CHAPTER SIX

Near Space Recovery Systems

> ***"What happens to the parachute if it rains?"***
> ***"It gets wet."***
> ***- Conversation with a fourth grader***

Chapter Objectives

1.0 Recovery Requirements

FAR 101, the Federal Aviation Regulation Section 101 that governs untethered balloon flight, requires that we fly near space flights in π such a manner that they are not a hazard to uninvolved persons and their property. Because a basic near space capsule costs at least $500 in parts, you have an additional incentive to recover it without damage. A latex balloon with sufficient helium is guaranteed to burst, so a recovery system guaranteed to operate is vital. This chapter explains how to construct (or purchase, if you want to go that route) the most popular recovery system, the parachute. Specifically, the hemispherical parachute is discussed. In addition, a means to terminate a flight and initiate recovery is also described. Note that a flight termination system is not required for the basic near space mission, but it can prevent the loss of a near space capsule when something goes wrong, like the balloon becoming neutrally buoyant, events which have occurred on Balloons Over Idaho (BOI) and Sky Science Over Kansas (SSOK) missions.

1.1. The Parachute

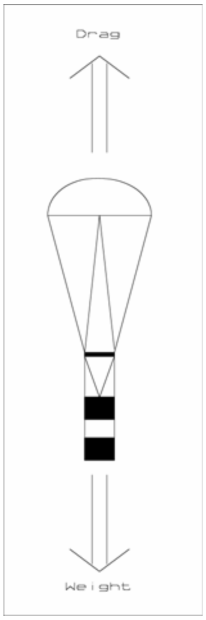
The simplest and most frequently used recovery device is the parachute. The balloon carries the parachute by its apex, which places the parachute in a position where it opens immediately upon balloon burst. A length of load line (about 30 feet long) separates the parachute from the balloon. Once the balloon bursts, we want what's left of the balloon to drop over the side of the parachute, rather than on top of it. A load line this long ensures this will occur. In near space the air is too thin for an opened parachute to break the capsule's descent very much. Even though the near space capsule is descending faster than 100 mph, the parachute is opened and ready to recover the near spacecraft at a safe speed.

A near spacecraft and its recovery parachute, a beautiful thing to see.

There are several requirements for a parachute. First, the parachute must be large enough to slow down the descending capsule to a safe landing speed. Second, the parachute must be constructed of materials that are not porous to the wind or stiff in the very cold temperatures of near space. Third, the parachute must be durable and must limit the size of any rips or snags put in the canopy. Fourth, it must be made of materials insensitive to UV exposure. Finally, it should be constructed of bright colors that can be seen from the ground, and that contrast with any landscape where it might recover.

2.0 How the Parachute Works

The parachute design in this chapter is a hemispherical cap that creates drag by catching moving air. A descending capsule travels at a terminal velocity that occurs when weight (always pointed down at the center of the Earth) is opposed by the same amount of drag (which always opposes the direction of movement).



There are two opposing forces acting on a descending near spacecraft, weight pulling down and drag pulling up. When the forces are equal the near spacecraft falls at a constant speed.

The force of weight is given by the equation,

$$\mathbf{W = m*g}$$

Physics, Halliday and Resnick, John Wiley and Sons, 1978.

Where m is the total mass of the descending equipment (balloon, capsules and parachute) and g is the acceleration due to gravity (which changes by 1% in middle near space, but can be treated as a constant in this case).

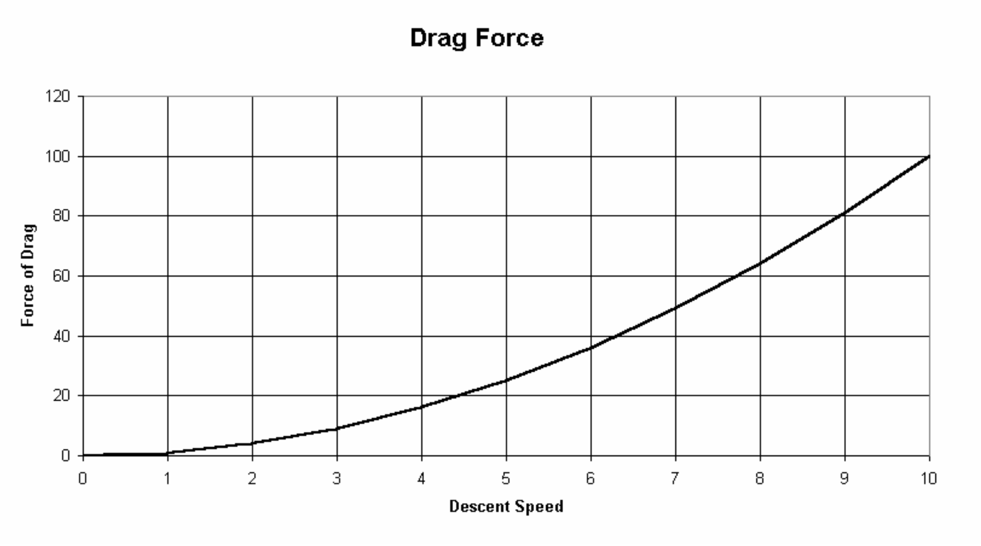
The drag created by a parachute is given by the equation:

$$\mathbf{F_d = C_d * A * d_m * (v^2/2)}$$

Encyclopedia of Physics, Lerner and Trigg, VCH Publishers, 1990.

Where C_d is the coefficient of drag (a dimensionless constant) of the parachute, A is the area of the parachute exposed perpendicularly to the air during descent, d_m is the density of the air the parachute is traveling through (and very nearly equal to the pressure), and v is the velocity the parachute is moving through the air. Of these factors, the coefficient of drag and area of the parachute are constants for a given parachute.

At balloon burst, the payload begins descending with increasing downward speed. Fortunately for the payload, the amount of drag generated by the parachute increases faster than the speed of descent increases. This is because drag depends on the square of the speed. Therefore, if you double the speed of descent, the amount of drag created by the parachute increases by a factor of four. This applies to more than parachutes; it's true in general for all objects falling through a fluid media (however, I wouldn't be surprised to see that this relationship doesn't hold at extremely high speeds).



The force of drag depends on several factors. The one of most interest to us is its dependence on the square of velocity. Double the speed, and the force of drag increases by four times.

At some velocity, the drag equals the force of gravity pulling the payload down. At this point there is no net force (remember, the force of weight acts in the opposite direction as the force of drag). When there is no net force acting on the parachute, the parachute no longer accelerates and falls at its terminal velocity. Dense bodies tend to fall with a greater terminal velocity than less dense objects because the higher density body has more mass per exposed surface area. The denser body has a greater ratio of weight pulling it down to surface area slowing it down. To increase the ratio of surface area to mass of a descending near spacecraft, we use parachutes as recovery devices.

In near space there is one more complication that we don't usually concern ourselves with here on the surface. In addition to surface area, the drag also depends on air density. If the air density doubles, so does the drag experienced by a moving object. Increasing the altitude decreases the air pressure, and therefore the air density. For a falling body, its terminal velocity decreases as it approaches the ground.

The terminal velocity of a body can be calculated by equating the force of gravity to the force of drag. By rearranging the terms, we end up with the following equation for terminal velocity.

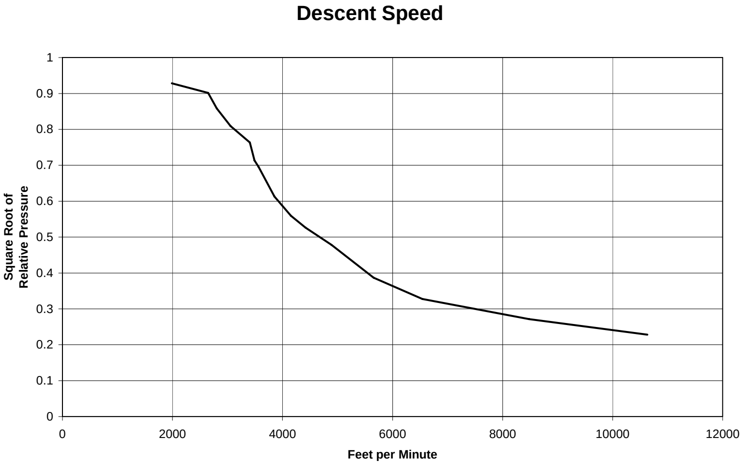
$$\mathbf{V_t = [2*W/C_d*d_m*A]^{1/2}}$$

In this case we see that every term in this equation is a constant except for air density. We therefore conclude that the terminal velocity of a falling body is proportional to the square root of the air density. A graph of air density compared to air pressure as a function of altitude shows that the terms air pressure and air density are closely proportional to each other. We get similar results if we substitute air pressure for air density.

