Introduction

The aim of this guide is to provide beginning builders information to become what could be considered intermediate builders, to go from an amataeur to a competitor. The guide seeks to give insight into many aspects of 'balsa events' (ie bridges, towers, boomilever), which are universal throughout these events while also seeking to provide some analysis of the specific boomilever event. The advice in this guide is mostly experience I have picked up in four years of doing balsa events and one year of coaching a div b towers team, and there is without a doubt more detailed and probably more accurate guides out there, however this guide seeks to make a competitor out of a beginner, not a champion out of a competitor. Everything in here is my opinion and you are free to disagree, if you do find something you think is not right please reach out to me! I would like to hear what you have to say and learn from it.

Building Techniques

In my eyes, the biggest difference between a beginner and an intermediate builder is the small details. Things not even necessarily related to design and actual building. That is where you can start to cut grams off your structure. So I am going to start there.

Glue

The most questions I have ever received about any type of building event is about glue. The most issues I saw with the team I helped were about glue. Personally, I have never had an issue with glue, I am lucky. In four years, I have used one type of glue for balsa events, Loctite super glue (see picture). It is a cyanoacrylate glue.

I have talked with other successful builders who have used other glues for their whole times as well, others who had never heard of the glue I used and even a few who strongly disagreed with my choice of glue. Ultimately, I think it comes down to finding a glue you like and works for you, experiment and find your favorite. Most builders agree that cyanoacrylate is the way to go. Here's a few glues you should probably avoid: Gorilla Glue, wood glue, and anything that doesn't say 'super glue' somewhere on the bottle.

The four things you need to look for in a glue are drying time, strength, weight, and price. Loctite dries in about 10 seconds, it is very strong in my experience, does not add an excessive amount of weight, and has a pretty affordable price, as well as being available at many craft or hobby stores.

Some food for thought about the actual gluing process. First of all: you are using too much glue. I can almost guarantee it. Too much glue is too much weight. Use less glue! Unless someone already gave you this advice. A general rule of thumb I have found is that if you have to wipe off excess glue, you put on too much (you should always wipe away

excess glue though. Excess glue is excess weight). A good way to start doing this, if you already are not, is spill some glue onto a piece of paper, and with a toothpick apply only what is necessary. With time you will be able to squeeze just what is necessary right from the bottle. The other thing I have found when it comes to glueing is the position of the structure when you glue something onto it. Right now, you probably are gluing things two dimensionally: one piece is flat on the table, and another is glued next to it and held in place. Everything is glued on the table and clipped to the table or something of the style. The next step is to begin gluing three dimensionally: This comes in handy very much in later stages of the building process. At first, this will be hard and seem pointless, but I have found that it significantly speeds up the building process and allows you to see the final structure as it is being built.

Tools

I think it is important to touch on this before we keep going. The tools that you need throughout the building process are: An exacto knife of some sort. I have 3 different blades, of different sizes and blades for more precision or better cuts throughout the build. Glue. We discussed this in the above point. A scale, hopefully with a precision of 0.01g, but at least 0.1g. A level, this is incredibly important because balance and precision are very important, and you should never really trust the eye test. Sandpaper, fine grain and medium grain. A ruler and meter stick. The more precise the better, and having a good ruler versus a sketchy one will be very helpful. This is something I would invest in. Make a toolbox with all these tools so you have everything in one place. It doesn't have to be a huge super elaborate box, a small cardboard box will do perfectly fine.

The other things are accessories that will enhance your building process but their absence shouldn't impede your progress (it hasn't impeded mine). A T-square, to make right angles. (ruler will work for this too). A foam building surface and pins to secure the structure. I'm not a fan of that, but many people find it essential.

Wood

I'm going to kick this off by saying you should be weighing every piece of wood and writing it down. Preferably on the piece of wood, so the information is not lost. This is so incredibly important and I can't stress it enough. I have helped so many young builders who seek to better their efficiency, and think that the problem is that the structure doesn't hold enough: almost always, it's easier to cut off weight, when you are becoming an intermediate builder, and the best way to do it is to weigh every piece so you don't add unnecessary weight to your structure. When you are buying wood, if you are doing so in person, bring a scale and weigh all the pieces so you buy only the woods that you need. An easy way to buy wood however is to do it through specialized balsa, I will add that link at the end. You can select what weight you want when buying balsa.

