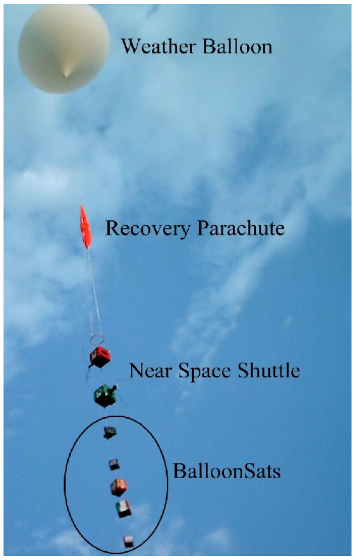
## 1.0 Constructing BalloonSat Airframes

In near space, experiments need a container to hold and organize them. This chapter is about that container, the BalloonSat airframe. After a short description of BalloonSats past and present, this chapter discusses the materials, tools, and methods used to machine and assemble a BalloonSat airframe. Afterwards, there's a suggested step by step assembly procedure. However, since the size and shape of your BalloonSat depends on the experiments you'll put inside of it, you should use this chapter as guidance and not as absolute rules.

### 1.0.1 The Recommended BalloonSat Configuration

The BalloonSat recommended in this book is a Styrofoam box with a hatch in front with two rubber bands stretched over it to keep it closed during its mission. The ends of the rubber bands hook to the BalloonSat through closure dowels on the side of the airframe. During it mission, your BalloonSat and others hang below the near space shuttle on four cords called the suspension lines. The suspension lines pass through the walls of the BalloonSats, allowing each to hang in series, one after the other. Protecting the Styrofoam walls of the BalloonSat from abrasion by the suspension lines are suspension tubes, plastic tubes embedded inside the Styrofoam. Each BalloonSat is free to slide up and down the suspension lines, within limits. Split rings on the suspension lines prevent the BalloonSats from sliding too much on the suspension lines.

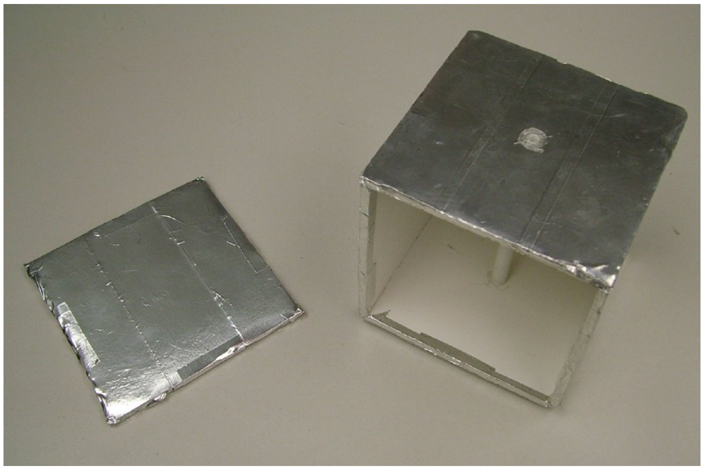
The near space shuttle contains the GPS receiver and radio equipment needed to track and recover the flight. Therefore, you won't add tracking electronics to your BalloonSat. Since the near space group providing the launch already provides the tracking and recovery services, your BalloonSat only has to operate its experiments and record its data for download and analysis after its recovery.




**A chain of five BalloonSats suspended below a dual-redundant near space shuttle. The redundant modules in the shuttle ensure the mission's success even if there's an electronics failure during the 2-1/2 hour mission. Above the two modules of this particular near space shuttle is its orange recovery parachute and balloon (the near space booster).**

