it still will not be entirely square. If the fold is what really causes us problems here, why not remove it? If we remove the fold then we do not need

the tab any longer. So go ahead and delete it. But now we still need a way to join the two parts.
Cut and fold a thin strip of paper (the part in red below), which we will use to join the green and black parts.

Now the green and black parts can remain square and we no longer have an exposed rounded corner from the fold. This technique works well for creating crisp joints, but it does take more time and effort to assemble than if we were to use glue tabs.

And as you can imagine, the more acute that corner angle becomes, the more beneficial it would be to use a glue strip as opposed to integrated glue tabs. We are back into the realm of recognizing that paper is not a two dimensional entity. While paper is thin, it does have a non-zero thickness.

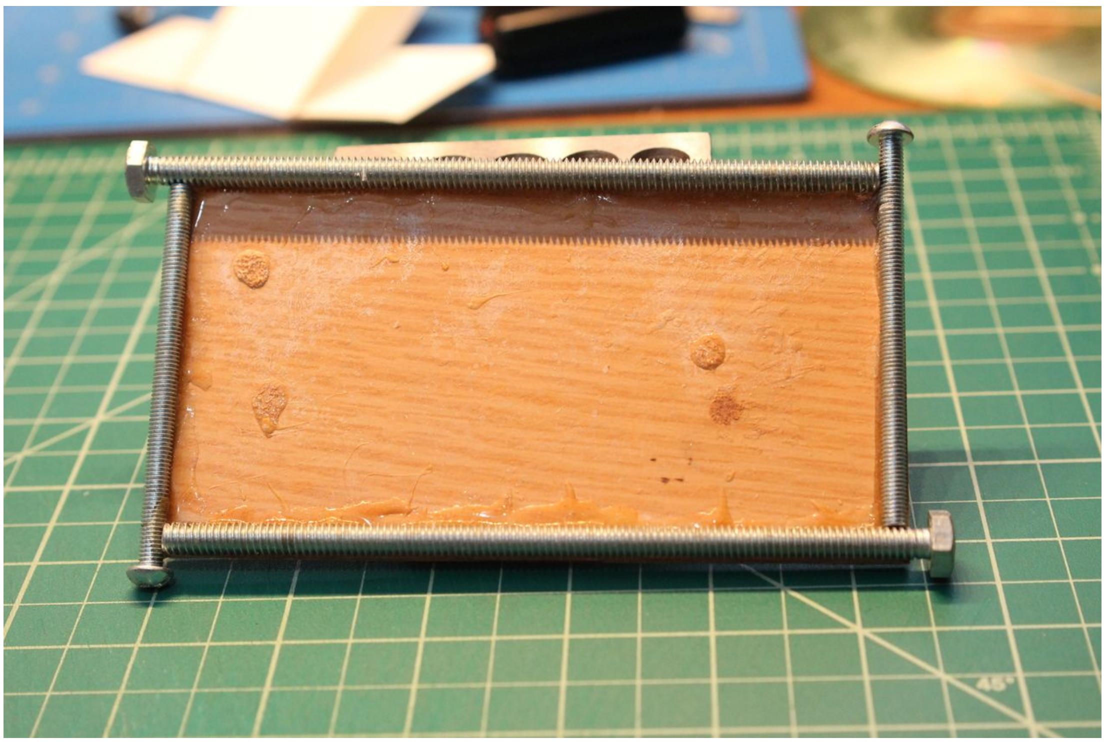


Any model you are building can have the glue tabs cut off and replaced with glue strips. You are not confined solely to the construction techniques implied by the model's designer. Similarly, you can add glue tabs to parts to speed up construction, but that is at the expense of joint quality.

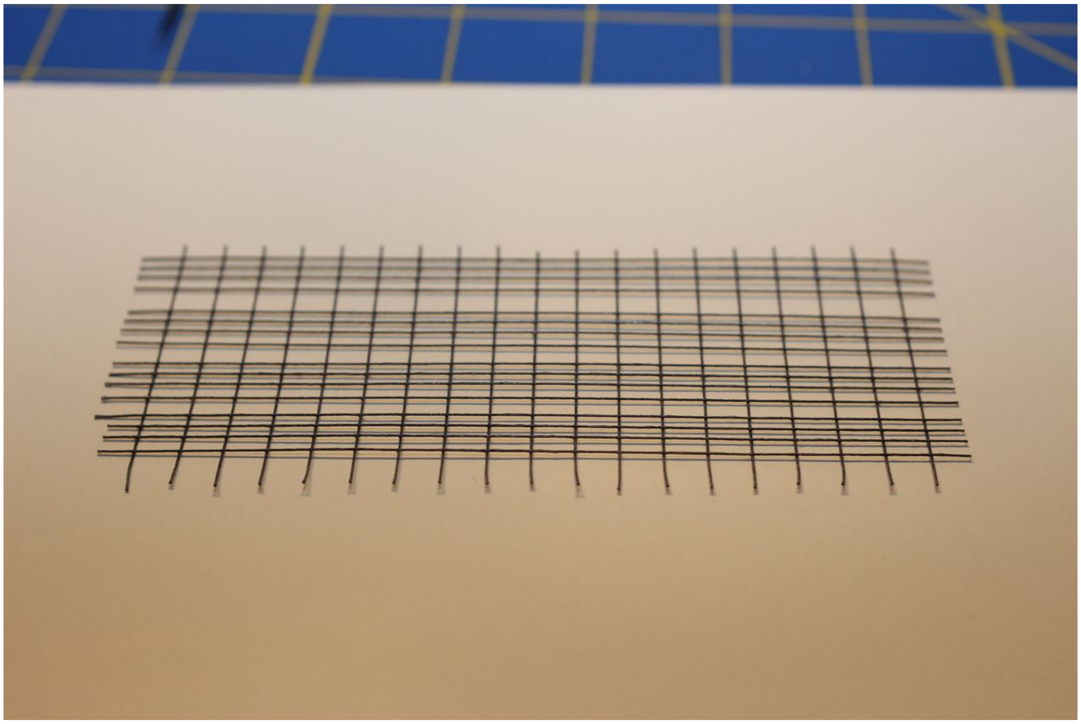
Railings and Ladders

Railings and ladders will apply the most to models of ships, but can be used on other types of models too. There are a number of companies that sell photo etched pieces of brass or laser cut paper in the shape of ladders and railings for various scales. But building these components yourself is often more enjoyable than ordering some parts (and far less expensive).

For this effort we will need to make a jig. I took a scrap of wood and glued four bolts to it like in the picture below. You will want a relatively fine thread pitch on the bolts.



With this, we can now use grey thread to wrap around the jig. Our goal is to form something that looks like this for railings.

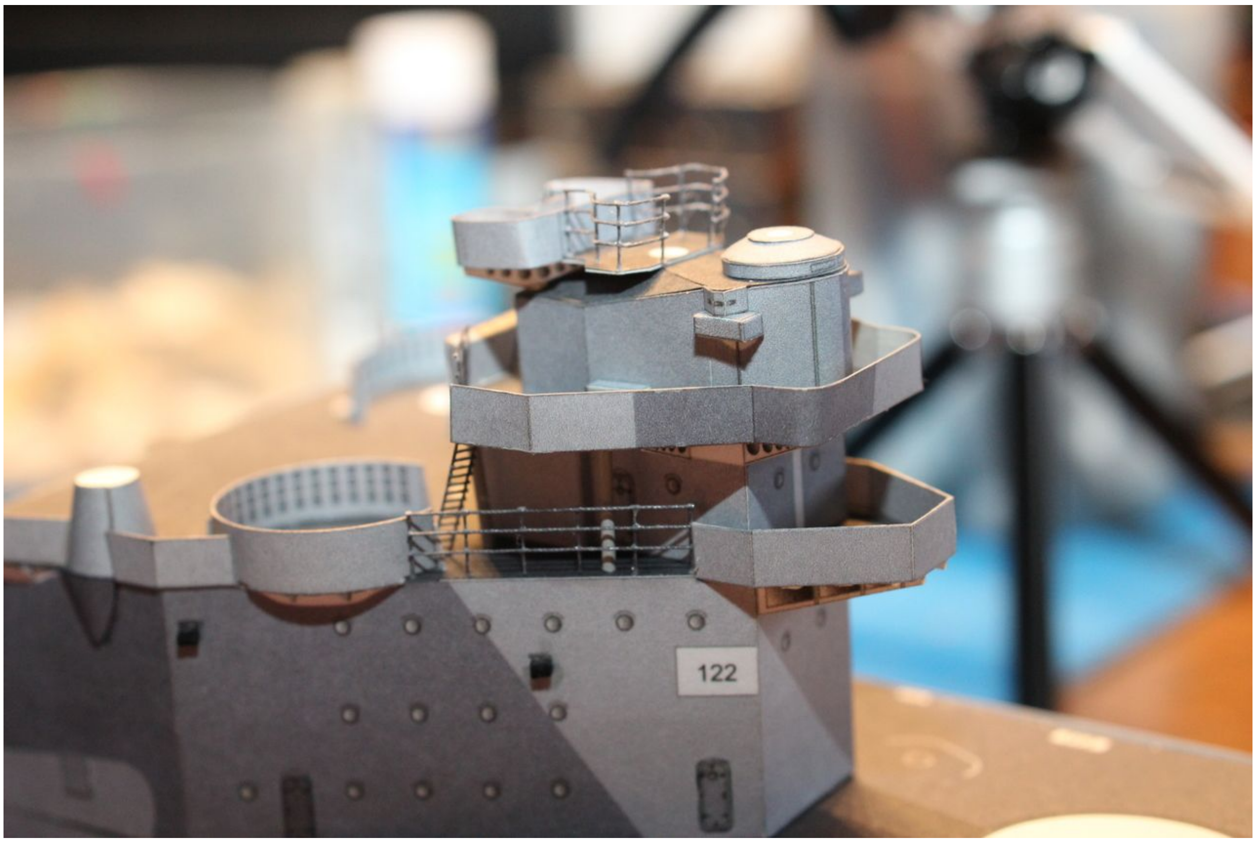


Change the spacing between threads on the bolts to build railings, or ladders, or whatever you need for your model. But just wrapping thread around a jig is not enough. We need to add some structural integrity to the thread before it will be useful. Below are the steps I use to create railings and ladders which can be manipulated and will still hold their shape.

1. Wrap the thread around the jig in the pattern you need. I found that cotton upholstery thread is thicker than most varieties and has more of a visual feel like that of a railing. It is my choice as it also absorbs the glue well (#3 and 4 below).
2. Wet the thread with water. This can be done with a spray bottle or with a paintbrush.
3. Using a mixture of thinned white glue (the cheap stuff plus water works well here) and paintbrush, paint on a layer of thinned glue while the thread is still wet. Eliminate any blobs or large droplets that cling to the thread.
4. Go back and put a 2nd layer of thinned white glue on the thread. Get rid of any blobs or large droplets again.
5. Let the white glue thoroughly dry.
6. Using super thin CA (super glue), apply a layer of glue to the thread in your jig. Use a scrap of tissue paper, facial tissue, or paper towel as an applicator. Drag the paper towel scrap across the top of the thread while applying CA on top of the paper towel. You will soak through the paper towel in doing this and use it as a glue wick, applied to the thread. This scrap will be ruined by using it as an applicator, as the glue will make it rock hard once dried. Dispose of the scrap as soon as you are done using it. Having a wet super glue soaked rag around is asking for disaster.
7. Let the CA thoroughly dry with plenty of ventilation.

8. Cut out your railings or ladders roughly with scissors. You will discard all of the thread that was wrapped around the back of the jig.
9. Trim the edges with a chisel blade and cut the various sections apart.
10. Using two sets of pliers or tweezers fold them as needed for your application.
11. Glue to your model with white glue (the good stuff this time).

You can achieve phenomenal results after a little practice. And once you get the hang of it, it can go quite quickly and you will make a whole ship worth of railings at once. All the railings and ladders in the image below were constructed with this technique.



Wirework

Previously, I have talked about some tools that can be used to bend wire. Some commercial models expect the builder to construct certain details (antennas, masts, rigging) from wire. Even if the model you are constructing does not explicitly call for wire details there is no reason you cannot add them yourself.

In order to work with wire you will need a few things at minimum.

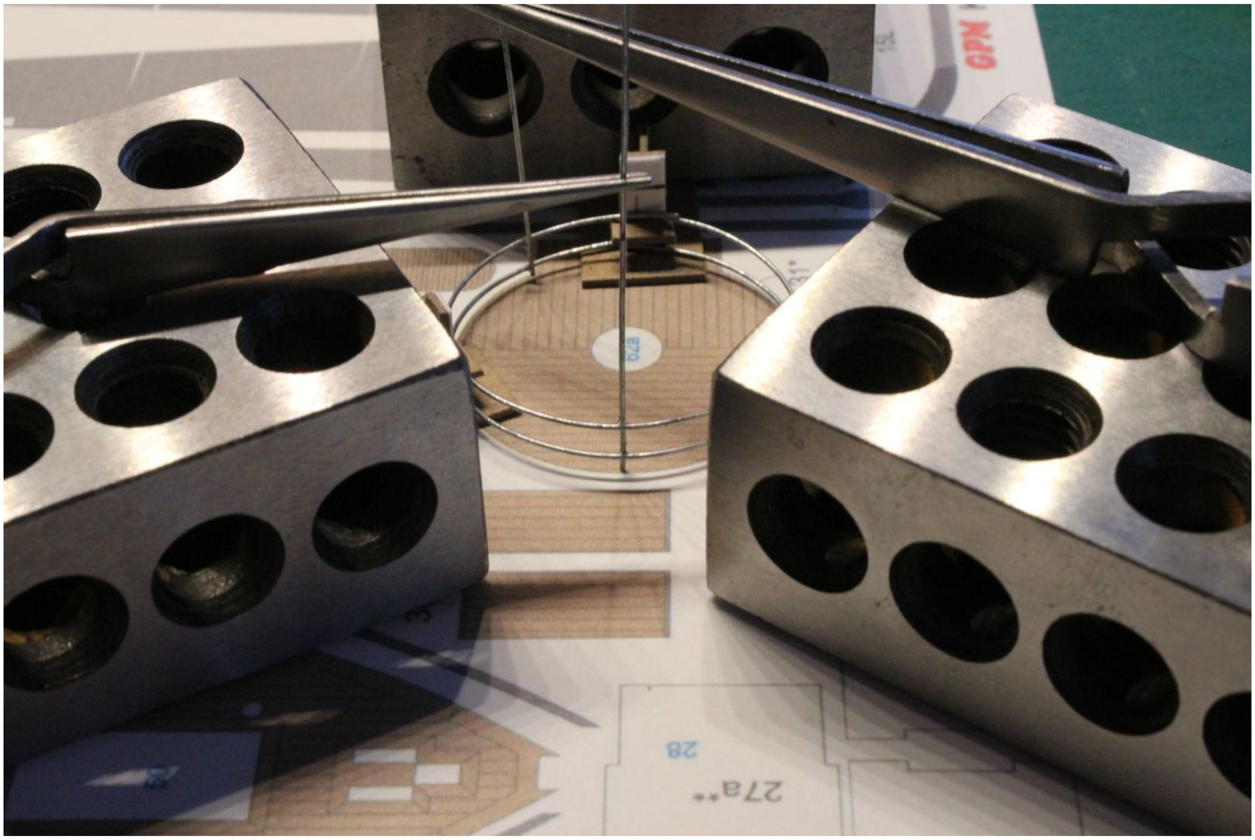
- Wire of various thicknesses
- Wire cutters
- Pliers or heavy forceps
- Paint

Beyond the must-haves, a few other items are helpful

- Mandrels
- Jigs
- CA glue
- Clamps (clothespins or forceps)
- Weights
- Soldering iron
- Solder

If the detail you are constructing involves multiple pieces of wire, you are limited to either CA or solder to connect them together. Use files or sandpaper to rough up the areas where the wires will connect. The roughed area will give the glue or solder a place to adhere which will offer a stronger mechanical connection. Adding abrasions to the metal is known as “toothing the glue” as it gives more surface area for the glue to grab on to.