Secondly: Basswood or Balsa? I only use balsa in my structures, however there are many people who include bass in their structures. Here is a quick comparison of both, and they are generalizations, there are exceptions.

- Balsa is lighter than bass. This is because it is less dense

- Balsa is cheaper and more commercially available than bass
- Bass has more uniform density, meaning it has the same density throughout the whole stick. Balsa tends to not be as nice
- Balsa is generally sold in 36” sticks, Bass in 24”. (keep this in mind when weighing your pieces.
- Bass tends to make stronger joints, that is, it does not tear off as much at joints.
- Balsa tends to be more affected by humidity

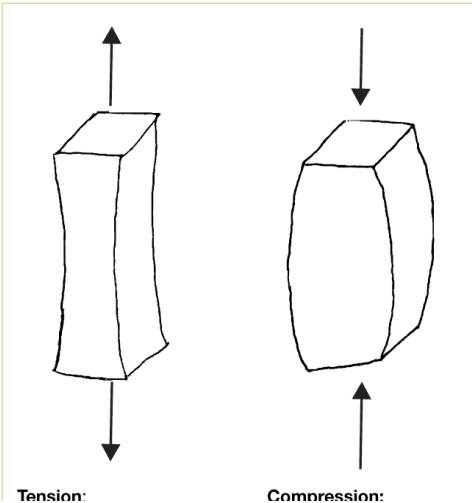
It is possible to make great structure both out of just balsa and just bass, I think it comes down to personal choice, and if you choose to use both be mindful of which to use where.

Process

When you build, there are a few things to keep in mind. First of all, draw out your design before you build it. Write down as many specifications about it as you can, such as the weight of all the pieces in the structure, and once you are done you can add the final weight, efficiency score, and where it failed. This is so so important! Because as great a memory as you may have, you will not remember all of these details, and many times they end up being crucial in the design and building of the next structure. Before you build, pick all the pieces you are going to use in your build and set those apart from your ‘wood pile’. With respects to actually building, usually it is easier to build the bigger parts first and the bracing and smaller parts last, but do what works for you. Make sure that throughout your building process, you keep things as symmetrical as possible, so if you want to leave a part to dry, make sure it will dry symmetrically. While building make sure you are as precise as possible to prevent errors that could turn into big problems when testing. Things such as having good lighting, and the tried but true saying of “measure twice cut once”. Always remember to go easy with the glue. When you are done building, use the sandpaper to shave off any excess glue or wood that may be on the structure. This usually doesn’t do much, sometimes it saves you around 0.1-0.3g, which is helpful. Make sure however, not to oversand your structure as this will cause it to weaken, and this is not helpful. Always let the glue finish drying completely for about 24 hours before you test. If the structure you are building is for a competition, my suggestion is that you build another structure which is as identical as you can get it so that you can test one of the two before the competition. Testing before a competition is a very good habit, as it can help avoid unpleasant surprises.

Parts of a Structure

In any balsa event you compete in, you will run across the same kinds of parts within a structure that behave the same way under stress (weight from the sand). Knowing how to identify them will help you a great deal in knowing how to create a stronger structure and knowing where you can take weight off your structure.



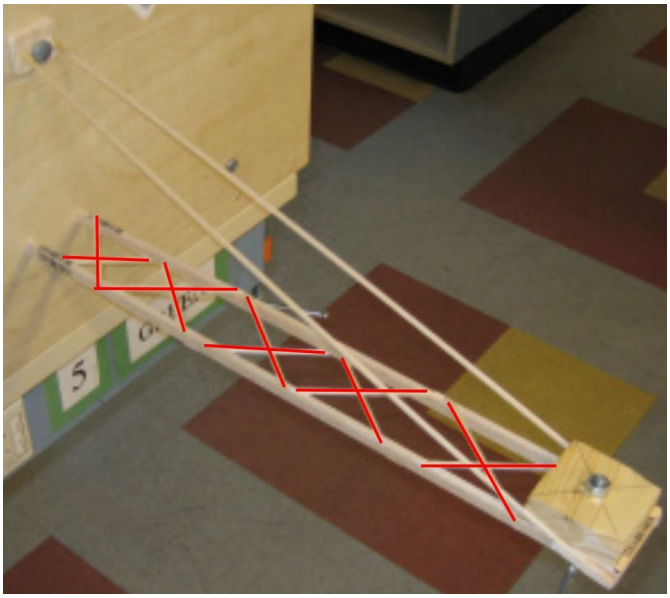
When stress is applied to the structure at the loading point, that stress is distributed throughout the structure, and each individual piece within the structure is put into two different conditions: it is either under a compression force, or a tensile (tension) force. There are more forces which can act on a piece within a structure but those two are the most relevant.