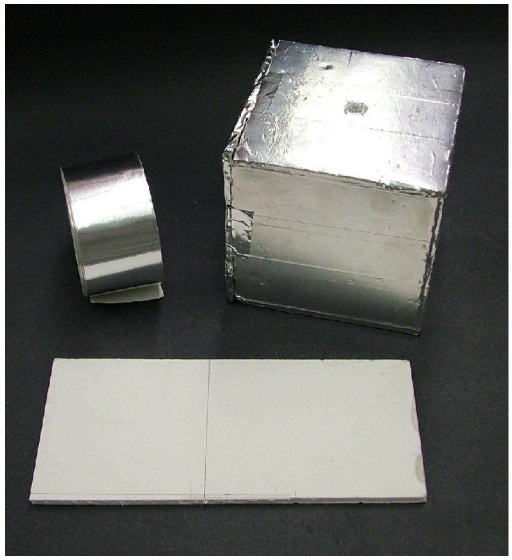
**A sight everyone wants to see, the near space shuttle with its payload of BalloonSats safely on the ground. The next stop for these BalloonSats is a return to their owner for data analysis.**

## 1.1 Materials



**An example of a traditional BalloonSat airframe.**

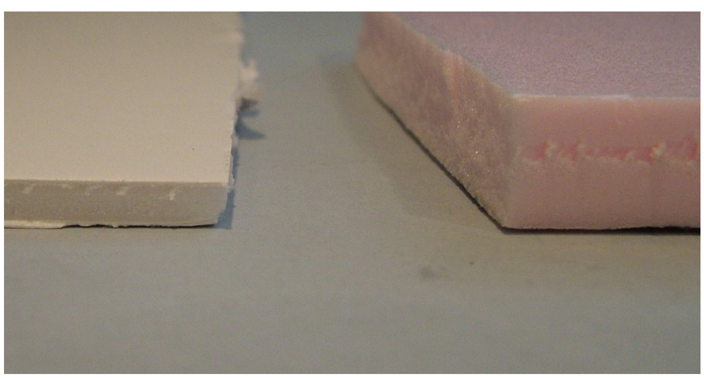
The traditional BalloonSat is a cube constructed from foamcore and aluminum duct tape. Foamcore, a 3/16 inch Styrofoam sheet with paper facing, and is a popular backing for printed artwork like posters. It's available in 20" by 30" sheets at many art and big box retailers. Aluminum duct tape is a thin metal foil with an adhesive coating. Most home improvement stores carry it in rolls two inches wide and 50 feet long.



**The traditional materials of foamcore and aluminum duct tape.**

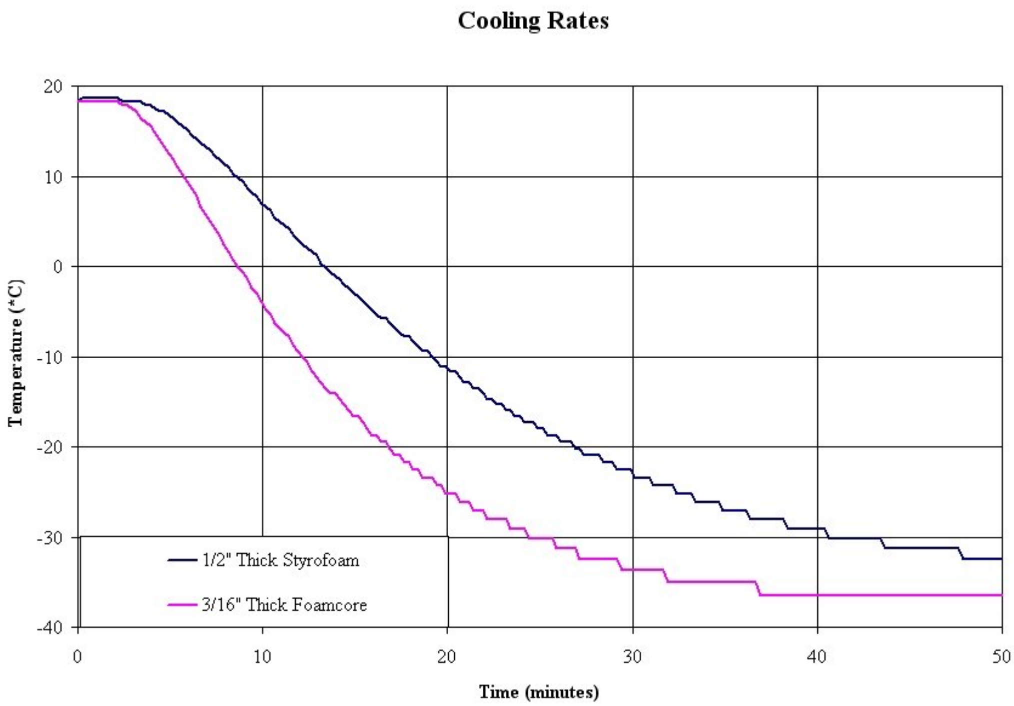
Instead of foamcore and aluminum tape, the BalloonSat Principia recommends constructing a BalloonSats with ½ inch thick Styrofoam and colored poly shipping tape. Styrofoam is light in weight, easy to cut and shape, and quick to glue together. It's available in four by eight foot sheets at many home improvement stores who sell it for home insulation. Be careful; this is not the beaded white Styrofoam sheets, which are also available at home improvement stores. White Styrofoam is too crumbly and fragile to make a good BalloonSat airframe. The proper Styrofoam is light blue (not white), solid, and with a fine grain. Home improvement stores sell several thicknesses of this material, but it's the ½ inch thick material you want to use. There's no need to use the thicker stuff as it adds unnecessary weight to your BalloonSat (but it does increase its insulation). The colored poly shipping tape is the same tape hobbyists use to cover the wings and fuselage of Styrofoam gliders. The company Uline (see the later reference) sells this tape as does many hobby stores that carry Styrofoam gliders.