As you can see in the image below, there are small jigs which hold the rings of wire at distinct heights all the way around the circumference. Weights are being used to hold those jigs in place and to support forceps holding the vertical posts. This was all left in place until the CA dried properly and gained full strength.



In this example, I found a jar or bottle that allowed me to wrap steel wire to get the proper circular shape. This effort now starts to touch upon some basic metallurgy.

If you take a paperclip and start to bend it in one particular spot, after a few bends it will break. This is known as work hardening[64]. Every time you bend a piece of metal, the spot where it flexes becomes more brittle while becoming stronger. This is why after a few bends of the paper clip it will break. So if you are repeatedly trying to shape a piece of wire you may eventually cause it to break in your hand. This can be reversed though by a process called annealing[65]. If you apply high heat to a work hardened material it allows the crystalline structure of the metal to flow and relax. Annealing a work hardened piece of metal will restore its flexibility and reduce its internal stresses, but reduce its overall strength.

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[64] Work hardening (v.): Increase in hardness of a metal induced, deliberately or accidentally, by hammering, rolling, drawing, or other physical processes.

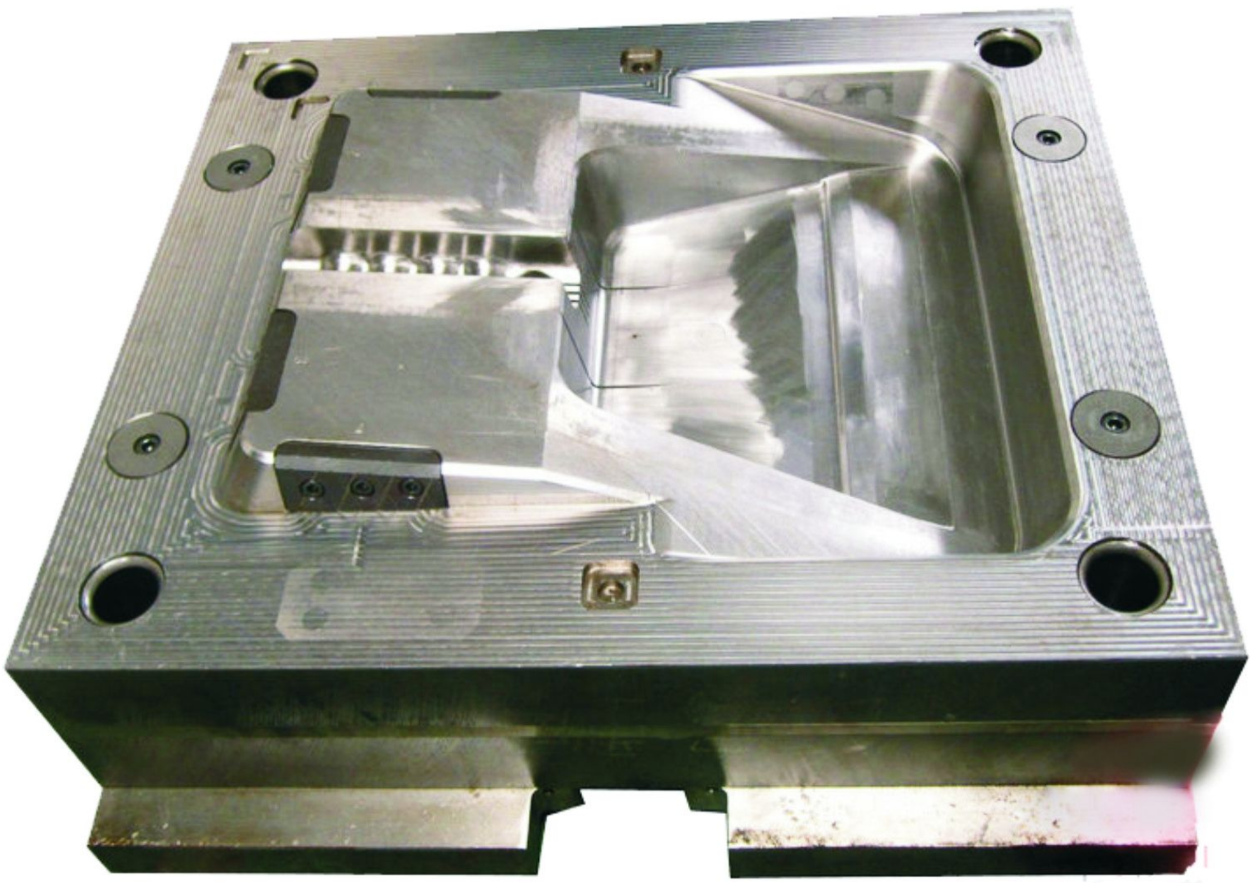
[65] Annealing (v.): Heat (metal or glass) and allow it to cool slowly, in order to remove internal stresses and toughen it.

To attach a piece of wire work to a paper model part, you can drill a small hole in the paper part and apply high quality white glue to the inside. For things such as railings and small antennas, you can simply use the good white glue and attach the part to the paper part without drilling a hole.

Once you have constructed your wire detail, you will likely need to paint it. Most of the time a bare steel colored wire will not be what your model calls for. Color the part as needed and then glue it to your model.

Paper Moulding

Paper moulding is a rarely used technique that you can think of as being similar to injection moulding for plastic. In injection moulding, a steel die is machined as an inverse of the object you want to create.



Plastic is heated until it flows like liquid and then it is injected into the mould, forming the object desired. The image above is half of a die for a dustpan.

Paper moulding is similar in that an inverted mould is created and a slurry of paper and binder is pressed into it, yielding the object you wish to create. It is an option for when you need to create a number of identical objects with compound curves. An example like this would be spheres or nose cones for a rocket.

The first step is to create the mould of your object, which cannot be made with water soluble materials or it will break down when the paper slurry is put into it. Good materials for the mould are plastic and silicone (ala silicone casting). As you can imagine, creating a complex mould is a non-trivial task and another art form in and of itself.

Once you have your mould, you will need a paper slurry. There are many different recipes for slurries and each person has their own preference. Fundamentally, they all involve putting paper, water, and some glue or binder into a blender and blend until smooth. Once blended very well, it is poured and pressed into the mould and allowed to dry… and that might take a good amount of time.

Once dried, the part can be popped out of the mould and go through some finishing stages. A common finishing effort might entail sanding, sealing, priming, and painting. Painting is a definite must for moulded components.

I have attempted this technique a few times, but due to the complexities of forming the mould, extensive finishing efforts, and mess... I am not a fan of it and my results were entirely underwhelming. It definitely does work for some people and in some situations, but if you are designing a model that you expect others to be able to construct, please find another mechanism than paper moulding to form a given shape. The majority of the paper model building community will not be interested in moulding parts for a kit you produce.

A related idea to paper moulding is paper mache[66]. This entails making a pulp of paper and then forming it into the shape you desire. You can think of this as the mature equivalent of chewing up paper in 3rd grade to make a spitball. This can be used to form small spheres and other odd shapes. But you do need to use filler, sand, prime, and paint if you wish to achieve a uniform smooth surface.

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[66] "Papier-mâché - Wikipedia." https://en.wikipedia.org/wiki/Papier-m%C3%A2ch%C3%A9. Accessed 27 Nov. 2018.

Filler

Fillers are good to use to seal up gaps and seams in paper models (and also plastic models). The downside in the paper model world is that you now have to paint or touch up the finished model. Without painting you will have raw filler exposed on your completed model.

There are commercially made fillers that work very well, such as the Mr. Surfacer line of products. You can create your own sandable filler at home though.

A mixture of CA glue and baking soda will form a thin paste which can be applied to your model. Be sure not to use the varieties of CA that dry rapidly. Baking soda will cause CA to cure faster than normal, and if you are using this as a putty you will need additional time to get it in place and shape it. And once you have put the filler on your model, a small spray of CA accelerator can cause the filler to set in short order. This mixture, once dry, is sandable. After it is dry, sand away, prime, and paint.

Again, the downside with using filler is that painting is now required. Since most paper modelers do not wish to paint the entirety of their model, filler is not used all that often.

Converting Scales

One of the great things about paper models, at least if you have them in an electronic format, is that you can change the size of them. If you want a smaller version of a model you can print the parts off shrunken down to smaller than their original size. You can do the same to enlarge model parts, but once they grow past the size of a single page of card stock you may have to re-engineer that part a bit… and that can take some effort depending upon the situation. We can recalculate scale and size with a little bit of algebra.

Let us say we have a model that is 1/72 scale and we wish to shrink it to half its original size to 1/144. Just saying that sentence tells us how much we need to scale the image… by half. So when printing the parts you would set the scaling in the application to 50%.

Doing the math out looks like this, where x is our scaling factor.

(original scale) * (scaling factor) = (new scale)

$(1/72) * x = (1/144)$

Simplify slightly: $x/72 = 1/144$

Multiply both sides by a common denominator (144 in this case): $2x = 1$

Divide both sides by 2 to get x on its own: $x=\frac{1}{2}$

$\frac{1}{2}$ is 50%.

Let us do the same thing with something that is not as clean. Let us convert a 1/24 model to 1/87. 1/87 happens to be the scale for HO train sets.

$(1/24) * x = (1/87)$

$x/24 = 1/87$

$87x/24 = 1$

$87x = 24$

$x = 24/87 = 27.586\%$

So if we scale the 1/24 scale model to 27.6% of its original size it will now fit in with other 1/87 scale models.

We can use similar math to determine how long a given model will be once it has been constructed. Let us say we are making a model of a space shuttle orbiter, which is 184.2ft long in real life. If we are making a 1/144 scale model of it, we should expect the model to be 1.28ft long (184.2/144).

If we need to scale the parts down further so that it fits into a 1ft long display area, that will be a scale of 1/184.2. Doing the same math that we have previously, we will find that we need to shrink the 1/144 scale parts to 78.2% of their original size.

Adding Durability

One factor that continually comes up with models of any variety is that they can often be fragile. You, as the builder, have the opportunity to make your models more structurally sound as you construct them. It is emotionally draining to finish a model to find the following morning that parts are drooping and falling off from their own weight… or if you move a model on a shelf and parts break off.

There are details on models, such as antennas and wires, that are inherently weak and to a certain extent that has to be accepted. But there are techniques that can be applied to make models stronger so that they will last longer and can survive more handling.

A step I add to nearly every model now is to cut chipboard and laminate it to the inside of any large flat surface. I take this far enough as to list it in the instructions for models I have designed. This, on its own, adds a large amount of structural rigidity to a completed model.

Similarly, if you have larger internal structures for a model, consider building internal reinforcements so that they do not flex or wobble. Make some measurements and cut out some chipboard to run along the length of a sub-assembly.

When your model includes details such as antennas, cabling, or wires you can add strength to the connections for each of these. Instead of gluing the detail part to the surface of the model, consider using your pin vise to make a very small hole, cutting the wire longer than you need, and gluing it internally to the model. That is, put glue inside the model part and run your wire or antenna into the hole. You can even reinforce the paper from the inside so the antenna sockets into the paper model part.

What makes sense will vary depending upon the model you are making, the techniques you are using, and the materials involved. Think ahead as to where the weak points will be in your construction and plan ahead to make those areas more durable. This goes double for a model that you are building as a gift or to sell as a commission. There is an expectation that what you produce for others will hold together over time and that it will resist some amount of handling.

For very long models, such as that of a space station, I would also consider running a metal or PVC rod through the center of the model. The addition would add a lot of structural stability in the form of a skeleton to put space station modules onto.

Weathering

Weathering is the technique of adding details to a model that make it look used. This comes in to play both during the design of a paper model and the construction of it. The design aspect will be discussed later in this book. Various weathering techniques used while building a model have a lot of overlap between paper and other forms of model making.

Let us pretend we are making a paper model of a warplane and that the original designer laid out the colorings of the plane as it would appear coming out of the factory. But you want to make the plane look like it has gone on a dozen missions and been used hard. From this point you could add oil streaks on the skin, smoke/soot on the body behind the engines, more dirt behind the gun ports, chips in the paint, corrosion, and mud on the wheels and landing gear. All of this would add to the realism that this was a plane that was flown and used.

These details could have been added by the designer and would have been printed with the rest of the coloring on the parts. But the designer had no idea what you desired your model to look like and could not have included all the details you wanted. You can take a factory fresh plane, and using the art supplies we talked about earlier, add those details you desire.

Weathering is another art in and of itself, and I cannot hope to do it justice in this book. But the techniques definitely push into the realm of artistic application. You can use pastels, paint, pens, and all kinds of other materials to pull off your look. Use reference images of similar real life objects to study how oil streaks might appear, or how rust grows on a ship's hull. It will take practice to achieve the look you desire and will begin as a bit of trial and error to find what works for you.

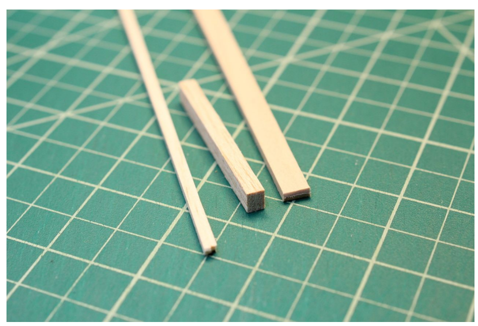
Non-Paper Materials

There are some that will claim that a model is not truly a paper model unless all you use is paper for its construction. From a certain purist perspective this is accurate. But someone looking at a model you have made will not care in the slightest whether it is 100% paper or not. It also ignores that many commercial models specifically instruct you to use wire and thread to add details. This is most commonly seen in kits of model ships.

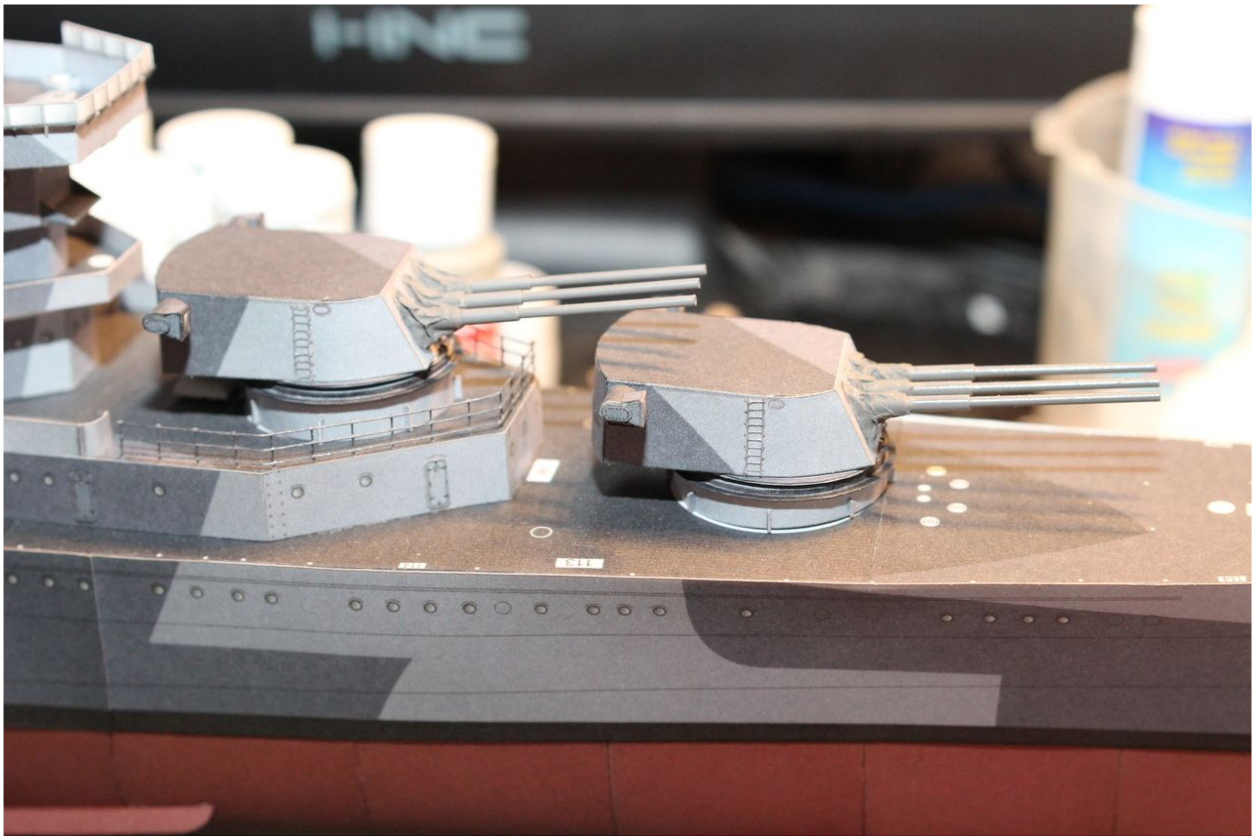
I regularly use whatever materials I have around that will make a model look better, even if it is not what the model's designer really intended. But again, non-paper materials will require painting or coloring of some type because they are not printed by your printer.