Compression is simply a pushing force on a structure (see picture). The strength of a stick under compression depends on the effective length of a piece, the cross sectional area of a piece, and the inherent stiffness. By changing these variables, you change the strength of a piece under compression.

Length: when you cut a piece in half, you have nearly quadrupled the strength of each piece. That is, there is an inverse square relationship between the length of a piece and it's strength under compression. So, what we do to cut down the length of a piece is to create "stacked columns", that is, to add bracing which separates the full column into many smaller pieces which are all part of the big column. You can calculate the strength of a piece at the full length (usually 36"/91.5 cm) by performing a single finger push down test, which is where you put the stick onto a scale and push down, and record the reading of the scale at the moment that the stick fails, that is, it buckles or bows. Then, you can calculate the amount of stress on the full column to determine how much bracing you need.

Cross sectional area: This is almost like a sort of tie breaker in my eyes. If you have two pieces of balsa that weigh 2g, one of them is ⅛"x⅛" and the other is 3/16"x3/16", then you can assume that the second one is stronger because it has a greater cross section. The shape of the cross section also changes the strength of a piece... cylinders are the strongest shape under compression. That's why you always see those greek temples with cylindrical columns. In scioly you rarely see that however, because it is quite difficult to correctly glue bracing to a cylinder than to a rectangular prism, which is what we use.

Inherent stiffness: If we built the same exact structures out of metal instead of balsa they would be stronger. At the same time however it'd also be heavier. This is one variable people don't really touch. Some food for thought though... Bass has a greater inherent stiffness than balsa, so if you made your compression parts out of bass they would be stronger, however they'd also be heavier.



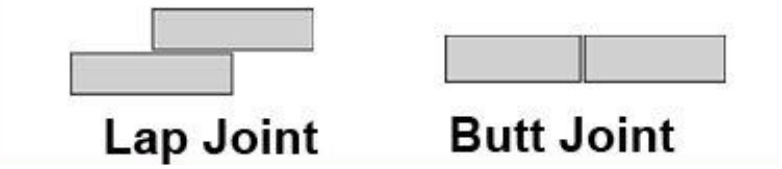
All in all what you need to remember is that strength under compression greatly depends on the length of a piece, and to change the length of a piece under compression you add bracing. In the case of a boomilever, you would add lateral bracing as shown in the picture in red.

Tension is simply a force pulling on a structure. Any type of bracing on a column is almost always under tension (there are some exceptions). I'm not going to go nearly as far in depth about what affects the strength of a

piece of balsa under tension, in part because I don't really know about it as well as I do about compression. Tensile strength is mostly affected by factors that aren't easily controlled, such as the molecular structure of each piece.

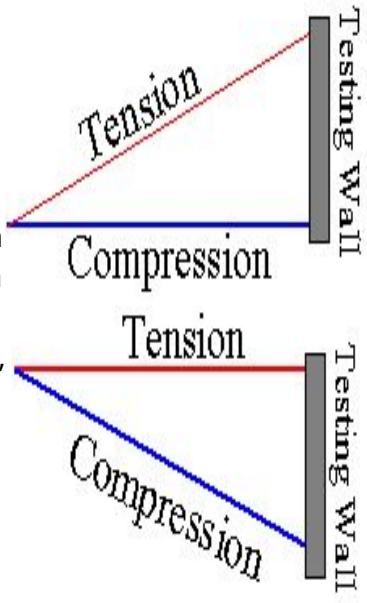
One thing you do need to know is this: a piece of wood has about the same tensile strength no matter how long it is. With that piece of knowledge in mind, we can draw a very important conclusion. The place to take weight off your structure is in the pieces under tension: Make those light as you can. How light? Find out through experimentation.