### 1.1.1 Comparing Styrofoam to Foamcore



**A close up of Foamcore and Styrofoam. Foamcore is heavier than 1/2 inch thick Styrofoam per unit area and doesn't insulate as well. Because of its paper covering, it doesn't stand up to moisture as well as Styrofoam either. Styrofoam is expanded polystyrene plastic. It's lightweight and insulates well because of the trapped air in its cell structure.**

According to my Pelouze digital scale, a 25 square inch sheet of Styrofoam weighs 8 grams while the same area of foamcore weighs 10 grams. Therefore, a ½" Styrofoam BalloonSat airframe weighs 20% less than an equivalent BalloonSat airframe constructed from foamcore. Reduced weight is not the only benefit of using Styrofoam. Placing a traditional BalloonSat inside a Thermal Test Chamber along side a Styrofoam replica illustrates a second benefit of using Styrofoam; a Styrofoam BalloonSat is warmer inside than a foamcore BalloonSat.




**The interior of a Styrofoam BalloonSat takes nearly 20 minutes longer to cool to the same internal temperature as a foamcore BalloonSat. Its warmer internal temperature will protect its internal batteries and electronics from the extreme cold of near space for a longer period of time.**

According to the experiments of Galileo, the thicker a material, the greater strength it has. Therefore, it's reasonable to assume that ½ inch thick Styrofoam is stronger (resists bending) than 3/16 inch thick foamcore. However, foamcore is a Styrofoam sheet with a bonded paper surface. That makes it a composite and in general, composites are stronger than their constituent materials. Is thinner foamcore really stronger than thicker Styrofoam? Appendix I explains how to test the strength of materials.