I use all kinds of stuff that might be lying around.

- Balsa strips
- Small dowels
- Thread
- Scrap brass and aluminum rods
- Tissue paper
- Wire
- Window screen
- Thin ribbon (makes excellent seat belts)
- Anything else that looks good

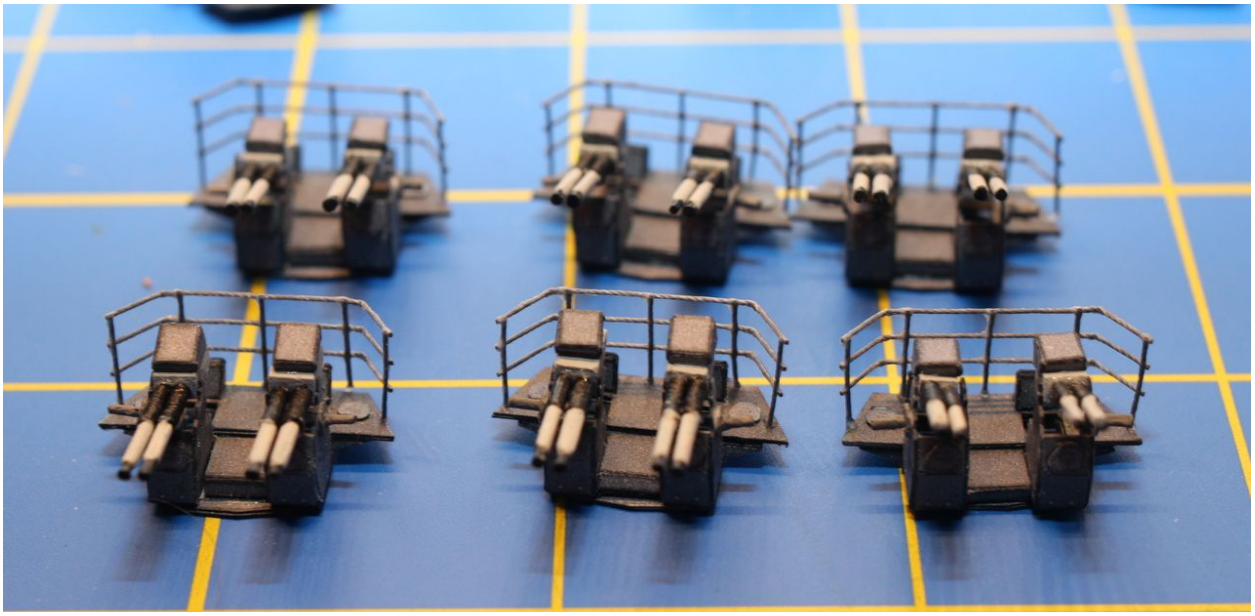




Here is an image of the USS San Francisco that I made a couple of years ago. If you look at the barrel bags, which protect the section closest to the turret, that effect is impossible to create out of a printed piece of paper. The bags are made from small bits of tissue paper which was then brushed with a watered down mixture of PVA glue before being painted to match the rest of the structure. It is worth noting that I also find it incredibly difficult to roll long thin tubes. So the barrels below are made of sections of scrap brass rod painted grey.

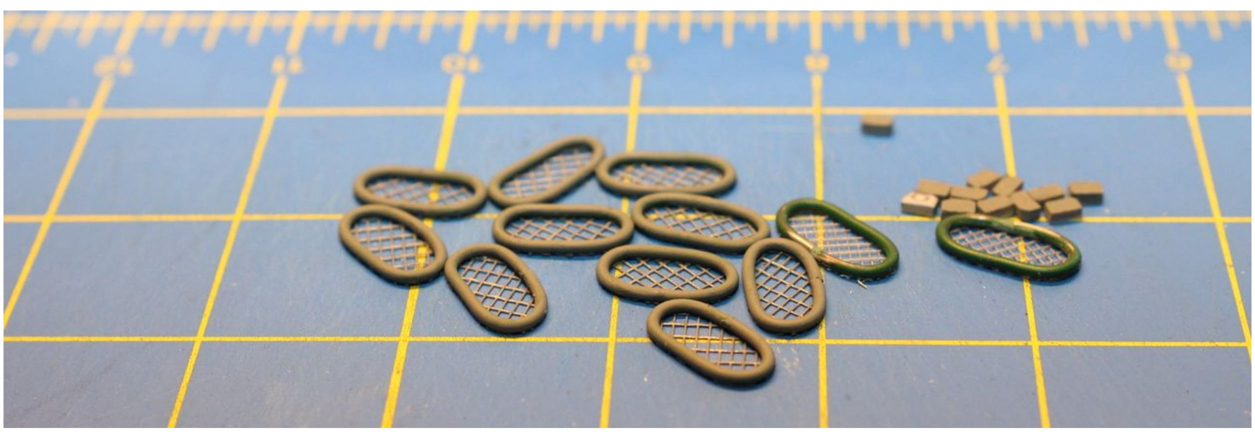


An old plastic model trick is to use tissue paper or facial tissue to represent canvas of any variety. At scale it very much resembles the rough canvas you might find draped over the bed of an army truck, the covering on an army tent, backpacks, duffel bags, rain tarpaulin, or a rain poncho on a soldier. Once the tissue has been cut to approximately the right shape and roughly put in place, wet it with a mixture of watered down white glue (the cheap stuff is fine). Once it dries it will set up hard enough that it will hold its shape and you can paint it the proper color at that time.

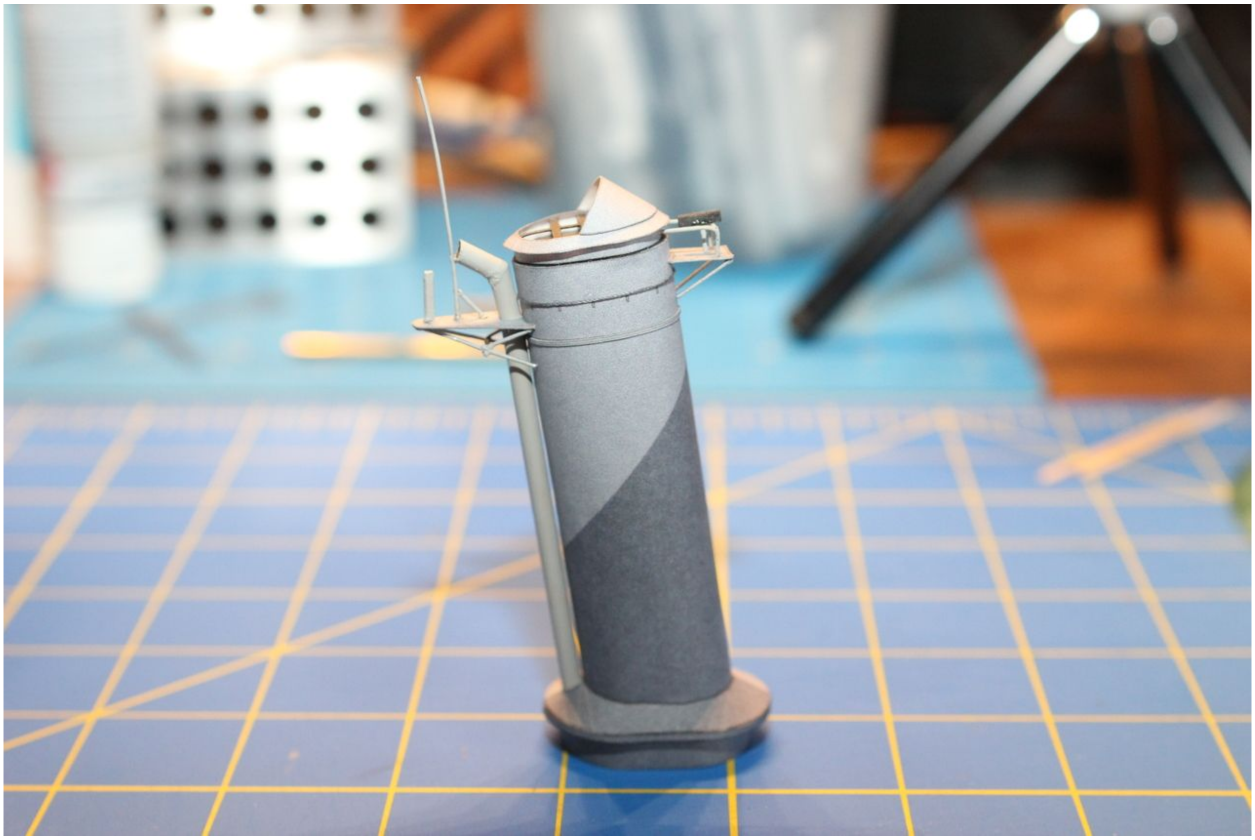
Here is an image of the 40mm guns from the same model. The barrels here are carved from toothpicks, painted, have the rear section wrapped with thin thread to look like recoil springs and then glued to the assembly. The railings are made of thread and constructed in a manner previously described.



This image is of the life rafts for the USS San Francisco. They were made by bending floral wire to shape, filling the seam in each link, painting, then gluing a segment of fiberglass window screen to it. The window screen gives the raft the look of the appropriate netting.



Here is another example. The smaller pipe running up the back of this smoke stack is made from brass rod cut, filed, glued, and painted to match the rest of the stack. The supporting wires for each platform are made from steel wire, just as the antenna is.



All of these details make the end result more convincing and more visually interesting. Add as much or as little as you would like to your creations, as they are ultimately yours. There is no downside to recognizing that a particular detail is not well suited to being rendered in paper. When you find those situations choose a different material that yields a better result.

Design

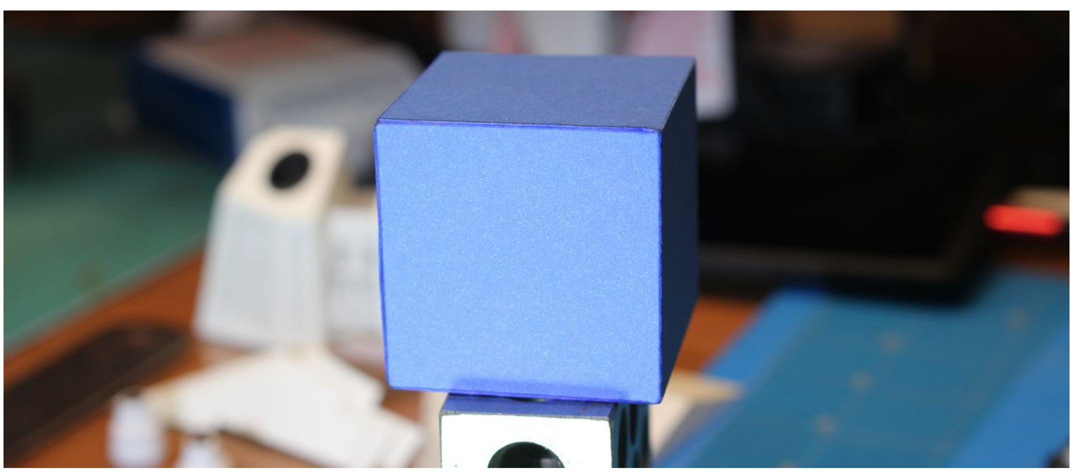
This portion of the book will focus on the thought process and considerations that you, as a model designer, may need to take into account as you create your masterpiece. Every choice you make will be a trade off between various competing factors. Through all of your design efforts, think about how the builder will construct the model and how they will generate a high quality example of the subject.

Toolset

The toolset you choose will directly and drastically impact your workflow in creating models. Some toolsets will focus more on the structural engineering aspects of a design and others on the artistic side.

Through this section there is some vocabulary we need from a structural standpoint. I will define more terms later on when we get to the artistic considerations.

We need to think of our models in three dimensional space. Our model will be made up of one or more objects[67]. Objects are discrete subsections of a model. If we take the cube that was used earlier as another example, this model would be made up of a single object (the cube). If it was slightly more complicated and was a model of a cube, a sphere, and a cylinder, then the cube would be just one of three objects.



[67] Object (n.): Discrete subsections of a model.

Within the cube, there are six sides to it. Each of these sides is known as a face[68]. In 3D modeling we generally expect faces to be planar, which means that they are a flat surface. In the example of a cube, each face is a square.

Within each square face, there are four edges[69]. These are the edges of the square. Linking multiple edges together is how we define a face.

Each edge is then a line made up of a starting and ending point. A point is known as a vertex[70] and multiple points are known as vertices.

Two vertices form an edge, three or more edges form a face, and multiple faces form an object.

Manual Toolsets

Manual toolsets are what has been used the longest in the design of paper models. Simplistically, these are old style drafting[71] tools such as graph paper, protractors, rulers, geometry, and drafting skills.

Except for simple objects, I would not recommend using the old style drafting techniques. While you can do all of the math with a basic trigonometry calculator, a geometry textbook, protractor, and ruler; it becomes a lot of repetitive math to complete anything. And as we know, computers are very good at repetitive operations.

Drafting on paper, and the manual skills that go into it, are not taught anymore and those skills are all but absent from the engineering disciplines today. Computers have taken over all of these duties.

Beyond aspects of automation that you will not have present when doing things by hand, the manual efforts only focus on the structural aspects of a model. They will not help with the coloring and artistic efforts that go into creating a model. They also do not lend themselves to duplication so that others can build your creation.

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[68] Face (n.): The presented surface of an object. In 3D models, this is usually a planar construct.
[69] Edge (n.): The outside limit of a face. Multiple edges make up a defined face.
[70] Vertex (n.): The points in space that make up the ends of a line.
[71] Drafting (v.): Technical drawing, drafting or drawing, is the act and discipline of composing drawings that visually communicate how something functions or is constructed.

Computerized Toolsets

Once we step into computerized tools we achieve a large amount of automation, in many areas, that go into creating a paper model. There are many tools available and I will not profess to understand all or even a large portion of them. I will focus on topics that are of a global concern when designing a paper model. I will not attempt to explain how to use the various software applications, as they could each have multiple books written upon them (and many have already).

From this point forward in the book, I am going to assume you are using some kind of computerized toolset and speak of things in that manner.

I have already touched upon the topic of automation. If we use our example of the blue cube from earlier and we move one of the vertices on it (and it would no longer be a cube at that point) we would have to recalculate the position of that vertex… and the angle of each edge… and the length of each edge... and the area and size of each face that is made up of that vertex. We are up to a minimum of 12 calculations that need to be run, just by moving a single vertex around in our 3D model. You can imagine how many more calculations would need to be done if our object was more complicated. This automation allows us to focus on designing and creating instead of doing the iterative math required.

Automation also allows us to do things such as duplicate objects, rotate them, and stretch them with minimal effort. We can also change the scale of a model relatively simply using this same type of automation.