As far as a descending parachute is concerned, it is descending through the air at a constant speed. This speed is called the Indicated Air Speed (IAS) and is affected by the mass of the air passing by the parachute in a given amount of time. Air mass is influenced by the air's density, and since air density depends on the altitude, the IAS is also influenced by altitude. The speed at which the parachute descends through the air relative to the ground is called the True Air Speed (TAS). The TAS is equal to the IAS only at sea level, where the air pressure is approximately one bar. At higher altitudes, and therefore at lower air density, the IAS is greater than the TAS by a factor of the inverse square root of the air density. So if the air density is 1/4 of its value at sea level (this occurs at an altitude of 36,000 feet), the IAS is $1/1/[4]^{0.5}$, or twice as great as the TAS.

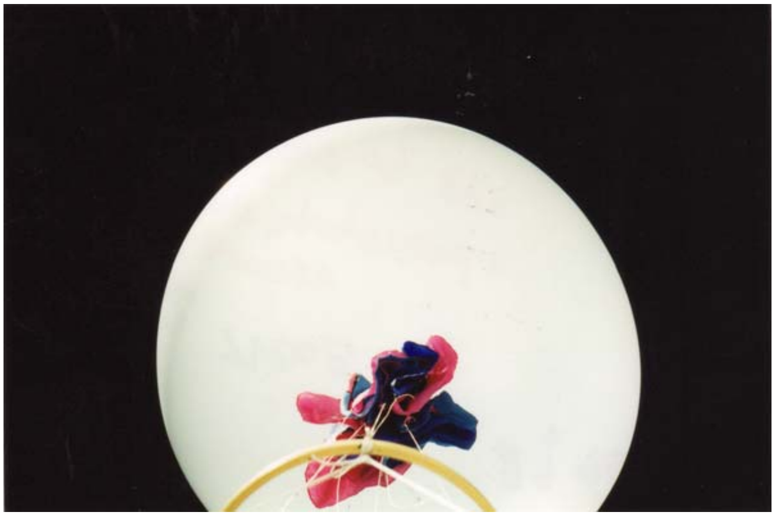
As another example, suppose a parachute lands a payload at 22 ft/sec (TAS of 22 ft/sec). At 100,000 feet where the air pressure density is only 10 millibars, or 1% of surface air pressure, or 1/100th of sea level pressure, the parachute descends at a speed ten times greater than it does at sea level, or at 220 ft/sec. So do not be alarmed when you see your near spacecraft at 100,000 feet begin its descent at a speed of 145 mph. But do be alarmed if the descent speed continues to be 220 feet/minute below altitudes of 50,000 feet. Note: Changes in air density closely match changes in air pressure. If air pressure is substituted for air density, the calculated descent speeds are almost identical.

Let's look at another example. I've taken data from one of the TVNSP flights that reached an altitude of 90,000 feet before the balloon burst. Entered in a spreadsheet are the altitude, UTC time, and air pressure according to the Standard Atmosphere model. A graph was generated from the descent speed at altitude and the inverse square root of the air pressure at altitude (times a constant scaling factor). The resulting graph is illustrated below. Notice that the inverse square root of air density tracks the TAS of the parachute almost perfectly.



Altitude vs. Descent Speed -
Due to the extremely low air pressure in near space, the initial descent speed of the near spacecraft can be ten times higher than at sea level.