### 1.2 Styrofoam Tools

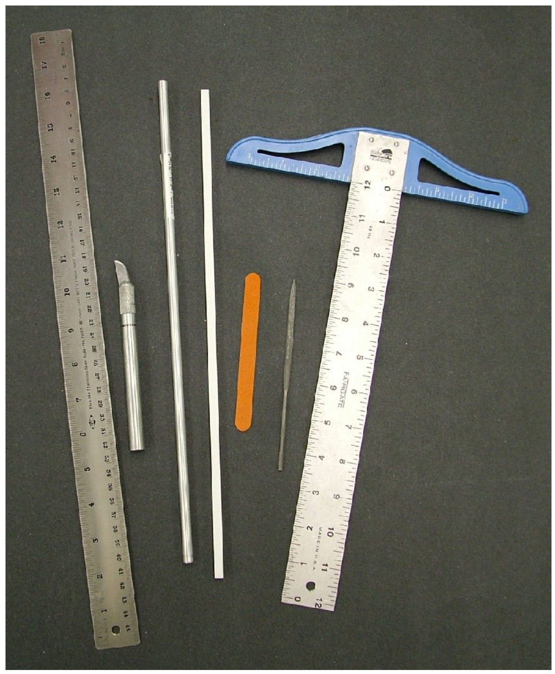
Most of the tools required to convert a sheet of Styrofoam into a fleet of BalloonSats are common to other hobbies. Therefore, you probably already have most of the tools you need to measure, cut, shape, and assemble Styrofoam.

#### 1.2.1 Tool List

Metal Straight Edge
Exacto Knife

Hollow tubing *
Hollow channel *
Emory Board (cardboard nail file)
Metal Hobby Files
T-square
Pencil
Hot Glue Gun

* Made from aluminum, brass or plastic



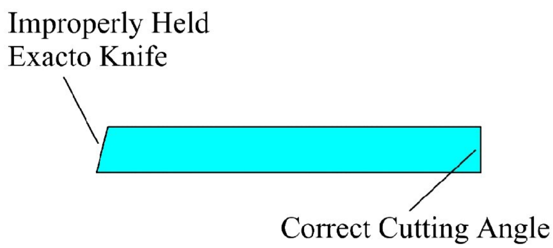
**Airframe machining tools, except for the pencil and hot glue gun.**

### 1.3 Machining Foam
This section briefly describes the cutting, drilling, channeling, and sanding operations you need to know to make a BalloonSat airframe. In some ways, a BalloonSat is a near space version of a CubeSat. Since Styrofoam is easier to machine than aluminum, a BalloonSat is easier and faster to make than a CubeSat.

#### 1.3.1 Cutting
One difficulty is cutting a clean edge in Styrofoam. Table saws cut clean edges in Styrofoam, as does a hot wire (which cuts through Styrofoam like a knife through, well, you know...). A table saws naturally cuts straight lines while a hot wire requires a very steady hand or a jig to cut a straight line. If don't have access to either of these tools, and can't justify purchasing them, then the only option is to cut Styrofoam with an Exacto knife.

Styrofoam cuts well with a sharp Exacto knife and metal straight edge. In addition to the knife and straight edge, you'll need a T-Square to draw right angle corners and a protractor to mark out non-square edges (no one said your BalloonSat had to be a cube).

Use a metal straight edge and T-square to lay out the cut to make in your Styrofoam sheet (don't use wooden straight edges as the Exacto knife will knick and create a crooked line). Press lightly with your pencil and don't gouge the Styrofoam when you draw a line. Load a new #11 blade in your Exacto knife handle. Place the metal straight edge along the line and hold the Exacto knife as close to perpendicular as possible. If the Exacto knife is not perpendicular, you'll cut an edge that looks like this.




Make several cuts through the Styrofoam; don't cut through in a single pass. Begin your cut with the Exacto knife held vertical, but leaning back. When the Exacto blade leans back, it slices through the Styrofoam and is less likely to chip it.

As the blade of the Exacto knife begins to dull, you'll notice that it cuts better in one direction than in the perpendicular direction. Apparently, a "grain" is created in Styrofoam when it's extruded. As the Exacto blade dulls, it begins to chip or break out chunks of Styrofoam instead of making smooth cuts. Be prepared to replace the blade when the Exacto begins to make bad cuts.