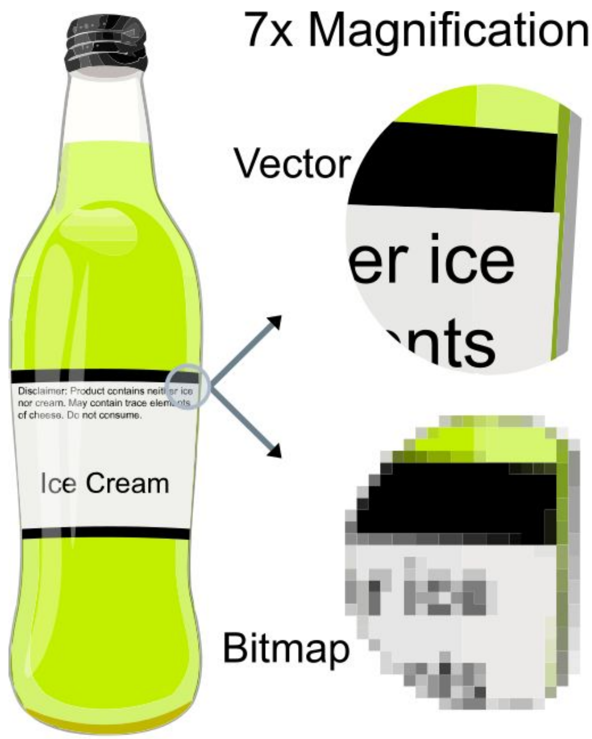
Another huge benefit of computerized toolsets is that our digital creations will be vectorized once we have unfolded them into two dimensional shapes. Vector graphics are 2D representations made up of calculations based off of our 2D points and the lines and curves that connect them. This is opposed to bitmap graphics, which are just color values for each XY coordinate in an image.

In bitmap graphics, each XY coordinate (representing a single pixel in the image) has a color value. If we have a line running from one point to another, every pixel along that line has a color value.

With vector graphics, the start and the end of the line have coordinates and the calculations behind the scene draws a line between them.

If in this example the width of our bitmap line is 2 pixels and we zoom in 7 times, we will get a 14 pixel wide line with a jagged edge along it. The more we zoom into a bitmap image, the worse it looks.

If we do the same with the vectorized graphic, the length of the line grows by a factor of 7, but the start, end, and width of the line have not changed. We can zoom in as much as we would like and all of the crisp details remain.



Fundamentally, bitmap graphics record the color value at each of the XY coordinates in an image. Vectorized graphics record the points, calculations, math, paths, and properties behind the lines and objects that make up the image. For a given point in a bitmap graphic, there is no relationship between any pixel in the image and any other pixel.

A very important pair of details for vector graphics applications, as it relates to paper modeling, are paths and strokes. A path is a dynamic line that connects two points and it may or may not have a curve to it. If you move one of the points, the line you have defined stretches and moves around accordingly. You can imagine how powerful this is when working with the layout of parts.

The second concept, that of a stroke, is basically the border around a 2D object in your vector graphics application. Think of it as a border around a 2D part. By manipulating the displayed pattern of a stroke or a path we can easily create cut and fold lines on a part.

Graphics Software

You will need some form of graphics software in order to design models with computerized help. Again, the various pieces of graphics editing software can each have multiple books written on their capabilities. But, you will likely need to be able to work with bitmap graphics and vector graphics. For bitmap graphics, something as simple as MS Paint may suffice for your needs. Software packages can become incredibly complicated and expensive as well, but generally have more features and capabilities.

If you are on a tighter budget, I would suggest looking at GIMP[72] and Inkscape[73]. Both are open source software with large communities and enough features to handle all the needs of making paper models that I have encountered.

For simple models, you may be able to create them without the need of computer aided design (CAD) software. In those situations, you can use the graphics software like that of a digital drafting table and lay out the parts and details similarly. But most of what is designed will not easily be laid out by hand in this manner.

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[72] "GIMP - GNU Image Manipulation Program." https://www.gimp.org/. Accessed 24 Nov. 2018.
[73] "Inkscape." https://inkscape.org/. Accessed 24 Nov. 2018.

CAD Software

Computer aided design (CAD[74]) software is nearly a requirement for designing non-trivial models. Once you pass a very short threshold of complexity, it becomes mandatory. Without it there are too many details to keep track of and too much rework as you modify objects.

There are many CAD applications available, which range from inexpensive to full blown professional digital cinematographic modeling and editing suites and high end engineering design suites. For the purposes of paper model design, those high end applications have far more features and resources than you will ever use. Those higher end applications will be wasted on our needs.

For our use, we need an application that will allow us to create, edit, and manipulate objects and also impart image maps and coloring to those objects. Again, if you are on a tight budget there is software like Blender[75], which is open source. Commercial applications include the likes of Sketchup[76], Maya3D[77], and Rhino3D[78].

Allow your software to do the hard or repetitive work. If the model you are designing is symmetrical, utilize the software's mirror functionality so you only need to create one half and mirror the other half. If you need a dozen of the same object, then allow the software to duplicate the object instead of making twelve of the same things. Play to the software's strengths so you do not have to do that work and instead can focus on creating your model.

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[74] "Computer-aided design - Wikipedia." https://en.wikipedia.org/wiki/Computer-aided_design. Accessed 24 Nov. 2018.
[75] "Blender." https://www.blender.org/. Accessed 24 Nov. 2018.
[76] "SketchUp." https://www.sketchup.com/. Accessed 24 Nov. 2018.
[77] "Maya | Computer Animation & Modeling Software | Autodesk." https://www.autodesk.com/products/maya/overview. Accessed 24 Nov. 2018.
[78] "Rhino." https://www.rhino3d.com/. Accessed 24 Nov. 2018.

Unfolder

Another required piece of software is some form of unfolder. This is a class of software that takes your 3D model from your CAD application and unfolds it into 2D shapes that can be manipulated on a page and printed.

Unfolders can be stand alone applications, like with Pepakura[79]. Unfolders can also be implemented as plugins that integrate into your CAD application. Each have different features and capabilities, so you may want to investigate several options.

Once you have unfolded your model into 2D shapes you will need to arrange the parts on pages, manage fold and cut lines, number parts, and manage glue tabs. Some of the unfolding software will allow you to do this within the application and yet others do not focus on this functionality. If your unfolder does not allow you to manage these details you will need to export the unfolded parts to a 2D vector graphics application (such as Inkscape). Within that vector graphics application you can create and position glue tabs, move parts around, modify lines, and add numbers and instructions.

With the unfolder I use, I do not like the algorithm that it uses to position and create glue tabs. I can create a much more streamlined set of parts by doing it myself in a vector graphics program after the unfolding is complete. This also gives me the opportunity to group related parts together and annotate those parts.

[79] "Pepakura Designer." https://tamasoft.co.jp/pepakura-en/. Accessed 24 Nov. 2018.

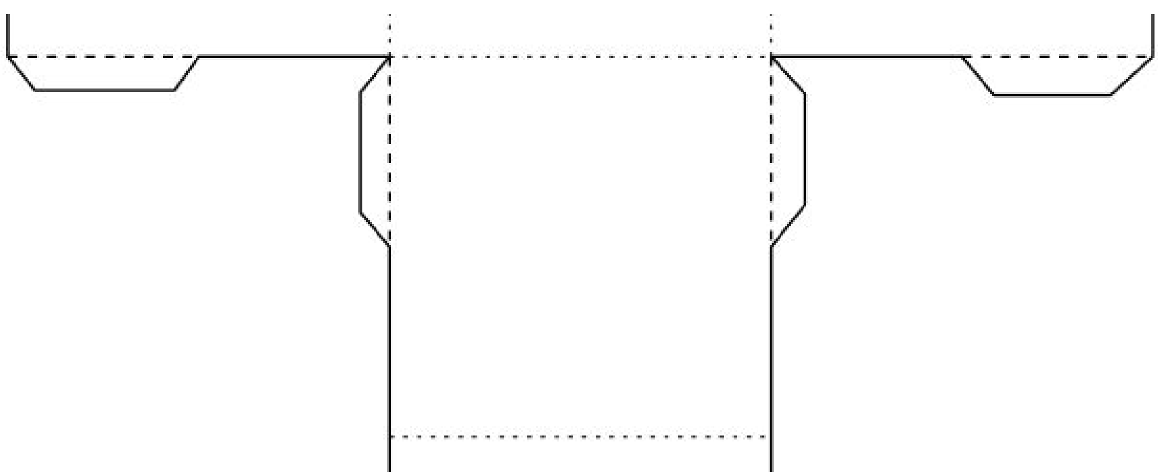
Presentation

Now that you have made a computerized 3D model and unfolded it into 2D shapes, it needs to be made presentable and publishable. The needs of someone who will build the model must be considered. A potential builder will be looking for a logical organization of parts and meaningful annotations. We have all seen models that were released as nothing but a large file of 2D parts… but without any form of instruction, part numbers, or indication of how it should be assembled. If a model lacks these details it is very easy for a potential builder to become lost and frustrated.

Glue Tabs

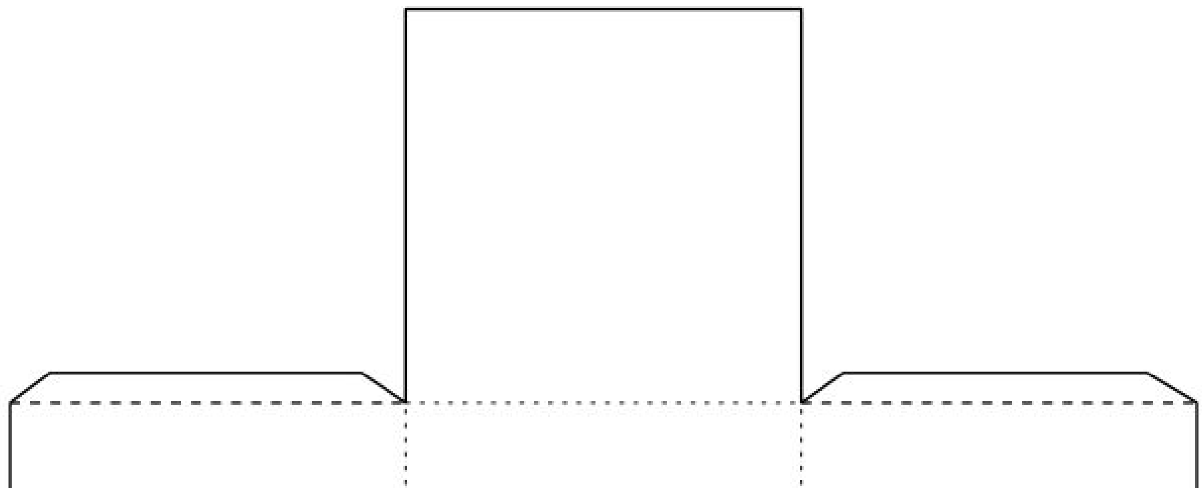
When it comes to individual parts, we need to consider how they will be joined together. Do you want to have glue tabs on the parts or not? If not, you should provide glue strips that are properly sized for the seams they join.

Speaking of glue tabs, there are three methods for laying them out. The first is in an alternating fashion.



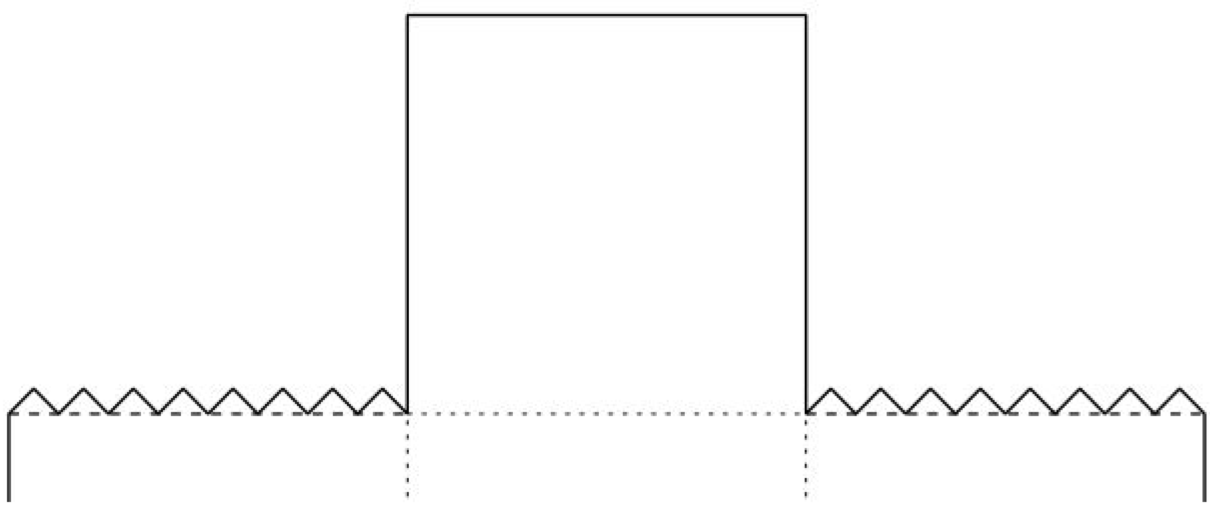
As you can see here, even through the horizontal edges and vertical edges connect for their full lengths, each one is split in half. Alternating halves have tabs on them. The benefit of doing this is that it will help force the builder to have an even alignment along the edge when gluing. The downside is that due to the thickness of paper there will be a slight bulge in the center of the edge where the two tabs meet. [There is that pesky detail again, the one that says paper is not two dimensional.]

The next option is to have long even tabs along one side of the edge as opposed to on both sides.

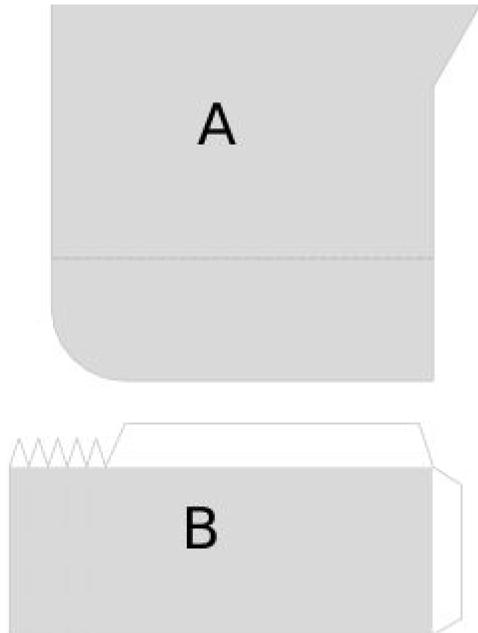


This requires a slightly greater skill level on the part of the builder to create an even joint. But it will avoid bubbles in the center of the glued edge like we saw in the situation with alternating tabs. For the most part I suggest using this mechanism.

The third option is to use triangular teeth as glue tabs instead of long strips.

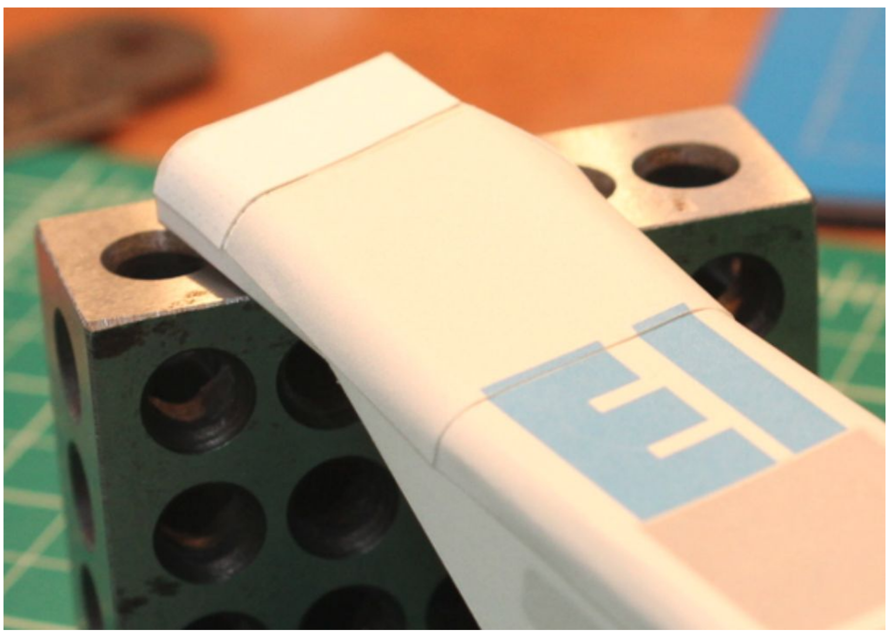


This mechanism is less practical for long straight edges. It allows for far more error to creep in while building as compared with the long tabs mentioned previously. The straight edge can easily have ripples and waves imparted to it as the triangles are glued to the opposite face. This makes it less ideal for straight glued edges. That being said, it is a good technique when determining how to join curved surfaces.