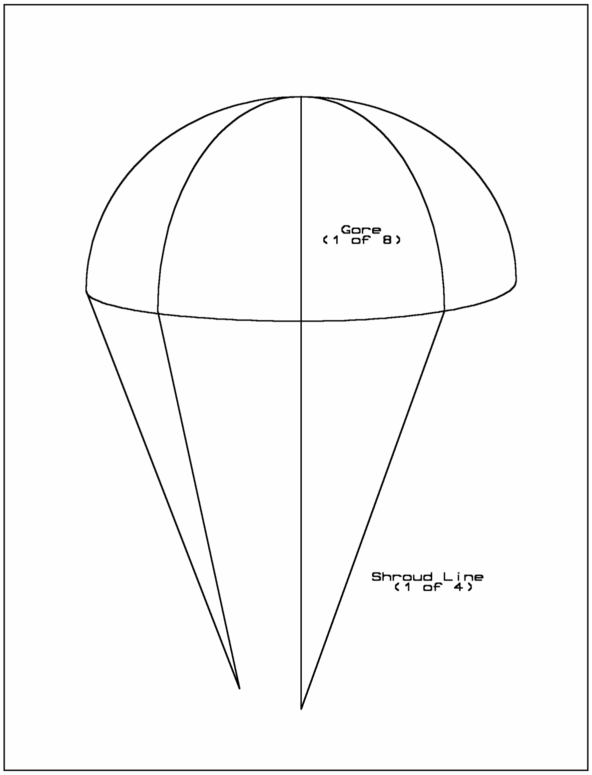
The author recommends you generate a similar graph or table from your first flight data and laminate it. The graph or table should be left with Mission Control so they know what kind of speeds to expect during descent. Seeing a fast descent for the first time puts people into a panic.



Before balloon burst -
The parachute and balloon shortly before balloon burst. The parachute drapes below the balloon. Note how black the sky is and that the parachute is not experiencing any wind.

After balloon burst -
The parachute shortly after balloon burst. It appears that some of the balloon remains are wrapped around the parachute ring. At this point, descent speed is around 100 mph!

3.0 Making a Hemispherical Parachute



The hemispherical parachute -
Imagine cutting a ping-pong ball in half.

A simple sheet of fabric can make a parachute (as well I remember when I was in grade school) but is wasteful of material. The hemispheric parachute is a simple design and efficiently uses the fabric it is constructed from. Expect to spend about $75 making a seven-foot parachute. If time is more important than money, or if the handcrafting a parachute doesn't appeal to you, then purchase a complete parachute from a high-power rocket company, like RocketMan. Check the list of suppliers at the end of the book for recommendations.

As the hemispherical parachute descends, air pressure builds up inside of it and eventually escapes. In the simple hemispherical parachute, built-up pressure escapes from under the parachute's canopy by forcing the parachute to rock or tip from side to side. One way to reduce this tendency to rock back and forth is to cut a spill hole in the top of the parachute. Spill holes keep the pressure from getting so high that the parachute has to rock from side to side to release it. The spill hole needs to be about 20% the diameter of the parachute.

3.1. Materials

- Canopy fabric, amount depends on parachute diameter (16 yards should be the maximum) Note: More than one color of fabric can be used on the parachute canopy.
- A 150 foot roll of 150# test woven Dacron[A] kite line
- 50 feet of ½" twill tape (for a seven-foot parachute)
- Four or five sheets of poster board
- Eight bearing swivels, 100# test
- One bearing swivel, 200# test
- Cotton thread
- Colored pencil in a color that contrasts with the canopy color
- Fabric label or fabric marker
- Scissors or soldering gun with a cutting tip

3.1.1. Notes on Parachute Fabrics

I recommend making the parachute out of ripstop nylon, the kind found in local fabric stores. This material is coated with a water repelling film, making it less porous to the air, but still supple and flexible. Kite fabrics have a "harder" coating to them, making them more crinkly. The lower porosity of the fabric means a smaller parachute is required to slow the near space capsule down. In addition to reducing fabric porosity, the urethane coating also protects the ripstop nylon from damage due to UV exposure (which is at greater levels in near space). Being a ripstop fabric, the growth of rips and tears in the parachute canopy is reduced by the thicker threads woven into the fabric. Finally, ripstop nylon is readily available and dyed in many bright colors. Use a combination of several different colors of ripstop when making the parachute so it has the best chance of standing out. If you decide to use a single color, then think about using a florescent color to increase the parachute's visibility. If the cost of ripstop fabric (about $7/yd) is a concern, then another source of parachute canopy material is a retired hot air balloon envelope. After 500 hours of use, the FAA requires that these fabric envelopes be replaced. You can purchase a lot of ripstop this way on a budget. If you decide to use balloon material, you'll have fewer color options. You'll also have to wash the fabric several times to get the gas smell out of it.