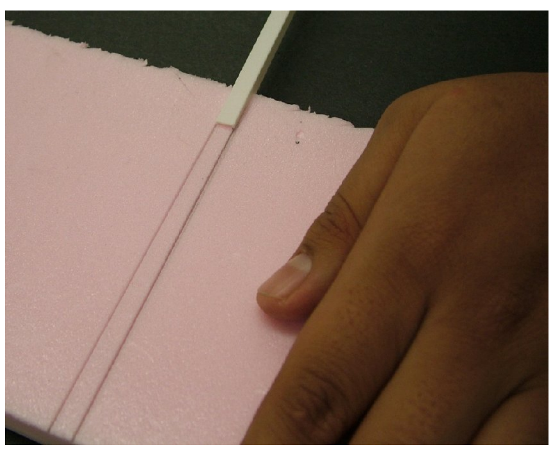

**The edge of Styrofoam cut with a dull blade (I used a very dull blade to emphasize the damage done).**


**The cut edge of this Styrofoam sheet is much smoother because it was cut with a newer, sharper blade.**

Since you can go through a lot of blades making BalloonSats, purchase your Exacto blades in the black plastic box of 25 blades.  In bulk, the cost per blade is lower and besides, the box protects the unused blades and is a safe place to dispose of the used, but still sharp, blades.

### 1.3.1.1 Cutting Channels

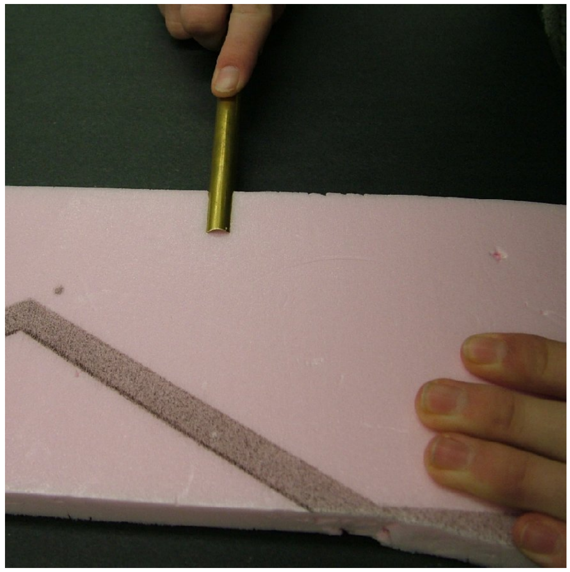
An easy way to cut channels into Styrofoam is to cut two parallel lines and then run a sharpened brass channel between the lines.  Back the channel out occasionally to clear it of Styrofoam shavings.  A sharpened square plastic tube can also cut channels as described in the next section.



**Using a sharpened channel, plastic in this case, to clear out the space between two parallel cuts.**

### 1.3.2 Drilling Holes

A drill bit doesn't do a very good job cutting holes into Styrofoam; it tends to tear it up.  So use a sharpened brass tube.  Sharpen the inside edge of the brass tube with a small metal hobby file then twist the brass tube as you push it through the Styrofoam.  Occasionally pull the tube out of the hole to clean out the Styrofoam shavings.



**This person is twisting the brass tube as he pushes it through the Styrofoam. He's also being careful to keep the tube at a constant height relative to the Styrofoam so the hole is straight.**

### 1.3.3 Sanding

Cardboard nail files and hobbyist metal files shape and smooth edges in Styrofoam. A piece of sand paper can also shape the edges and faces of Styrofoam. There are two ways to maintain a flat surface on Styrofoam while sanding it. The first is to lay the sand paper face-up on a flat surface and run the Styrofoam back and forth on the sand paper. The second is to sand the Styrofoam with a stationary belt sander. However, be aware that sanding a glued piece of Styrofoam with a belt sander will eventually gum up the sanding belt.

### 1.3.4 Gluing

Hot glue bonds the pieces of an airframe together very quickly. It's also easier and less messy than either the JB Weld or silicone glue recommended in sources, like the Space Grant BalloonSat book.