In the example above, part A has a fold along the dotted line. Part B is rolled so that the left ¼ of it completes a 90 degree bend and all of the tabs on the top of the part are folded at a 90 degree angle. This way, the small teeth on part B can be glued to the backside of the rounded corner on the bottom of part A. This will also force part B to retain its curved face.

You can see this in the following image in the upper left hand corner. You can just barely make out the start of the triangular glue teeth underneath part B.



Overall, tabs should be placed in places that hide the seam from the viewer of the finished model. This idea falls under the heading of “hiding your sins” and will be discussed further on in the book.

You will also need to consider how the parts should be laid out across the pages. If a model is not terribly large, it may make sense to group them together by location. That is to say, if two parts are joined together in the finished model, then they should be beside each other on a page. If you have a large number of parts that need to be laminated, it may make sense to put all of those parts on a single page. In that situation the builder can laminate the entire page instead of laminating pieces off of every page.

If you have a large model, such as a six foot long version of the USS Sulaco[80], you will want to break the model into subsections and treat each subsection as a model in its own right. Within each subsection the related parts would be located next to each other on each page.

Another factor to consider is that of part numbering. If you have only a couple dozen parts, then labeling them A through Z may be sufficient. If you have more than 26 parts, starting with 1 and numbering up may work. If you have subsections of your model presented separately, labeling the first section A with part numbers 1 through 25 then the second section being B1-B63 and the third section being C1-C41. In the end, the labels you put on parts need to be clear, understandable, and delineate one section from another. You are organizing the work that the builder will undertake with this step and it can make or break their ability to construct your model.

If you have no intentions of ever distributing your model, then you are the sole consumer of the parts. Do whatever you wish that allows *you* to construct your creation in this case.

[80] "Sulaco.cz." http://www.sulaco.cz/. Accessed 24 Nov. 2018.

Fitting to Page

Prior to this I have been referring to a generic “page” or “piece of paper”. As was mentioned earlier, there are two standards for paper dimensions, imperial and metric. The dimensions for a letter sized piece of paper and an A4 sized piece of paper are slightly different. If we add into this situation the unknown of what size paper the builder will be using, we now need to consider both options (imperial and metric).

Beyond the size of paper you use to lay out your parts, there will be some amount of border enforced by the printer. This will be an area around the edge of the paper where the printer cannot apply ink. To combat this, parts should be inset from the edge of the page a bit. I tend to place parts a .25 inch (6.3mm) from the page’s edge as this will accommodate nearly all modern printers.

Now looking back at the two different sizes of paper… We could easily layout the parts in one size and if someone is printing on the other size tell them to scale the pages down until they fit. The downside to this is that it will change the scale of the finished model.

If we want to keep the same scale we should limit our page size to that of the overlap of printable area of both letter and A4 paper. That is to say, we should construct a virtual size page that is the minimum of both the width and height of both sets of dimensions combined. Once we do this we come up with an overlapping area of 8.27 inches (210 mm) by 11 inches (279 mm). If we now figure in our ¼ inch borders, we have a printable area of 7.77 inches by 10.5 inches (197 mm by 267 mm). If we confine our parts to this overlapping printable area nearly any builder will be able to print off the parts without scaling the pages or affecting the scale of the model.

Design Concerns of Paper

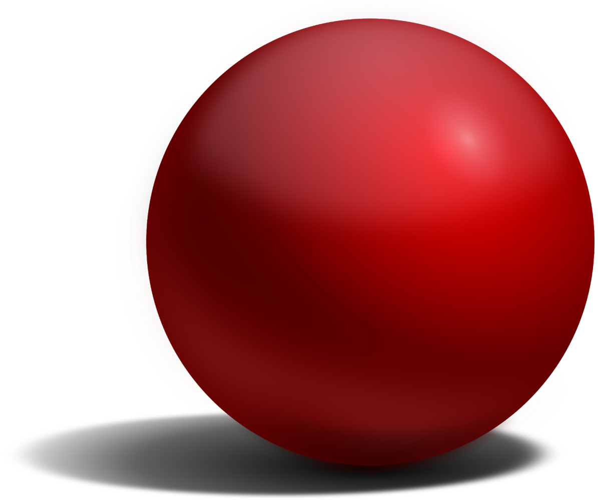
In this section we will talk about some of the constraints that are inherent to paper models and paper as a building medium.

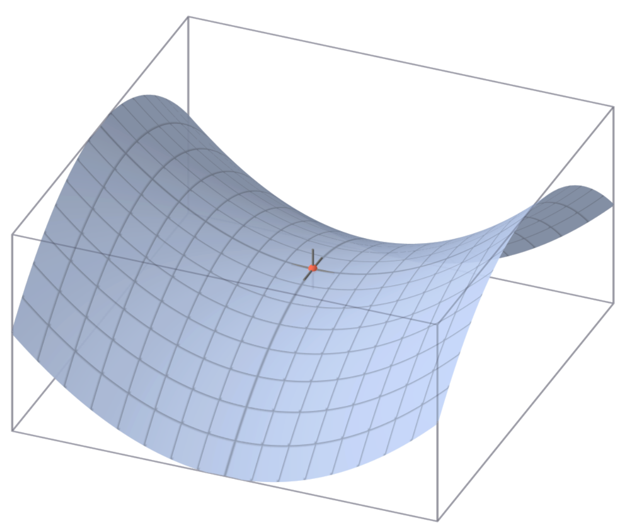
The first concern that comes up is sizing. As designers we need to keep in mind what we are asking the builder to do. Builders have different levels of ability and come in a spectrum of very new to experts. But even for expert builders, there are still results that are not realistic.

For example, if we have a detail on a 3D model that results in a .125 mm ridge, that detail can very easily be represented in the 3D model. If we sent that 3D model off to be made out of injection molded plastic it is entirely feasible that said detail could be rendered via that process. But it is highly unlikely that anyone will be able to slice a part out of a piece of paper that is ⅛ of a millimeter wide. Details that are too fine or too small become unrealistic to create out of paper.

As you are designing a model you will need to keep in mind what can and cannot be done with paper parts and take that into consideration. Much of your knowledge of what is and is not possible will come from your experience building paper models that others have designed.

Another limitation of paper as a building material is that of compound curves[81]. A compound curve is made up of two arcs that have different radii or axial alignments. The two classic examples are that of a sphere and a saddle shape. The problem is that a single piece of paper can only curve in one direction at a time.

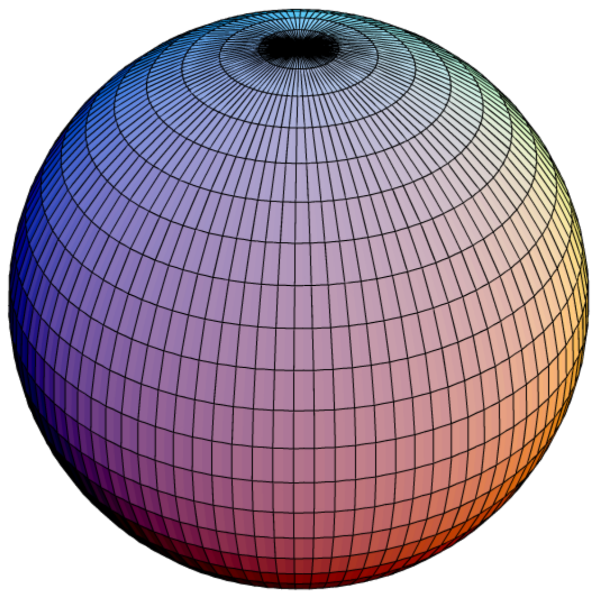




[81] Compound curve (n.): a curve made up of two or more circular arcs of successively shorter or longer radii, joined tangentially without reversal of curvature

In the example of a sphere, we have a circle (made up of an arc) in the XY plane and another in the YZ plane. There is no way to turn a 2D piece of paper into a sphere by cutting and shaping. If we were to try to do this with a piece of metal it would bend, compress, and stretch and it would be possible. But with paper, since it is inelastic, it would tear if we tried to do the same thing. The same result would occur if we tried to form a saddle shape out of metal and paper.

While we cannot form a compound curve with a piece of paper, we can approximate one by slicing the sphere and treating each slice as a portion of a cone with increasing angles.



In this image you can see the XZ axis slices that approximate a sphere. If we treat each horizontal slice as a truncated cone and increase the angle as we move from the equator to either pole, we now have an approximation of a sphere that can be constructed out of paper.

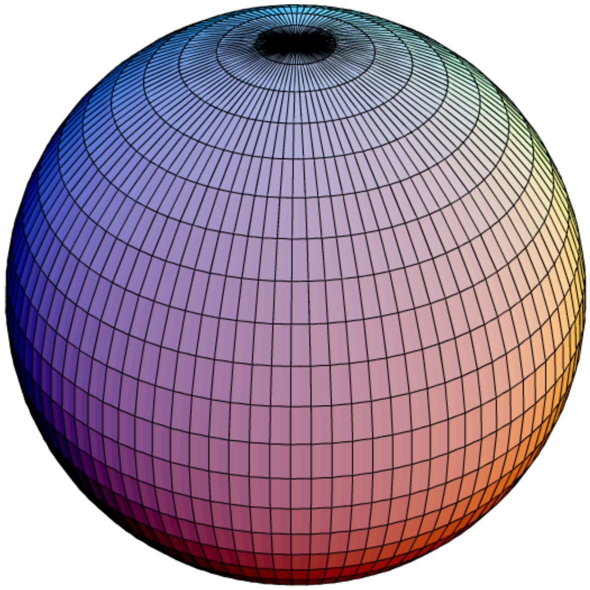
This is a great solution for dealing with complex shapes such as these. But the approximation of a sphere looks much better with 16 slices than it does with 4. So the more slices we make the better the result comes to our idealized sphere. With each additional slice it creates yet more parts to glue together when we construct it in paper.

If our model involves a 2 inch diameter sphere, we could make it look really good in the 3D model by having 100 horizontal slices. But trying to glue together slices that are 1/50th of an inch is a time consuming exercise in frustration. There is a balance that needs to be considered, that is between the ability to construct the design and approximating a good visage of the shape.

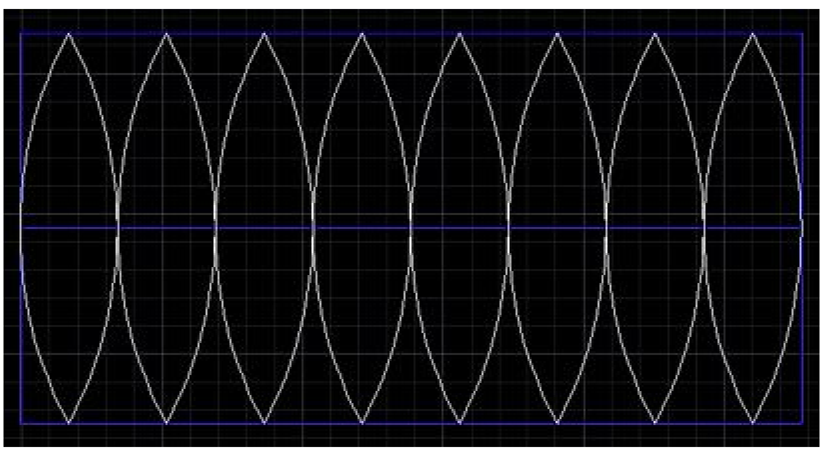
You can often see this in models of aircraft that have tapering noses.

This model with the front-most three segments of the nose is a good example of this compromise. On the real plane the diameter of the nose, forward of the canopy, steadily shrinks to a point on the tip. In this model, this was approximated by three partial cones (the section with 030 on it and the two black sections). This allows for a reasonable approximation of the compound curve.

Another way to look at compound curves, like those in a hemisphere, is to slice along the longitudinal axis instead of horizontally. Let us look at our sphere from earlier.



If we were to slice the sphere vertically instead of horizontally, we would end up with an unfolded part that looks something like this.



This mechanism of unfolding a sphere is known as “petals”. Sometimes it is easier to build a model part that has been rendered as a set of petals and other times as a number of stacked rings. Personally, I cannot stand building petal shaped parts into a dome shape unless that is how the original object was constructed (like that of a domed roof). If I were looking at the front end of a bomb, or missile, or nose of a jet, I would prefer to make it as a series of rings as opposed to a petal shaped component.

Another property of paper as a building material is that it is an unforgiving medium. That is to say if you get a drop of water on it, it will leave a stain and warp the spot. The same goes for misapplied glue. The benefit to paper is that it is inexpensive.

Also, if we are trying to pull a part into a particular shape that involves acute angles, the paper will eventually tear on us. This can be made worse if the glue on one end of the part has dampened the joint and we start to put stress on it.

The upside to paper, as a building medium, is that if a part is torn, mangled, or you are otherwise unhappy with the result, another one can easily be printed. While it is disheartening, another attempt can be made and hopefully a better result achieved based upon what you learned from the previous attempt.

Using Non-Paper Materials

I touched upon the idea earlier in the build techniques, but you have the ability to specify the use of non-paper materials in your model designs. This is a topic that can become a religious debate among paper model fans. Some will argue that using materials other than paper ceases to result in a “paper model”. It is your model design so I would suggest that you do whatever you wish to do regarding non-paper materials. If you wish to use only paper, then do that. If you wish to specify the use of other materials, then do that.

If a model is to be entered into a contest that clearly specifies that everything needs to be made out of paper, then it should be made completely out of paper. But if there are no requirements of that sort, I would design the model with whatever works even if that includes certain details which are not made out of paper. It is worth noting that it is not at all uncommon for commercial paper models to specify the use of thread, wire, or rods in the construction of their kits.

If you do incorporate other materials into the design of a model, not all builders will have access to the same materials that you do. You may specify to cut down a 1.5 mm diameter toothpick to use for part of a radio mast, but another builder may only have 3 mm toothpicks available. My suggestion in this situation is to provide a paper part and then also specify that a toothpick of 1.5 mm diameter may be used in its place and can achieve a better looking result.

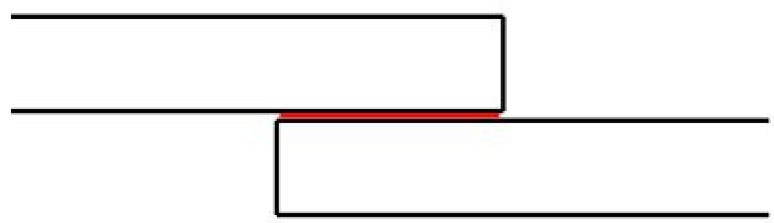
Another factor is that non-paper materials will usually need to be properly finished so that they fit with the rest of the model. This will likely involve sanding, applying filler, sanding, priming, sanding again, and painting.

Glue Joints

There are a number of types of joints which are borrowed from woodworking and welding that will also apply to paper models. These are the mechanisms by which parts are glued together.

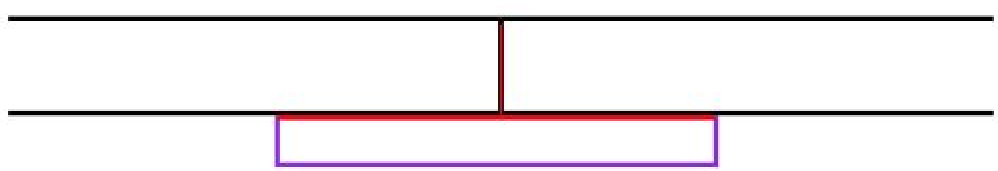
Below, the black outlines represent the paper that makes up a set of parts. Red is where glue is applied. Purple is where a glue strip or glue tab will be placed.