3.2. Procedure - Determine the parachute's diameter

Notes on Parachute Diameter

The equation below is typical of parachute formulas used in model rocketry. It calculates the diameter of a circular parachute (flat sheet of round fabric) based on the weight of the payload to land at 15 mph and a typical coefficient of drag.

$$\text{Diameter (inches)} = [\text{weight (pounds)} * 0.454]^{1/2} * 39.6$$

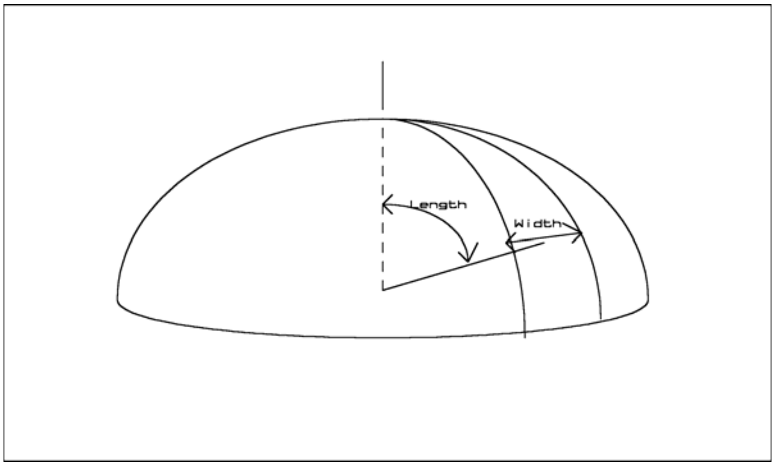
From http://www.info-central.org/recovery_psize.shtml

I modify the results by assuming the calculated diameter is actually half of the circumference of a sphere. So multiply the results by $\pi/2$, or about 1.5 to determine the diameter of the hemispherical parachute. The results match the diameter of the hemispherical parachute I currently use. One factor has a big influence on the accuracy of an equation like the one above. That is the porosity of the fabric being used to make the canopy. If a “leaky” fabric (with a higher porosity) is used, then increase the diameter of the parachute.

For most cases, assuming a payload weight of 13 pounds is sufficient. Why 13 pounds? Because you can assume the parachute weighs one pound, which must be added to the near space capsule weight of 12 pounds.

Making a Parachute Gore Pattern

The parachute described here is a simple hemispherical cap made from eight identical gores. To increase the parachute’s stability, there is a hole in the top of the parachute to vent excess pressure inside the canopy. The vent is 20% of the parachute's final diameter. The pattern for this hemispherical parachute was calculated by dividing a hemisphere into 90 rings, each one-degree thick. The diameter of each ring with respect to the central axis of the parachute is proportional to the angular elevation of each ring. From this the diameter of each ring was calculated. Next, from the calculated diameters, the circumference of each ring was determined. At this point the distance of the ring from the apex of the parachute and its circumference has been determined. Divide each circumference by eight (the number of gores) and the width of the gore at each point has been determined. Add a little billow to the parachute by adding another 5% to 10% to the gore width.



Gore dimensions are calculated by measuring the width and length of pie-shaped wedges cut out of a hemisphere.

3.2.1. Generating Your Own Pattern

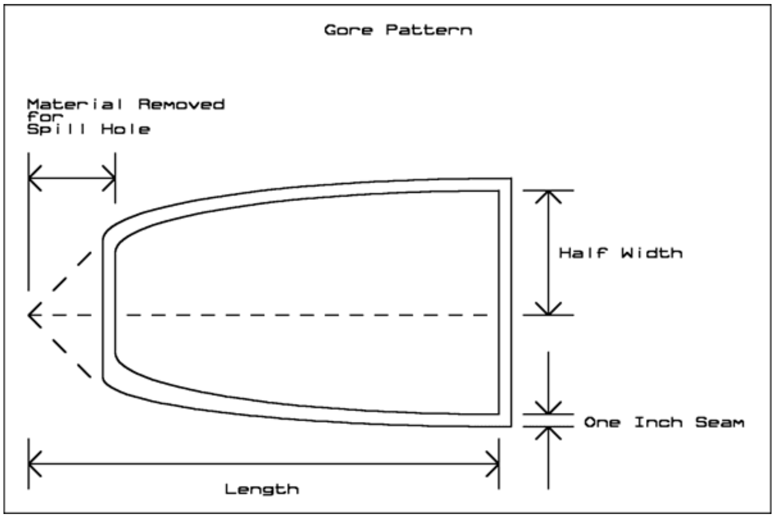
If you wish to design your own parachute using your own spreadsheet program, the commands I used are shown below.