## 2.0 Constructing Airframes

Aside the tools listed above; you need the following materials to assemble an airframe.
Styrofoam sheet, 1/2 inch thick
Color coded or colored poly shipping tape, 2.2 mil thick *
Wooden dowel, 3/16 inches in diameter
Polystyrene tubing, 1/4 inch in diameter **
Rubber bands
Black enamel modeling paint or black felt tip marker

**Optional Material**

Foamcore
Aluminized Mylar (space blanket)
Scrim (wedding veil material)

Kapton tape (1/4 or 1/2 inch wide) ***
Black plastic model paint or black felt tip marker

* Uline (www.uline.com) sells this tape as item S-700.  It's also available at many hobby stores that sell Styrofoam gliders.  Modelers like to wrap the tape around their Styrofoam gliders in place of painting them.  In addition to adding color, the tape makes the glider more durable.

** Plastic tubing is available at many hobby stores.

*** Also available at Uline

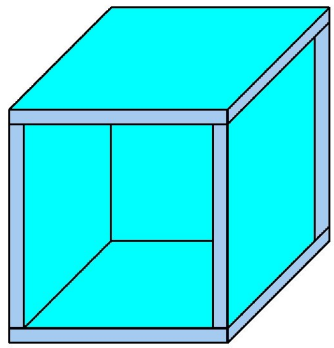

**Half inch thick Styrofoam along with a wooden dowel and hollow plastic tubing.  The rolls of tape in the center are a 2.2 mil color coded tape at the top and a roll of Kapton tape below. Both rolls of tape are available from Uline.  Kapton is the material used to hold thermal insulation together on real satellites.  Space blanket, on the right side, is another covering material for BalloonSats that will help to give yours a real spacecraft look.**

### 2.0.1 Dimensions of Airframe

First layout the contents of your BalloonSat, then position each item as you want it organized inside the BalloonSat.  Take your time and make sure each component will work well in its place and not interfere with each other.  Sensors that need to sample the outside environment must be located next to the wall of the airframe and cannot be buried inside.  Items that need to be manipulated shortly before launch must to be easily accessible from the hatch of the BalloonSat and not buried deep inside the airframe either.

Once you're happy with the placement of components, measure their outside dimensions. The BalloonSat you'll now design must have an interior volume large enough for the arrangement you just measured.

Before drawing the sides of the airframe, remember that the Styrofoam has a thickness of ½ inch.  Also plan for the hatch, which must cover one entire side of the airframe.  It can't close the top or bottom of the airframe. Now draw and cut out the sides. A simple cubic BalloonSat will have an arrangement of sides as illustrated below.

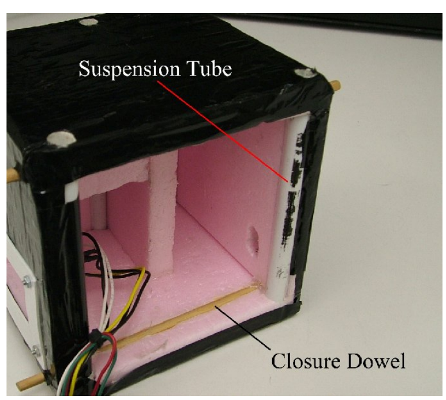


**An opened airframe displaying a recommended placement of sides.**

Don't start gluing the sides together yet; test fit them to make sure they were cut correctly. The only side that should be a little larger than necessary is the hatch, as you'll trim it to the proper size after the airframe is glued together.

### 2.0.2 Channels in the Sides

Before gluing can begin, you must cut channels in the Styrofoam sides for the suspension tubes and the closure dowels. Remember that the suspension tubes are vertical hollow plastic tubes and the closure dowels are horizontal (usually) wooden dowels. A BalloonSat should have four suspension tubes for stability and two closure dowels for security. However, these numbers can change depending on the near space group carrying your BalloonSat and the volume of your BalloonSat. Place the vertical plastic tubes and horizontal wooden dowels so that they won't cross each other. The photograph below shows one possible arrangement.