The overlap or lap joint:



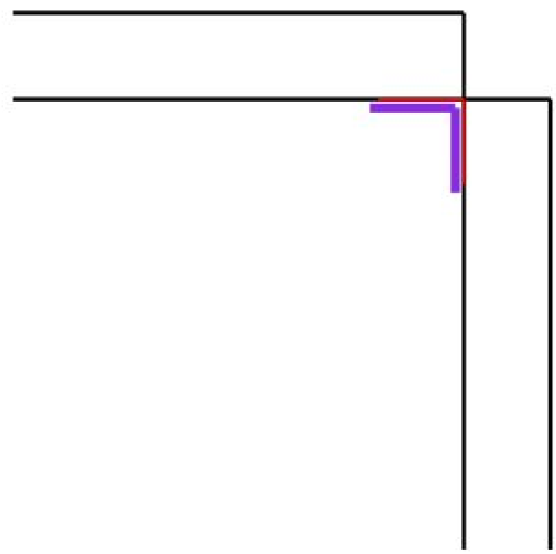
This is the simplest of the glue joints as you can see. Two parts overlap with a layer of glue between them.

The butt joint (with glue strip):



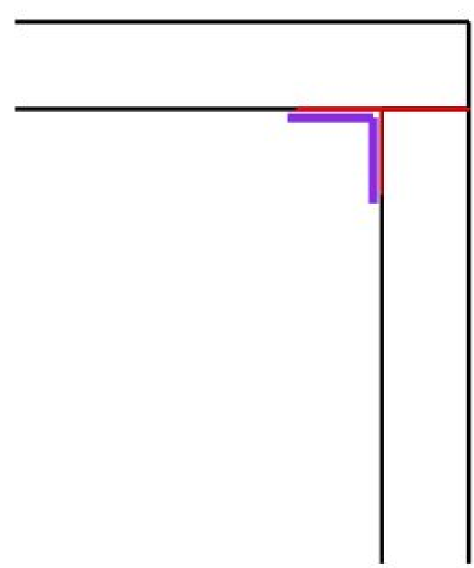
This is an example of a butt joint with a reinforcing glue strip. The edges of the parts are pushed against each other with a layer of glue between them. In this case there is also a glue strip underneath the join with glue between it and the parts.

The open corner:



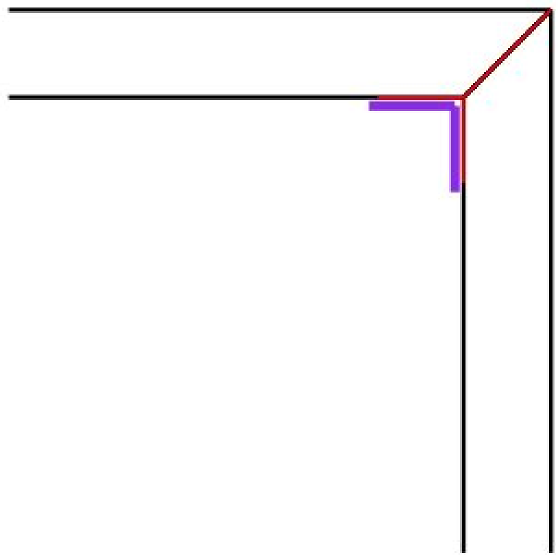
The defining element of the open corner is that the edges of both parts are exposed. The two parts do not directly touch each other except at one point. They are held together by a glue strip with a layer of glue applied to each part. This joint has the least strength of those noted here.

The closed corner:



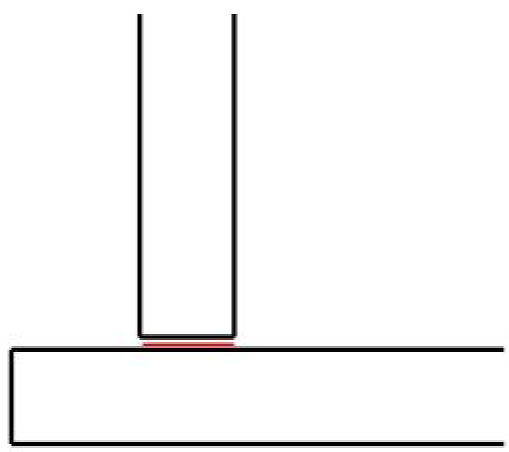
With the closed corner, one part overlaps with the edge of another. In this manner only a single edge is exposed. Again, a glue strip is used and there is a layer of glue between the two parts.

The miter joint:



In the miter joint, both parts have beveled edges and no edge is exposed externally. Again, a glue strip is used and there is a layer of glue between the edges of both parts. The miter joint is the most difficult to achieve with paper as it entails cutting a consistent and accurate angle on the edge of both parts to be glued.

The edge joint:



With the edge joint, one part is glued edge on to another part. It is only suited to small or detail parts that do not require significant structural connections. This type of joint does not offer nearly as much strength as the other types mentioned above.

Overall, the closed corner is the easiest type of joint to build and offers a significant amount of strength. The types of glue joints you employ are more important as the paper increases in thickness. With thinner paper, the differences between and open or closed joint are minimal.

Printed Detail

In this section I will address some concerns as it relates to printed and physical detail. This is very much a set of topics that focus on the application of artistic skills.

Coloring

For the most part, you will want to impart some color upon your model. The basic white of cardstock will generally not be enough for your needs. To help with this there are various and sundry standards for indicating colors. Here are just a few:

- RGB[82] - used in graphics applications - Red Green Blue
- CMYK[83] - used by 4 color printers - Cyan Magenta Yellow Kroma
- Federal Standard[84] - official color chart and identifications used by the US government
- RAL[85] - color standard used in Europe by several governments
- Pantone[86] - commercial color standard used in print, textiles, paint, and plastics

Your applications will utilize at least one of the digital color standards and will likely have other options as well. This is great, right? If we say that a RGB value of #FF0000 (each of the pairs of characters is a hexadecimal value representing each of red, green, and blue, with hex numbers running from 0 to F) is our pure red, then any part we color this way will look the same for every person that prints and builds your model, right? Well... not quite. A large series of variables will go into exactly how the color appears once printed on the page.

If we started with an RGB value for pure red on our computer screen, that needs to be converted into CMYK for the printer to be able to do something with it. Each set of printer drivers converts from RGB to CMYK using a set of vendor specific algorithms and can achieve a slightly different result.

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[82] "RGB color model - Wikipedia." https://en.wikipedia.org/wiki/RGB_color_model. Accessed 25 Nov. 2018.
[83] "CMYK color model - Wikipedia." https://en.wikipedia.org/wiki/CMYK_color_model. Accessed 25 Nov. 2018.
[84] "Federal Standard 595 - Wikipedia." https://en.wikipedia.org/wiki/Federal_Standard_595. Accessed 25 Nov. 2018.
[85] "RAL colour standard - Wikipedia." https://en.wikipedia.org/wiki/RAL_colour_standard. Accessed 25 Nov. 2018.
[86] "Pantone - Wikipedia." https://en.wikipedia.org/wiki/Pantone. Accessed 25 Nov. 2018.

Once the information is sent to the printer, the next detail in this chain of events is the ink. Not all inks and pigments are created equal. This applies when comparing one brand of ink cartridges to another. It also applies from one supplier of ink to another. Think of the aftermarket ink cartridges or refill kits here. Would you necessarily expect the quality (luster and color saturation) of a $10 ink cartridge to match that of a $50 one from the manufacturer? Each source of ink has a slightly different quality and makeup. Any given OEM tends to do a lot more to ensure ink quality and consistency than some random basement refill operation. If we are comparing inkjet to laser technology, that will also impact the exact shade of color that is deposited onto the paper.

Now that we are ready to spray or fuse some ink onto the page, the paper comes into the equation. There are varying brightnesses of paper and cardstock. The brighter the paper the more the color will pop and appear vibrant. The grain of the paper will impact how much the ink bleeds as it is absorbed by the paper. If you have a coarse grain the ink will bleed more and the area where two colors touch will take on a muddier appearance. The finish on the paper also makes a huge difference. If you use photo paper, which is glossy, this allows much more light to bounce off the paper and back through the pigment. This will also cause the colors to look brighter and more vibrant.

All of these factors combine together to determine how a particular set of color and pigment appears on paper. Your print can range from dull and muddy to bright and vibrant with the same source color specified in your electronic page of parts.

For the most part we just have to live with this situation as the physical and ink factors are out of our control as designers. One way to avoid the variability is to specify the use of colored cardstock. With this option the dye is already present in the paper and is consistent throughout. The drawbacks to this though is that not everyone has access to colored cardstock, the selection of colors is limited, and it is more expensive and less versatile than white cardstock.

Within various model building circles, there are always individuals that insist that there is correct color for a model representing an object out of history. On the surface this statement is correct, but is quickly becomes apparent that it is missing a number of details and factors[87]… details such as how the human eye perceives color.

Let us take a tank from World War II as an example. Out of the factory, all tanks would have been painted a particular color of green. From this aspect, there is a color that is correct for this vehicle. But it ignores that the hue of the paint used in military factories often varies slightly from batch to batch. This is even more likely to happen during wartime and the paint would be even less consistent in hue. Even a factory fresh tank that is made in multiple facilities can have examples fresh off the assembly line that vary from one manufacturing site to another.

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[87] "Scale Model Colours - PaperModelers.com." 27 Oct. 2018, http://www.papermodelers.com/forum/tips-tricks/42392-scale-model-colours.html. Accessed 25 Nov. 2018.

And what about a prototype version of the tank compared with a late production example? The prototype tank may have a completely different color of paint on it.

Next, we have the scale color effect. This says that up close the green may appear relatively vibrant, but as we back away from the tank the color becomes more muted and loses some of its vibrancy.

As we back away from the tank things such as smoke, exhaust, dust, dirt, water vapor, and other contaminants will be present in the air between us and the tank. This will continue to make the color appear more dull.

Assuming we are outside, the weather and position of the sun will factor in as well. The color of the tank at dusk appears much darker than at high noon.

Now if we look at that tank the moment it rolls out of the factory and then look at it again five years later, the color will most definitely have changed. There will now be dirt, grime, oil, smoke, exhaust, rust, corrosion and environmental weathering on the tank. All of these will change the color to a degree. If the passage of time has turned the finish on the tank from gloss to semi-gloss or even matte, then the impression of the color will be drastically modified. Even if the tank had been freshly repainted, it is entirely possible that the maintenance crew used an old batch that is close, but not quite an exact match for the original paint, and we now have a mix of the old weathered color and a newly applied color. Also, as time passes and the layer of paint becomes thinner, the underlying primer can begin to show through as the surface paint fades.

So what color is “correct”? This all depends upon the historical setting you are putting your model into, how much weathering you are trying to represent, how a maintenance crew would have handled the vehicle, what trials and tribulations it went through, and so forth and so on. Fundamentally, pick the color that you (the designer) thinks best represents the object in the context you are placing it. With whatever color you choose there will be *someone* that will want to argue about whether you got it right or not. Accept that such a person exists and that they will try to argue the correctness if any colorings you choose. With that out of the way, pick the color that you are happy with for the context of your model and proceed forward.

Shading

Once you have designed the model, applied coloring and textures to it, and built it; the physical shape will cause shadows to be cast in various places. If all of our details were three dimensional, then the physical nature of it would cast all the needed shadows. But when the detail becomes small enough it cannot be constructed, we put it into the coloring and print it onto the part. On a full size object that detail would cast a shadow, but that is not the case with our model and its printed detail. As a result, you should think about how the light would hit the full sized object and add appropriate shadowing into the printed detail.

You can see this effect in the engine bay of the Narcissus[88]. The shadows around the complex detail of the bay (mostly a two dimensional part) are printed on rather than cast by making 3D shapes.

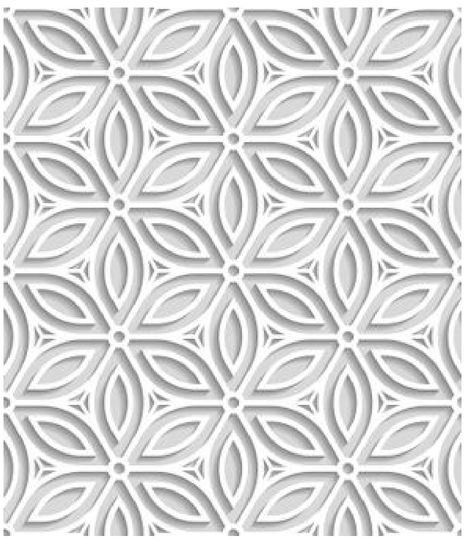
[88] "Album: narcissus." http://www.insanityunlimited.com/gallery/paper_models/narcissus/. Accessed 25 Nov. 2018.

Materials

Any application that is suitable for creating paper models has the ability to apply virtual materials to objects. This is more involved than saying “this face should be red and that one should be blue”. Materials add a significant amount of visual detail to an object with their application. These can be 2D images wrapped around the object or patterns that are based on an underlying algorithm.

When wrapping an object in a 2D image there are a couple of concerns to be aware of. Let us say you have an image based material that is 512 pixels by 512 pixels. Most likely, the model you are creating is going to be wider than 512 pixels when finally constructed. Assuming this is the case, the image will have to be scaled up in order to wrap all the way around your object. This is to say, the 512x512 image will need to be blown up to 2048x2048 in order to wrap all the way around the object. As we noted earlier in the section that talked about bitmap and vector graphics, blowing up a bitmap image in that manner will highlight the relatively low initial resolution. The word of caution is to make sure your images a large enough resolution to carry the detail you desire. You will be disappointed if you print off your model’s parts only to have the graphics on them to appear like they came off an 8-bit computer from the 1980’s.

Another form of image material is one that is configured to endlessly repeat. Images for this purpose are known as seamless images. The top and bottom of the image match up so there are no abrupt transitions and the left and right do the same. This prevents resolution problems like noted above. Seamless textures will present as a repeating pattern and the downside is that the human eye will notice this repetition. Be aware of this possibility and take it into account as your create your model’s materials. You will either want to intentionally use that repeating pattern to your advantage, such as with paneling on a spaceship or tiles on a floor, or you will want the repeating texture to be something very fine in detail, such as sand grains.



Most applications suitable for creating paper models will have a feature that allows you to create procedural or generated materials. These are materials that endlessly repeat and are based upon an underlying set of procedures or formulas. Since these are endless, they avoid the issue of resolution problems. The well made ones also have enough randomness or noise incorporated into them that you cannot easily identify the seams with your eye. The downside is that they can definitely be more complicated than image maps and can be more computationally intensive.

One of the more confusing parts of using image maps in a 3D model is the UV map. When using a UV map you are placing and wrapping a 2D image around a 3D object in your CAD model. The letters ‘U’ and ‘V’ are used because ‘X’, ‘Y’, and ‘Z’ are already used to indicate an object’s location in 3D space. ‘U’ and ‘V’ are the next letters in the alphabet and are used to describe where an image appears wrapped around a 3D object. There are a great many permutations as to how this gets applied and they also vary from CAD application to application. You will need to learn the intricacies of your particular 3D modeling application. Using UV maps is a very powerful tool and when used effectively can generate some truly amazing results.

Markings

If your model is and object from real life, say a plane or a vehicle, it is likely that it will have some kind of logo on it. It may have warning labels on it, like with military vehicles. In order to make it look as realistic as possible, you will want to reproduce that logo or marking. Sometimes we can get lucky and find that graphic has been reproduced as an image on the internet. Other times we will need to recreate that set of markings ourselves.

Reproducing a logo or marking is very much an artistic effort. I encourage you to recreate any surface graphic in your vector graphics application so that is can be easily scaled up and down as needed. This will serve you well in the long run and allow for reuse on any related design in the future.

One of the difficulties is reproducing lettering on these markings. To help in that regard there are many font libraries available online. The trick here is figuring out which font you need. To help in that regard is a site called What The Font[89]. Based upon an image it will help you to identify which specific font is used.

Do not despair if you cannot find an image of the marking suitable to be included in a material on your 3D model. It takes a little bit of learning and time, but you can create your own markings and logos in your graphics application to place on your designs.

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[89] "WhatTheFont! - MyFonts." https://www.myfonts.com/WhatTheFont/. Accessed 2 Dec. 2018.

Printed Detail and 3D Detail

The previous portion of this section discusses issues and concerns as it relates to creating printed detail. If we take a wider view, there is a balance we need to strike between printed detail and 3D detail. If we apply enough 3D detail onto the surface of a model it will trick the mind and the eye into believing that the printed 2D detail is also three dimensional.