Spreadsheet Commands

	A	B	C	D	E	F
1	Diameter	(feet)				
2						
3	Degrees	Radians	Radius of Ring	Half Width of Gore	Length along Gore	Half width of Gore
4			units	units	inches	inches
5						
6	1	= +A6/57.3	= SIN(B6)	= (+C6*3.14159)/8	= (+A6*C1)*0.105	= (+D6*C1*6)+1

Procedure
Enter the diameter of the parachute to design in cell C1 (diameter in feet). Column A values begin at one degree (cell A6) and increments in units of one degree until the angle of 90 degrees is reached. Remember, the number generated in column F is half the width of the gore at the distance down the center of the gore indicated in column E.

Before cutting parachute gores out of fabric, a pattern in poster board is needed. The poster board pattern is placed on top of a sheet of fabric and the outline of the gore traced in pencil. Then the fabric can be cut into eight near identical gores. Several pieces of poster board are needed to make a gore pattern. The maximum dimensions of the gore pattern determine the number of sheets of poster board required to make a gore pattern. Tape the poster board sheets together to make a single sheet large enough to fit the pattern. Draw a straight line down the center this sheet of poster board. Mark along the length of this centerline at every point listed in column five of the spreadsheet. Draw a perpendicular line from each marked point that extends both directions away from the centerline. Mark a distance on the perpendicular line equal to the distances indicated in column six of the spreadsheet. Every 15th line, make an extra dot near each end to indicate where seam-matching marks will be transferred to the fabric. Ignore the spreadsheet values where the angle is less than about 9 degrees, as that is the location of the spill hole. You can use your spreadsheet's graphing ability to take a peek at the final pattern, but remember the graph will not by default print the X and Y-axis to the same scale. Your final pattern should look similar to this one below.



The pattern for a single gore. Make eight of them.

Before cutting the poster board pattern, add a one-inch seam allowance to the top and bottom edge. There already is a one-inch seam allowance included on the sides.

3.2.2. Tables of Gore Patterns

If you would rather not calculate your own gore pattern, I have included several calculated gore patterns below. Add a one-inch seam allowance all the way around the dimensions given below.

Six Foot Diameter Parachute			
Length (in.)	**Half Width (in.)**	**Length (in.)**	**Half Width (in.)**
0.0	4.3	27.6	24.8
1.3	5.3	28.9	25.5
2.5	6.4	30.6	26.2
3.8	7.5	31.4	26.8
5.0	8.6	32.7	27.4
6.3	9.6	33.9	27.9
7.5	10.6	35.2	28.5
8.8	11.6	36.4	29.0
10.1	12.7	37.7	29.4
11.3	13.6	39.0	29.8
12.6	14.6	40.2	30.2
13.8	15.6	41.5	30.6
15.1	16.5	42.7	30.9
16.3	17.5	44.0	31.2
17.6	18.4	45.2	31.4
18.8	19.3	46.5	31.6
20.1	20.1	47.7	31.8
21.4	21.0	49.0	32.0
22.6	21.8	50.3	32.0
23.9	22.6	51.6	32.1
25.1	23.4	52.8	32.1
26.4	24.1		

Seven Foot Diameter Parachute			
Length (in.)	**Half Width (in.)**	**Length (in.)**	**Half Width (in.)**
0.0	4.8	32.2	28.8
1.5	6.0	33.7	29.6
2.9	7.3	35.2	30.4
4.4	8.5	36.6	31.1
5.9	9.8	38.1	31.8
7.3	11.0	39.6	32.4
8.8	12.2	41.0	33.0
10.3	13.4	42.6	33.6
11.7	14.6	44.0	34.1
13.2	15.8	45.4	34.6
14.7	16.9	46.9	35.1
16.1	18.0	48.4	35.5
17.6	19.1	49.8	35.9
19.0	20.2	51.3	36.2
20.5	21.3	52.8	36.5
22.0	22.3	54.2	36.7
23.5	23.3	55.7	36.9
24.9	24.3	57.2	37.1
26.4	25.3	58.6	37.2
27.9	26.2	60.1	37.3
29.3	27.1	61.6	37.3
30.8	28.0		