**The closure dowels reside further inside this BalloonSat airframe than the suspension tubes. Because of this, the dowels don't pass through the tubes.**

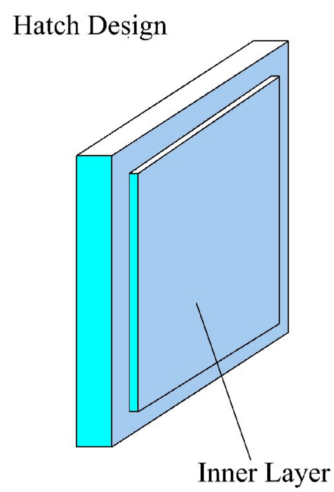
Draw the outline of the channels on the Styrofoam to guide your cutting. Then either cut shallow slits into the Styrofoam no deeper then the diameter of the tube and dowel and push a square channel tube through or push and twist a sharpened metal tube along the surface of the Styrofoam. Double check the depth and diameter of the channels to make sure the tubes and dowels fit properly. However, do not glue the tubes or dowels in place yet.

**2.0.3 Gluing the Airframe Together**

Hot glue is the glue of choice. However, since hot glue can melt Styrofoam, watch the glue gun's temperature on a regular basis. When it gets too hot and begins melting the Styrofoam, unplug the glue gun to let it cool. You can still use the glue gun while the glue cools if you monitor the glue temperature well. Check the fit of your pieces before gluing them together. Now assemble the airframe body, but not the hatch, at this time.

**2.0.3.1 Making the Hatch**

The hatch needs an inner layer that fits snuggly inside the opened airframe, so cut a sheet of Styrofoam to fit the opened airframe. Check the fit once again. Now glue this piece of Styrofoam on the center of the hatch. After the glue cools, close the BalloonSat airframe with the hatch and mark the edges of the airframe on the hatch. After removing the hatch you can trim it along the lines. In place of ½" thick Styrofoam, you can use thinner foamcore for the hatch's inner layer.




**2.0.4 Covering the BalloonSat**

The easiest way to add color to the exterior of a BalloonSat is with colored tape. To minimize the BalloonSat's final weight, use a thin colored poly tape like color-coding or Styrofoam glider tape. Don't use colored duct tape as it adds needless weight. The same applies to aluminum duct tape. It looks nice, but adds unneeded weight.

The tape strips should be long enough to go around three of the sides of the airframe plus a bit longer so they end and begin inside the airframe. Apply each strip of tape with a little overlap between strips. Rub down the tape to ensure it has a good contact with the Styrofoam.

### 2.0.5 Suspension Tubes and Closure Dowels

Measure the length of the airframe where the plastic suspension tubes will fit. Cut the tubes to that length and sand their cut edges slightly to remove burrs. Use an Exacto knife to cut out holes in the tape where it covers the openings to the channels. A little hot glue on the plastic tube is enough to hold it after sliding it into the airframe. Don't use very much glue though, it will ooze out of the channel as you slide the tube in and make a mess that needs to be cleaned up.

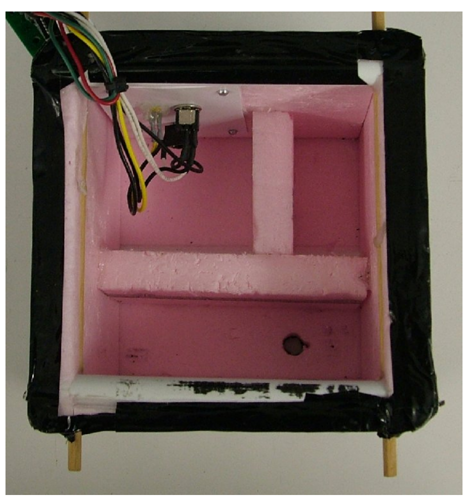
The closure dowels need to be cut one inch longer than the dimension of the airframe where they will be inserted. That way the dowels will protrude ½ inch from the airframe, long enough for the rubber bands. After cutting the dowels, sand their ends slightly to round them. Use either white glue or hot glue to hold the dowels in place. After the dowel is glued you may want to add additional hot glue around the dowel where protrudes from the airframe. A small bead of glue will help protect the exposed edges of the tape around the dowel.

## 2.1 Variations in Design

Here are four modifications you might find useful for your BalloonSat.