Effectively managing this balance most definitely adds to the visual appeal of the model. If we lean too far to the 2D side then the illusion is broken and the object looks as if the detail was printed onto it. If we lean farther to the 3D side then the complexity of building the model goes up and eventually we reach a level of detail where it is impossible to construct.


This is a technique I employed on my model of the Narcissus. All the paneling is done as 3D relief glued to a large flat face on the object. This breaks up the large, flat surface. The fine details, done as 2D markings printed on the paper, appear as if they are three dimensional as well when mixed with the offset paneling.

Project Definition and Scope

When I am looking to start a new design of a subject, there are a number of questions I ask myself. These help focus my efforts and give me a concrete path towards my goal.

What is going to be special about my design?
Fundamentally, why should anyone (including yourself) care about your model design? Are you going to create some variant that is not yet represented as a kit? Are you going to dress it in a different set of markings and paint scheme? Are you going to make it with more or less detail? Are you going to make it a specific size or scale?

If no paper model of the object exists, then that is easily the defining element that makes yours special. From these questions you should determine what will make your model distinctive and identifiable.

Does a paper model of this already exist?
If one already exists, can it be used as a starting point? What details did the previous designer include and ignore in their design? What do I like and what do I dislike about what they did? From a reference standpoint, does a 3D model exist even if it was not intended for paper models? Does a model in another medium exist?

Answers to these questions will start to frame up what you are trying to accomplish. It may clue you in to some details that can be omitted and others that are defining features of the subject.

Who is the audience of the kit?
Do you intend for this kit to be made by beginners? Experts? As a vendor give away at a conference and need to be fairly simple? Will it only be built by you?

This will determine the amount of detail and complexity that goes into what you create. It will also determine the content of instructions that go along with it.

Who is the audience of the finished model?
Will it be the builder that views the finished model? Is it intended to go into a display case? Will it go into a museum? Will it be a gift?

Each of these questions will factor into details such as structural integrity and the amount of fragile detail you include.

What features absolutely must be included for my design to be a meaningful representation of the subject?

These defining features will need to be present in whatever you generate.

Am I interested in the subject of this model?

I hope the answer to this question is “yes”. If you are not interested in what you are designing then there is a high likelihood that you will not finish it. If you do not finish then there is no point in ever starting, so choose subject matter that you are interested in.

Why am I making this design?

This is the crux of the matter. If you do not know why you are taking the project on, then I would encourage you to figure that out before you begin. It could be as simple as “I like this thing that I saw and I think it is cool.” That is a perfectly acceptable reason. Maybe you are lucky and someone is paying you to make it. :) We could all only be so lucky.

All the answers to the questions above will help frame up your project. They will tell you what you are trying to accomplish, what has to be included in the end, and why you are doing it. While it is very easy to assume we are embarking upon a project for all the right reasons, spend two minutes and ask yourself these things before you invest a lot of time into a project.

Research

A big factor in any design is that of research. A good bit of planning and research up front can prevent a large amount of rework later on. It can show you detail that you did not know you needed to incorporate and correct bad assumptions you may have initially. It can also potentially frustrate you as you find conflicting sources of information.

In a perfect world, your research efforts will give you a set of blueprints and three-plan drawings to work from. They will be for exactly the version of the subject matter you want to model and none of the sources of information will contradict each other.

We live in a world that is far from perfect. Thus, it is not uncommon to have nothing but pictures which disagree with other images, conflicting versions of the subject, and descriptions that clearly do not match images.

Based upon the questions in the section before this, do you know which version of the subject you are trying to represent? That is not to say that material for other versions will not be useful. Information on those other versions may help you fill in the details on your intended target if the information is not directly available for your version.

Begin by tracking down images of the subject you are trying to model. Google Image Search is a first stop, as is the library, and *gasp* books. Especially for older items, not everything has been digitized and books in the library can still be of help. Remember that the internet is not the sum of all human knowledge, it is just an index to it.

Beyond that, if it was a commercial item you are modeling, look up any old sales sheets from the manufacturer or their partners. Those will be filled with pictures of your intended subject.

Recalling our discussion on colors earlier in this book, pictures add yet another layer of complexity into it. Photographs can easily have multiple distortions in them, such as parallax, white balance, chromatic aberrations, and dirty lenses. If the picture was manipulated digitally you will also have to contend with whatever cleanup or effects were added in post-production by the photographer. The moral here is that even photographs (especially marketing photographs) may not accurately represent your intended subject. Think of the box of cereal which has a giant picture of the food on it. Most of these have an asterisk on them saying “enlarged to show detail”.

From a structural standpoint, having a set of design diagrams or blueprints would be ideal, but not very common. Though, for many vehicles there are three-plan drawings available on the internet. These will give you a front, side, and a top view of the object and potentially bottom, rear, and opposite side in addition. These are invaluable. Any shots from an angle can also help you properly model the object. Filling in gaps in what you can see with more research will make your project more successful. Again though, you will often find conflicting sets of information and you will have to judiciously choose which sets to use.

At least for older airplanes, the EAA Model Plan[90] site is an excellent source of diagrams.

Another source is that of videos and still frames taken from those videos. These also have their own form of distortions that can mislead you as well.

If there are multiple names or designations for your subject matter do not forget to search for all of those to acquire information. Related terms may also be useful as well. For example, if you are researching an F-14 Tomcat, you may find more images by searching for “aircraft carrier air wing”. Expand your search terms in order to find more visual references.

If it is a vehicle of some kind, you can likely find a set of length and width measurements for it. For vehicles you will want to get images of any logos or markings so those can be reproduced as well.

Research in and of itself is an art form and takes practice. Some of the time it is as much about luck as it is experience.

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[90] "EAA Model Plans | Flickr." https://www.flickr.com/photos/eaamuseum/sets/72157626922654148/. Accessed 27 Nov. 2018.

Internal Structures

Once you pass a certain size of model you will need to concern yourself with the structural mechanics of your design. This boils down to the question “When do I need to begin adding internal structures for strength?” Unfortunately, the answer to this boils down to experience and feel, but I can give you some tips. The internal structures become very important when your sub-assembly must retain its shape in order to properly mate with adjoining sections.

The first rule of thumb is this: The larger the sub-assembly, the more likely you will need internal reinforcement. If you are making the saucer of the USS Enterprise (NCC-1701) in a large scale where the saucer is two feet across, you will definitely need to have some internal reinforcing structure there. At that size, basic cardstock will not be strong enough to keep it rigid and hold its shape.

Also, if your model has large flat surfaces, that is another indication you will need internal reinforcement. Whenever I have large flat surfaces, they tend to bow inward when I construct them. I laminate pieces of chipboard on the inside to preserve their large flat shape.

The final test is to take the sub-assembly, once it is constructed, and apply some (minimal) force to it with your fingers. Does it twist, bend, or otherwise deform? If so, you will likely need some manner of internal reinforcement or bracing.

Design Tricks

Once you have all of these images, you can take the three-plan views and paste those into the background of your CAD scene. From here you can begin to trace the main outline and any indicated detail. Think of it as the 3D equivalent of using tracing paper.

If you have computer generated or good reference images that are at an angle, you can double check your CAD model by lining up the wireframe visual of your model in the same orientation. If all has gone well, your wireframe model should overlay on top of the reference image. If there are details that are off, you can then correct them. Once your 3D model lines up with the three-plan views and an angle view, you are pretty much done with the overall shape.

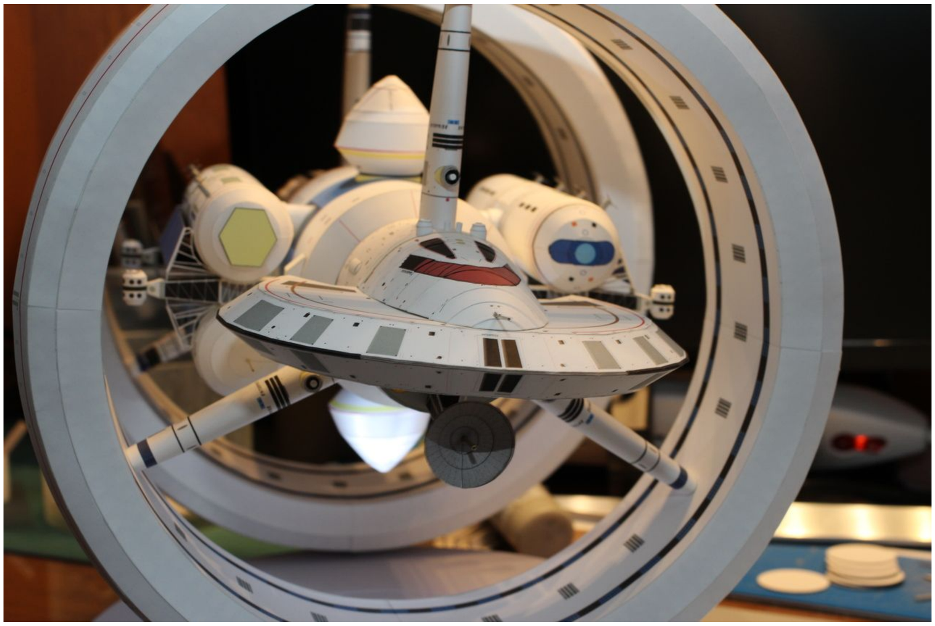
When working with panels on an airplane or spacecraft, it is not uncommon for that panel to be raised slightly up off of the main body of the object. By default, most unfolders will try to make this a panel with a thin wall running around the outside edge. But as you have likely encountered, trying to cut a 1 mm wide strip of paper for an outside edge is very difficult. For any panel that has a sidewall of 1 mm or less I would instead encourage you to design this as a lamination and instruct the builder to edge color that panel. This will vastly simplify construction.

A difficult item to reproduce in paper is that of a chain. This could be for an anchor on a boat or elsewhere. The solution is not to make the chain from paper. There are a number of small necklace link patterns that are very close to various types of chain. These can be found for relatively small amounts of money. Another option is to take two pieces of thin, uninsulated wire and twist them together. After they are twisted, put them between two heavy objects to partially crush the two wires together. Doing this plus adding paint is a reasonable approximation of an anchor chain.

Some vehicles, such as spacecraft, are made with a layer of mylar or plated foil in real life. The incredibly thin structure of the foil, along with being glossy and reflective, is incredibly difficult to reproduce in paper. For situations like this I use the real material. I have used aluminum and tin foil in models to represent mirrored or foiled surfaces. The obvious place to find foil is at the grocery store in the foil isle, but you can also use a cheap thermal blanket and slice it up as needed. There is a word of caution though. You do not want to use your nice scissors or blades to cut foil as this will dull your nice cutting tools. Instead use a separate blade that will not be used to cut paper paper later on.

Hiding your Sins:

Another trick is to hide your seams. If there is an additional piece that can cover a seam between two parts, go for it. If it cannot easily be covered then orient the seam to be hidden from view.



In this image of the IXS Enterprise, the smaller cylinders that are connected to the center of the main hull all have their seams directed in towards the center of the model. While it is possible to see them it is also very difficult to do so and they are hidden from the viewer.

If there is any construction detail that is particularly ugly or unseemly, orient it out of view. If a seam can be placed behind another part such that a viewer cannot see it, then in the observer's mind it does not exist. This type of thought process falls under the topic of "hiding your blemishes".

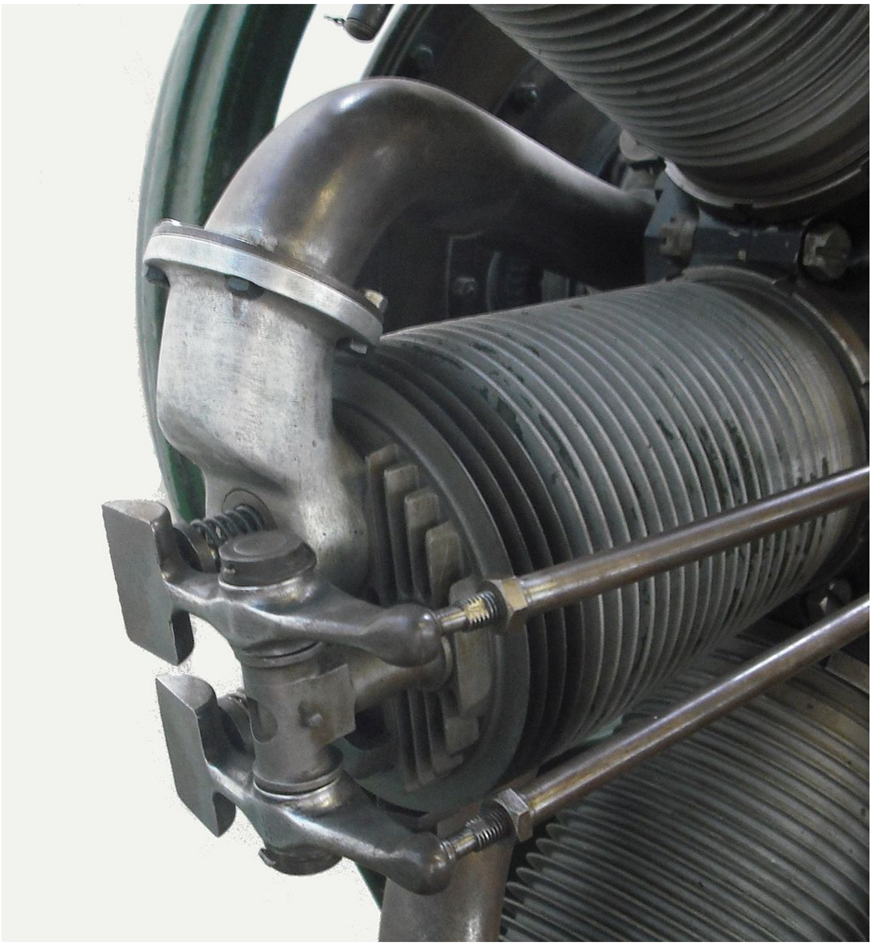
Small Parts:

In general, the smaller and more detailed the part, the thinner the paper you can specify for its construction. Thinner paper will allow the builder to make folds that are crisper and better defined. For non-structural parts you do not need the rigidity offered by thick card stock.

When gluing small parts, there are three ways to go about joining them to a larger piece. First, you can use a fully enclosed backside on the small part and glue that to its larger parent. This offers the strongest scenario with the largest amount of contact area between the parts. Second, you can put glue tabs on the small part and have them folded in. This is not as strong as the small part being fully enclosed, but still fairly robust. The last option is to put no glue tabs on the small part and leave the backside of it open. This forces a situation where you are edge gluing the smaller part to its parent. It is the weakest option, but allows for the most precise positioning of the small detail part. With smaller components you do not need the same structural capability as you do with larger ones, so the edge glued option is a reasonable consideration.

Change Orientation:

In the example of radial engines, you can change the orientation of how you design the parts. The straight forward approach would be to create a cylinder and then build a set of air cooling fins to be placed around the cylinder.



Instead of starting that way, we could create a series of large and small laminated disks (alternating) to build up each cylinder of the engine. Approaching it this way allows for a much simpler and less frustrating build.

Instructions

Just as important as the parts are the instructions that go along with them. These document how the model is to be assembled and act as a reference for the builder. They can make or break your model if you intend to release it to others.

FIrst of all, consider your audience. How much experience are you assuming the builder has? Does that experience level agree with how complex the parts are to assemble? It does no good to write instructions for the beginner but then have parts so complicated that they require many years of experience to assemble. The two sets of considerations have to go hand in hand.

Fundamentally, write instructions for your audience. If other people cannot understand what you are trying to tell them, then they will not be very helpful. Consider that there will be builders who do not have the same skills that you do. They also will not have all of the same reference material that you have in front of you and will not have been staring at those images for weeks on end. The builder will not understand what it is that they need to do until you have explained it to them.

Your instructions are the steps someone will take to construct a visual object. To that end, include visual data in the form of pictures, drawings, diagrams, and renderings. Do not take this to mean that you should not also explain the steps with language.

Some people learn in a primarily visual manner. If they look at the pictures and diagrams they will understand what you are trying to convey. Other people learn better with written information and will pick it up faster that way. So include both visual and written instructions so the one reinforces the other.