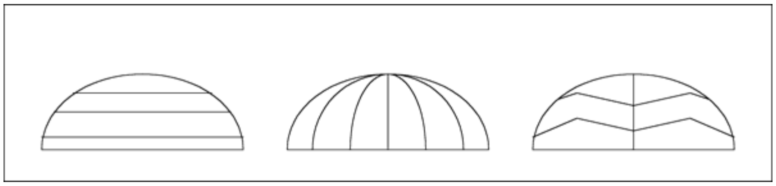
Eight Foot Diameter Parachute

Length (in.)	Half Width (in.)
0.0	5.3
1.7	6.8
3.3	8.2
5.0	9.6
6.7	11.0
8.4	12.4
10.0	13.8
11.7	15.2
13.4	16.5
15.1	17.9
16.8	19.2
18.4	20.5
20.1	21.7
21.8	23.0
23.5	24.2
25.1	25.4
26.8	26.6
28.5	27.7
30.2	28.7
31.8	29.8
33.5	30.8
35.2	31.8
36.9	32.8
38.5	33.7
40.2	34.6
41.9	35.4
43.6	36.2
45.2	36.9
46.9	37.6
48.6	38.3
50.3	38.9
51.9	39.4
53.6	40.0
55.3	40.4
57.0	40.9
58.6	41.2
60.3	41.6
62.0	41.8
63.7	42.1
65.3	42.2
67.0	42.4
68.7	42.4
70.4	42.5

Transfer the desired gore pattern to poster board. Every 15th line, make an extra dot near each end to indicate where seam-matching marks will be transferred to the fabric.

Note: If you don't want to make 90 separate measurements on the gore, throw out every other one; the result should be just as good. Be sure to make as many seam-matching dots.

Note: There's no reason the gore has to be in a single piece. The gore pattern can be cut into two pieces, and a different color of fabric used on each piece. Be sure to include an extra seam allowance where the panels overlap and extra twill tape to sew over the extra seams.



Some possible parachute patterns.

Transferring Gore patterns to Fabric

Align the poster board pattern along the major threads in the ripstop.

Trace the gore pattern on to the fabric with a contrasting colored pencil. Make an extra mark on the fabric on each side at every location where you indicated seam-matching dots on the pattern, about ½ inch in from the edge. Trace a total of eight gores onto the fabric.

Cutting the Fabric

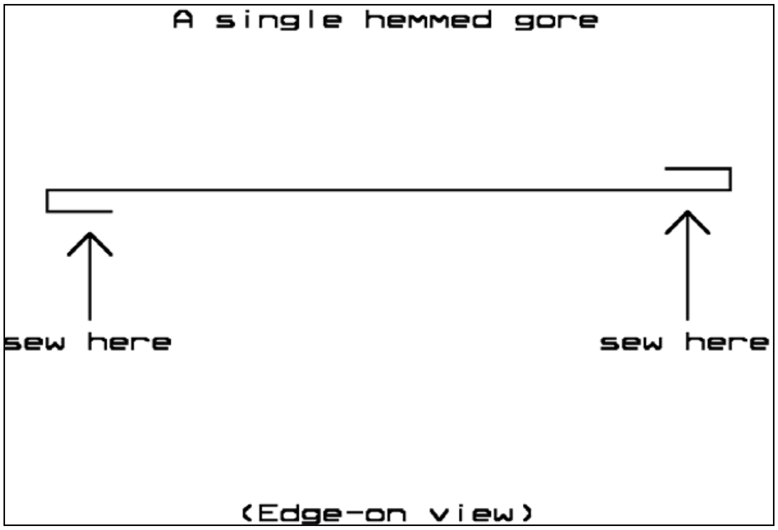
To cut the gores out of the ripstop nylon, it's best to use a hot soldering iron equipped with a cutting tip. The hot tip melts the nylon threads of the fabric together, keeping the fabric from unraveling.

Sewing the Gores into a Canopy

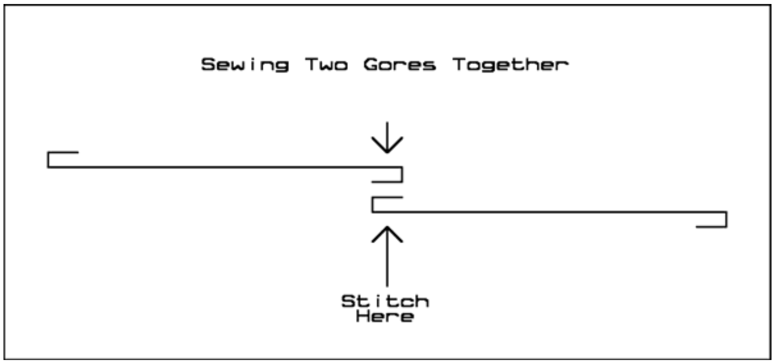
Note: I am not a seamstress; so if you're an expert, please do not get upset with my sewing directions. At the time of this writing I have constructed five parachutes successfully and experienced no failures. No doubt there is a better way to construct a parachute than I am describing here (sounds like another topic for a sequel to this book).