A variable that does affect the success of bracing is to make sure that your joints connecting your columns to the bracing are as sound as possible. The best way to do that is to increase the surface area of the glue joint. That brings me to my next point: different types of joints. There are two basic types of joints you can have. Lap joints and butt joints (see pic). The better of the two types of joints when you are considering bracing is lap joints. Why? You get much more surface area, which means your joints will be more sound and your structure will not break prematurely because of a poor joint which did not distribute the weight properly.

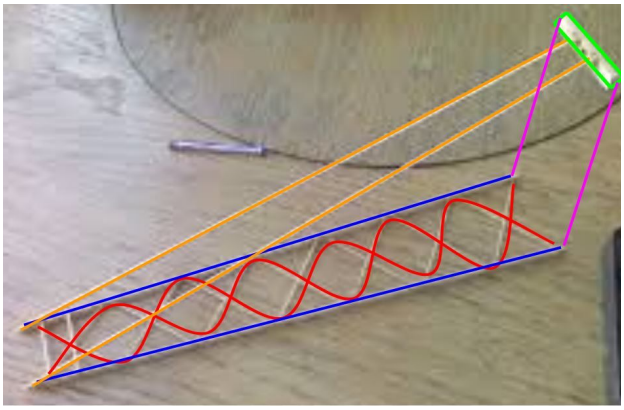


Boomilever Design

With this knowledge in mind, we can make a general design for a boomilever without yet knowing next years rules. There are two basic boomilever designs: A tension boomilever (first pic) and a compression boomilever (second pic). The better of the two is generally the tension boomilever. Why? In both boomilevers, there is the same amount of strain being distributed throughout the structure. If we simplify them both down to just the tension and compression pieces in each, the answer becomes clear: The compression boomilever has a longer piece under compression, which means that it will be weaker than the piece in the tension boomilever.

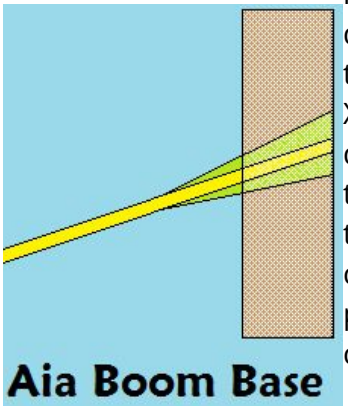


The next thing to think about is the place where the tension and compression piece meet, which is also where we will be placing the loading block. This is the most critical of all the joints, and it needs to be the most sound out of all of them. A good idea is to add more surface area so the joint is as sound as possible, there are many ways to do that, one is shown in the picture to the left.



When you begin to decide on which design to build, this is my suggestion: Make it as simple as you possible can. You can always make it more complex as you go on and begin to see, through testing, which parts need more

reinforcement than others. Attend lots of competitions, look at what other people are doing, take pictures of other people's boomilevers and watch them to learn from them. To the right is a simple design to start off the season. It has the base at the top, in green, the tension pieces in orange, the compression pieces in blue, a tension strip for stabilizing (optional) in purple, and the cross bracing for the compression in red. Keep in mind the inverse square relationship we covered in the compression section to determine how much bracing you want, and also experiment with different types of bracing, such as X's, (like in the picture, this is what I use most often), X's and ladders, etc. The most changing to the structure you will likely end up doing will be in the part that is under compression, and possibly some tweaks to the makeup of where the loading block will go and the base. When building the base, remember that more surface area makes stronger joints: If you could to some extent put the tension piece into the base, as shown in the picture left, that would create a stronger joint and more reliable base. The concept in the picture is not mine, it belongs to Aia and all credit to him/her.