### 2.1.1 Internal Shelves and Dividers

An experiment that needs support or separation from another experiment will benefit if there's shelves inside the BalloonSat airframe. Glue the shelves and dividers directly to the interior walls of the airframe after the airframe has been glued together. This is another good use for foamcore.



**An example of a shelf and divider inside a BalloonSat.**

### 2.1.2 Multilayer Insulation

Multilayer insulation (MLI) is the material used to insulate real spacecraft. A jacket of MLI acts like a lightweight and unbreakable Dewar or thermos bottle. Space certified MLI is very expensive, on the order of one dollar per square inch. However, you can make an inexpensive substitute.  While MLI works best in a hard vacuum found in space and won't be as effective in near space, it's still fun to make.

You'll need the following materials to make MLI
Sewing machine
One package of space blanket
One yard of plastic wedding veil material
Kapton tape, 1/4 inch wide *

*Kapton tape is available from Uline (www.uline.com) as product S-10518

MLI consists of alternating layers of aluminized mylar and scrim.  The aluminum coating on the Mylar reduces cooling by radiative cooling by reflecting thermal radiation back into the BalloonSat.  Scrim minimizes cooling by thermal conduction by creating a physical separation between the layers.  The near vacuum between the layers reduces the loss of heat by convection.

Make your MLI jacket by sewing alternating layers of Mylar and scrim together.  The layers should begin with a Mylar layer on  bottom and end with a Mylar layer on top.  Cut each layer the same shape that will fold properly to cover the airframe.  However, the top layer of Mylar needs to be cut a little larger so its edges can fold over the bottom layer of Mylar.  Cutting MLI layers should remind you of making paper polyhedrons in middle school.  After cutting the layers out, stack the alternating layers of space blanket and wedding veil material and then fold the edges of the top space blanket layer over the bottom layer.  Hold the stack together and run it through a sewing machine.  Only sew around the edges, there's no need to sew through the middle of the stack.  When they're sewn together, you'll have a durable thermal blanket that won't come apart.

Sew a second MLI jacket for the hatch, but in this case, the MLI is shaped to wrap around the face and sides of the hatch with a little bit protuding inside the hatch.

Now you can wrap the MLI around the airframe and use Kapton tape to hold it together.  When complete, the BalloonSat airframe will look more like a professionally built satellite.

**2.1.3 Ports**

Some experiments need to sense or see the world outside the airframe.  Examples include temperature and relative humidity sensors and cameras.  Ports are the openings in an airframe for these types of experiments.  If they're needed, they must be cut before the airframe is covered.  Begin making a port by marking its placement on the airframe with a pencil.  Use a T-square if you want the openings to be square.  Cut the port opening with a sharp Exacto knife and sand the edges if they're too rough.  For camera ports, paint the exposed edge of the port with black plastic model paint or a black felt tip marker to reduce the glare.

**2.1.4 External Sample Holders**
Some experiments need complete exposure to the near space environment. For these experiments, a plastic coin tube makes an excellent holder. The tubes have screw-on caps, so they're easy to open and close. And since they're transparent, their contents can easily be observed. One way to use a plastic coin tube is to glue a Styrofoam shelf to the outside of the BalloonSat that the coin tube can sit on. By inserting additional dowels in the airframe, rubber bands can secure the tube to its shelf.

Alternatively, a hole large enough for the plastic coin tube can be drilled into the airframe. Then the tube can be inserted into the BalloonSat with al least its cap protruding outside the airframe. Be sure the hole is just large enough for the tube as it must be snug so the tube won't fall out on its own.

**2.2 Completing the Airframe**
Just in case your BalloonSat is separated from the rest of the near space shuttle during its mission, put a label on the airframe with your name and phone number. The suspension lines should never break, but accidents can happen. With a name and phone number on your BalloonSat, there's at least a chance it will be returned. The label can be made with a label maker or PC printer and then covered with transparent tape.

Now close hatch and wrap rubber bands over closure dowels and hatch. You have a completed BalloonSat airframe ready for loading your experiments.