The organization of your instructions is also of critical importance. Jumping back and forth from one subsection to another and then back again will leave your builders confused. Not only do your steps need to flow from one task to another, your images and diagrams need to be clearly labeled and placed in context. If a diagram for an initial step appears half way through 10 pages of instructions then it is not of much use. Put the diagrams and images where they are relevant in the instructions and annotate them.

If you know a particular section of the assembly is complicated, spend more time on that in the instructions. Go into more detail and break down the steps into smaller tasks so they are more digestible. For the simpler areas a lower level of detail will suffice. Including more information around difficult spots also clues the builder into the fact that they need to pay more attention to that section of the build.

Sometimes the visual information you can put into a set of instructions is not sufficient. A two inch wide picture printed out may not be capable of capturing the information you wish to convey to the builder. Instead, consider including larger images and drawings for reference. Even if they double the side of the instructions, include them. Needing the information and not having it is far worse than the document growing by an additional 20% in size.

To that same end, make a build log of your model being assembled. Take pictures for every significant step along the way. You do not need to include these in the instructions, but provide a link to them somewhere in your document. This way builders can go see what you did and see how you constructed it if they need that information.

Test Builds

In three words… "test your builds". Resist the urge to publish a model without having built it at least once.

Test builds of a freshly designed model follow some of the naming conventions of software design. The very first attempt is called the alpha build and you will likely find the majority of things that need to be fixed at this time. The alpha build is often done by the designer or someone else close to the project that has helped with the design. Instructions may or may not exist at this point. The purpose is to make sure that all of the large scale details work. With the alpha build you want to verify that major hull sections line up properly, that all the parts are in the same scale, that graphics line up between parts, that proportions look correct, that all required details are present, and the parts fit together as intended.

The second build is known as the beta build. The beta build is often done by someone else who has not been involved with the design of the model prior to this point. They are both verifying the construction of the model and the usability of the instructions. After the beta build there may need to be some edits made to instructions or minor details touched up on the model itself.

If a design is particularly problematic or complicated you may need multiple alpha or beta builds. I know that these take time and can be frustrating, but they are well worth it. They help you produce a quality kit that others can enjoy without undue frustration.

Publishing

There are several common methods to publish your model kits. The first method is to print the model on paper and distribute it through a publishing house. This generates a physical medium that can be distributed and sold, if desired. But it is also the most expensive of the options as you need to manage the quality of the printing service, shipping, distribution, and all of the other details that go along with a physical good.

Another mechanism is to distribute the model through an online store. This allows you some control over the distribution of the model and potentially allows you to make some money off of it. A builder purchases the model as a set of files from an online store and prints off the pages themselves. This eliminates all of the requirements of handling a physical good.

A final option is to simply host the files for the model on a web server yourself. This may be on a website that you control or via a downloads area of your favorite paper model forum. With this you do not need to deal with any of the distribution or sales work. It is by far the simplest of the publishing options.

These options speak to where and how to publish your model. The next detail is the format in which you should publish your model.

First of all, the format you choose should be of high enough resolution to capture all of the detail you are trying to convey. This could be as little as 150 DPI (dots per inch) all the way up to 1000 DPI. The more dots per inch your files are configured for, the more detail that can be included. This does come at the cost of filesize though and files can get very large.

Next up, there are a number of file formats commonly used and each has pros and cons.

PDF: The PDF format is one created by Adobe and is intended for printing. It is relatively ubiquitous on the internet with pdf readers readily available.

SVG: Scalable Vector Graphics formatted files are those utilized by vector graphics programs. This contains all of the vector graphics data without any conversion to a display format. Your vector graphics application will interpret the vector data in order to display the file on the screen or print it out. The SVG format has advanced features that are far beyond what we need for paper models, but is great for laying out parts and adding glue tabs. A downside is that many of the web browsers have only partially, or incorrectly, implemented SVG functionality so they do not handle these files so well. A separate vector graphics application is needed.

DOC(X): This is the MicroSoft Office Word document format and is more suited to preparing your instructions than anything else. It does not have any advanced graphics or print capability.

BMP: The Bitmap file format is as it says, a bitmap file format. BMP files are limited to 256 colors in total, so they do not have a great color depth. There is also no print information included in these files as they are purely an image per file. BMP files have no internal compression.

PNG: Portable Network Graphics files are another form of bitmap, but far more advanced than BMP files. PNG files have a much greater color depth and features such as transparency. But they also contain no print information as they are a singular image per file. PNG files use a lossless form of compression. That is to say that the algorithm used to shrink the file size preserves all of the data in the image.

JPG: JPEG files are another form of bitmap, which is more advanced than BMP files. The downside to JPG files over PNG files for models is that JPG files use a form of lossy compression. This means that the algorithm used to shrink the file size does not preserve all of the data in the image. To achieve a smaller file size some data from the image is sacrificed. Because of this, JPG files are not suitable for distributing model parts unless the compression is all but eliminated (which defeats the benefit of using it), but it is good for photographs to go in your instructions.

My Workflow

Now that we are nearly through the book, you are probably wondering what my workflow look like to design a model. I have shared many options for the various stages of a project previously without major comments on my overall design thought process.

So here is an outline of my workflow….

1. Think about what interests me and what I would like to design.
    a. Find something that does not have a good paper model for it yet.
    b. Talk with others to see what would be “cool”.
    c. Change my mind several times and go back and start at #1 above again.
2. Research
    a. Track down images or descriptions of the subject material. (Find 3-plan drawings if all possible)
    b. Go back and restart #1 several more times.
    c. Determine how big I want the end model to be and calculate backwards to determine the scale.
3. The 3D model in Blender
    a. Set the 3-plan drawings in the background of each of the six primary views (front, back, left, right, top, bottom) and scale them appropriately.
    b. Using the 3-plan views, create the basic structure of the subject material. For larger sections, split them into sub-assemblies which can be handled separately.
    c. Add in as much detail as I want.
    d. Assign colors to the various parts of the 3D model.
    e. Using GIMP and Inkscape, layout materials and map them onto the parts of the 3D model.
4. For each object in the 3D model...
    a. Using an unfold module in Blender (io_export_paper_model.py), unfold each object from the 3D model. Export to SVG files with at least 600 DPI resolution, omit tabs, and include full rendered textures.
    b. Open those SVG files in Inkscape and organize the parts. Add glue tabs where needed. Change the color and thickness of the part outlines and score/fold lines so they are less obtrusive. I chose a color that is distinct enough to see, but that will also blend into the part once assembled.
    c. Print off the parts for that object or sub-assembly.
    d. Assemble that object or sub-assembly, taking pictures along the way for documentation. Use all of your fancy construction skills here.
    e. Post pictures in a gallery online.
    f. Once I am happy with how the object or sub-assembly came out I move the SVG files to a directory that is set aside for all of the completed parts pages.

    g. Create instructions for that object or sub-assembly using the images I took along the way. I use google docs for this.
5. Do the final assembly of all the sub-assemblies and components
    a. Join the sub-assemblies together. Use all of your fancy construction skills again. This will be your alpha build.
    b. Document with a camera and turn that into instructions.
    c. Add non-paper detail as needed and document. Use your artistic and MacGyver skills here.
6. Finalize the instructions with everything that should be in them.
    a. Include a version number in the instructions so you can determine what version is current if/when corrections and additions are needed in the future.
    b. Share the google docs file with a proof reader to make sure what you wrote makes sense.
7. Convert all of the SVG parts files to PDFs. This is where the DPI of the SVG files is shrunk down if a large value (600+DPI) is not needed. I built a script that does this for me.
8. Export the instructions as a PDF.
9. Join the instructions to the parts files and output one large PDF file with the version number in the filename. I built a script that does this for me.
    a. Have someone read through again to verify that it looks good.
    b. Have a beta build done. [I do not follow my own best practices here.] Revise as needed.
10. Post the file for others to download.
    a. http://insanityunlimited.com/modelplans/
11. Appreciate the enjoyment that others get from the work you have put in.

This workflow is based upon my toolset (Linux PC, Blender, GIMP, Inkscape, Cameras, printer) and will most definitely not work for everyone. But at least it gives you a sense of what fully goes into creating a paper model. Develop your own workflow to meet your needs, as the designer. You are in charge of your own creations, so if you have steps that do not make sense or do not provide any value to you, then they should be questioned. From that point you can either revise or eliminate them. If you use different pieces of software there will be different and equivalent steps to accomplish the same result.

Licensing

The license you assign to your model design will determine how a purchaser or builder may use it. This is a legal agreement that sets for rights and restrictions on their part. With the license you are telling the builder what they may do with what you have produced.

All of these legal concepts vary from country to country and locale to locale. In this regard, your specific location may have a slightly different interpretation of what is and is not permitted under a given license.

For the most part, copyright is assigned to the author of any work by default. You may need to include some form of a © or the word copyright along with the year and your name. This means that nobody else is supposed to claim your work as their own. If they build your model the plans and instructions are still your intellectual property, but the finished model is theirs and they can usually do with it what they wish. I could build a model that you designed and then sell the completed model to another party.

A commercial license is one where a potential builder would pay some fee to acquire your model kit. You still own the copyright on the kit.

A second type of license is known as open-source. There are a multitude of standard and semi-standard open source licenses. These often do not require a fee to acquire the model kit. Some of these licenses permit the recipient to modify and improve the work and then redistribute it with or without reference to you or your original creation. Some of them only permit the kit to be used for non-commercial uses. Some of them require attribution to the author.

If you happen to be lucky enough to get paid to design a model, then it is likely the party paying you will own all the rights to the end result. This would be the situation where a local company asks you to design something as a promotional give away at a convention. You do the design work and hand them the files and all rights to the model, then they print and distribute it.

If you are distributing the model design yourself, it is likely that someone else will try to redistribute it. It does not matter whether you are trying to charge money for the kit or what license you have assigned to it. Someone will try to send the files to others. Tracking these parties down is an exercise in frustration, doubly so if people live in other countries that have differing laws.

In my humble opinion, it is not worth my time to chase these individuals down and attempt to stop them distributing my models. I take this stance for several reasons. First, I am not making a living off of the models I publicly distribute. Second, I do all of my design work for the satisfaction of having done it. I want to see other people enjoy and learn from what I have created. Thirdly, those publicly available models act as an example of what I can produce in case someone does wish to hire me to create something for them.

If someone will pay me to build or design something for them then that is how I will primarily make money off of it. In that situation either there is a physical good exchanged which cannot easily be easily reproduced or I am transferring all of my rights for the model to someone else and it is out of my hands to worry about.

My compromise, for my publicly available models, is to include a paragraph explaining that a lot of time goes into creating these models and ask for the builder to send a few dollars if they think the model is worth something. I include a link to an online tip jar to make it simple for people to send me a donation if they wish to do so. In fact, it is very similar to the forward at the start of this book.

Glossary

1-2-3 block (n.): A block of steel, commonly used in metal machine shops, that has holes drilled through it in each direction. They measure 1x2x3 inches in size.

Annealing (v.): Heat (metal or glass) and allow it to cool slowly, in order to remove internal stresses and toughen it.

Brayer (n.): A rubber roller used to press two layers of a lamination together.

Burnishing (v.): Deformation of a seam to smooth the texture of a transition from one surface to another.

CA glue (n.): A glue made of cyanoacrylate. Also known as super glue.

Chipboard (n.): A thin variety of cardboard.

Chisel blade (n.): A straight edged blade that is placed perpendicular to the material to be cut. As opposed to drawing the blade across a page, it is used to sheer vertically through the paper.

Compass (n.): An instrument for drawing circles and arcs and measuring distances between points, consisting of two arms linked by a movable joint, one arm ending in a point and the other usually carrying a pencil or pen.

Compound curve (n.): a curve made up of two or more circular arcs of successively shorter or longer radii, joined tangentially without reversal of curvature

Dowel (n.): A cylindrical piece of wood or metal tubing.

Drafting (v.): Technical drawing, drafting or drawing, is the act and discipline of composing drawings that visually communicate how something functions or is constructed.

Draw plate (n.): A draw plate is type of die consisting of a steel plate with one or more holes through which wire is drawn to make it thinner.

Drawn blade (n.): Any blade that you hold at an angle and pull across the materials you are trying to cut.**Finger injury (n.):** Ow ow ow ow. Don’t do it.

Edge (n.): The outside limit of a face. Multiple edges make up a defined face.

Edge coloring (v.): Applying pigment or ink to the exposed white edge of a part, that white edge being exposed after cutting the part out of the remainder of the piece of cardstock.

Face (n.): The presented surface of an object. In 3D models, this is usually a planar construct.

File (n.): A tool with a roughened surface or surfaces, typically of steel, used for smoothing or shaping a hard material.

Finish (n.): A description of how shiny or dull a particular surface is on an object.

Fixative (n.): A chemical application used to preserve or stabilize markings on paper prior to construction.

Forceps (n.): A pair of pincers or tweezers used in surgery or in a laboratory.

Former (n.): A structure that is used inside a section of a model to help shape the externally seen surface.

Fuser (n.): Component of a laser printer that heats the toner causing it to adhere to the page.

Grain (n.): The longitudinal arrangement or pattern of fibers in wood, paper, etc.

Glue (n.): An adhesive used to fix two objects together.

Hemostat (n.): An instrument for preventing the flow of blood from an open blood vessel by compression of the vessel.

Inkjet printer (n.): A printer in which the characters are formed by minute jets of ink.

Jig (n.): A device that holds a piece of work and guides the tools operating on it.

Laminating (v.): The technique/process of manufacturing a material in multiple layers, so that the composite material achieves improved strength, stability, appearance, or other properties.

Laser printer (n.): A printer producing good-quality printed material by using a laser to form a pattern of electrostatically charged dots on a light-sensitive drum, which attract toner (or dry ink powder). The toner is transferred to a piece of paper and fixed by a heating process

Mandrel (n.): A tool used to shape wire or another material.

Martini (n.): A cocktail made from gin or vodka and dry vermouth, typically garnished with an olive. The best beverage ever (if you omit the olive).

Model stash (n.): A collection of models that have been acquired but not yet built.

Mould (n.): A vessel used to contain a liquid material that will later harden. It is used to impart shape and detail into the exterior of the material injected into it.

Mountain fold (n.): A fold where the fold line appears like that of a mountain peak, where the fold line is pointing up.

Object (n.): Discrete subsections of a model.

Paper model (n.): A model made primarily of paper or cardstock. Also known as a card model.

Papercraft (n.): Any creative art form that uses paper as the medium. It includes paper models, origami, and paper mache.

Photo etched brass (n.): Thin brass that has been prepared with a film, exposed to UV light, and etched with acid. This produces very fine details in the resulting part.

Punch (n.): A device or machine for making holes in materials such as paper, leather, metal, and plaster.

PVA glue (n.): A water based glue made with polyvinyl acetate.

Ream (n.): A bundle of paper consisting (usually) of 500 pages.

Rolling (v.): To impart a curve to a piece of paper such as to create a tube or cylinder.

Scale (n.): the relative size or extent of something

Scalpel (n.): A knife with a small, sharp, sometimes detachable blade, as used by a surgeon.

Scissors (n.): An instrument used for cutting cloth, paper, and other thin material, consisting of two blades laid one on top of the other and fastened in the middle so as to allow them to be opened and closed by a thumb and finger inserted through rings on the end of their handles.

Score (v.): To impart a crease or weak line across a piece of paper. This allows for a clean fold to be created across the scored line.

Scoring tool (n.): An implement for creasing material.

Scratch build (n.): A model made without utilizing a prepared kit. From the phrase "from scratch", meaning that there is no defined kit or set of parts.

Software (n.): The programs and other operating information used by a computer.

Straight edge (n.): Any device capable of being utilized as a guide that has a perfectly straight edge for long straight cuts.

Tea (n.): A hot drink made by infusing the dried crushed leaves of the tea plant in water. The best drink ever excluding martinis.

Test fit (v.): The act of testing a part in a larger section of a model. This involves aligning seams, matching textures, and verifying the proper shape and orientation without permanently affixing it.

Valley fold (n.): A fold where the fold line appears as if it is a valley between two mountains, where the fold crease points down.

Vertex (n.): The points in space that make up the ends of a line.

Work hardening (v.): Increase in hardness of a metal induced, deliberately or accidentally, by hammering, rolling, drawing, or other physical processes.