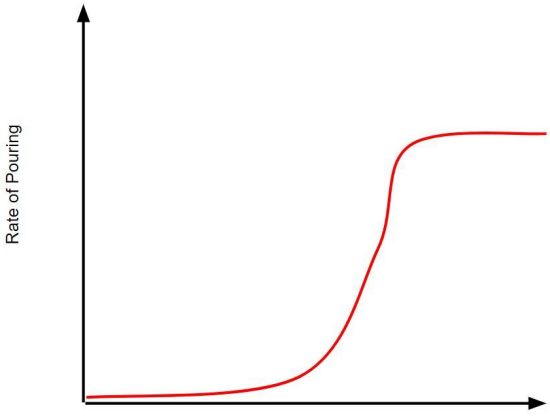
Competition

I wanted a little section of the guide for a few miscellaneous thoughts and reflections about the competition process when competing in a balsa event.

Transportation of a structure to an event: Most of the competitions I've attended are fairly close, so usually what I have suggested to people when it comes to transport is to carry your structure. Put on some latex gloves (the oil and dirt from your hands can do bad things to the wood if you're holding it for a few hours) and drive safe and slow. Another option is to find a box to put your structure in (or you could build one! I did this for towers 2 years ago) and glue cotton balls to the inside of the box so your structure is safe. One other important thing is that humidity affects the weight of your boomilever, because it is made out of wood. This usually isn't a big issue, unless you are traveling to a competition where the humidity is significantly different than that of where you built the boomilever, in which case it is a good idea to put a few silica gel bags in the box to keep the boomilever dry. It also won't hurt your structure to do that even for competitions with similar humidity.

What to bring: Ideally, you should make two identical or nearly identical structure for a competition, it is always good to have a backup in case something bad happens. Additionally, or instead of that, you should bring extra wood, of all the sizes you need, and especially your tools to make any last second fixes should anything happen on the way there, for example a bit of bracing breaks, or a bracing joint becomes loose.

Loading: There are many different approaches to loading, and ultimately I think it comes down to what works best for you and what you are used to. There are two ways to load a structure, by hand or with a machine, and that depends on which competition you attend. Usually the more important the competition,



they are more likely to use a machine to load. When loading with a machine, once you start don't stop until the structure breaks or you run out of sand. When you first start, pour slowly the first kilogram or so, and then increase the rate of pour significantly. Why? The more time the structure is under stress, the more likely it is to fail. You want to get as much as possible in the bucket, in as little time as possible. Look at the graph for an illustrated description. The same concept goes for hand loading, except each 'handful/bucketfull' of sand is treated like the graph.

Always, always always take videos of your structure while you test! Or ask a friend or coach to do so. This video could be useful when determining where and why the structure broke. Take videos when you are test for practice as well, ideally in slow motion to get a better idea of what part of the boomilever failed first. It can be very misleading to try to identify the point of failure of the boomilever based on the broken remains of the structure.

More things to explore

Once you understand all the things in this guide, I encourage you to take a step back from this and use your experience to judge this guide. What things worked for you? What things didn't? What's missing? Which concepts were simple and which were complex? (hopefully most of them were easy to understand). With all this information and all the valuable experience you have/will have, the next step is to make things more complicated. One very fun thing to do for you math oriented people is to begin throwing a lot more math into your designs: Learn how to solve a truss (this video may help), look up Euler's buckling theorem to understand how compression really acts in a piece. Maybe you want to experiment with more complex designs; try arches, try trusses in your compression piece. Understand how different trusses spread out loads, and which bracing works best for what situation. These are just some ideas to get you going. Stay curious, that's the best way to learn.

Other Assorted Tips

Here are some other rules of thumb which I couldn't figure out how to weave into this guide, plus a few things that are covered but they're important enough to be restated. These are meant to be thoughts which are applicable to all balsa events

- Too much glue is too much weight, use it sparingly
- Build and test a lot, as much as you can. Practice makes perfect
- Go slowly when you build to make sure everything is as precise as possible
- Compressional strength depends on length and cross section
- Tensile strength does not depend on length
- Lap joints are better than butt joints
- Always draw your structure out on paper before you build

- Keep a record of every structure you test, and if you know where it broke write that down too
- Good artists borrow, great artists steal: Don't be afraid to copy designs you see at competitions or in pictures. This will help you become better
- Take videos of every structure you test
- Simplicity is the ultimate sophistication: Sometimes, trying to overengineer a structure isn't a good idea
- Be sure not to over sand your structure
- Always try to test your structure before a competition