Sew the parachute with a strong cotton thread and use a needle with an eye to match the diameter of the thread. Lock the beginning and ending of each seam by backstitching a few times, running the sewing machine briefly in reverse each time.

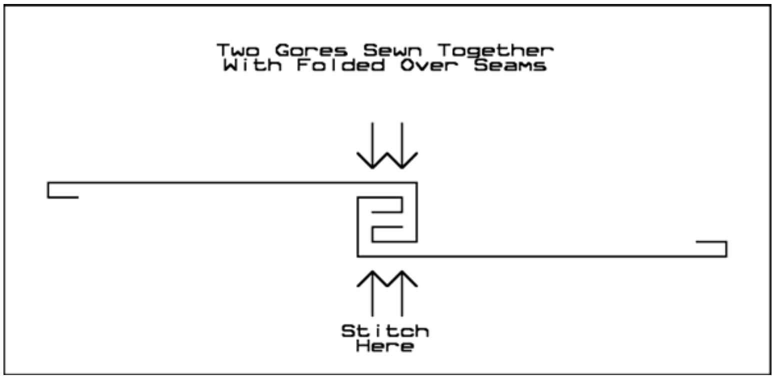
- √ Draw a line ½" from the edges of the long sides only on each gore.
- √ Fold the fabric along these lines, folding the right-side edges up and over and the left side edges down and under. You may run a fingernail along the seam as you fold to "iron" in the creased hem.
- √ Sew these folded hems in place with a single line of stitching on each gore.
- √ Take two gores and overlap their hemmed edges, with a down-folded hem facing an up-folded hem so the seam allowances are sandwiched in between.
- √ Align and pin the top and bottom edges of the two gores, and also align and pin the seam-matching marks you made.
- √ Sew down the middle of the overlapping edges. You will be sewing through four layers of fabric. Pull out the pins as you approach them; try to avoid sewing over pins.
- √ Rotate the sewn seam by 180 degrees, interlocking the folded seams. You may use pins to keep the seam rotated and taut.
- √ Sew down the interlocked seams. You will now be sewing through six layers of fabric.



Overlapping seams before sewing them together.



The top and bottom seams of the sewn parachute canopy.

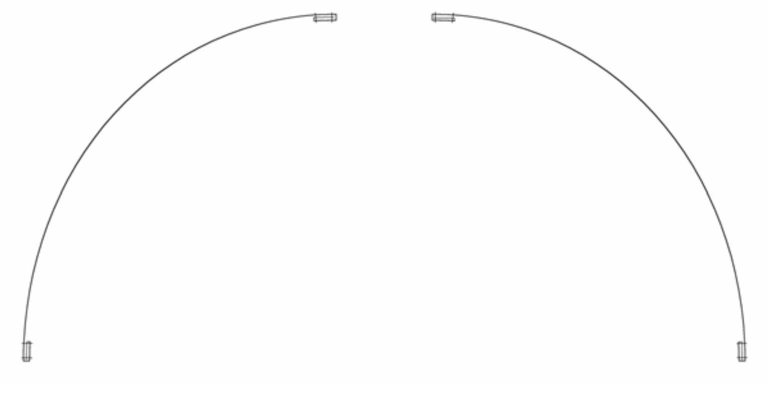


Rotated Seams - Interlocked

Add the next gore in the same fashion, until all the gores are sewn together to form a single sheet. Close the parachute by sewing the first and last gores together. If you're like me, the edges of the canopy will not line up. In this case, I start the seam at the spill hole first and make that my reference.

Top and Bottom Seams of the Parachute

Trim the top and bottom edges of the parachute canopy to make even edges all the way around. Hem the top and bottom edges by folding the edge over by ½ inch and sewing it down, then turning this hem by ½ inch again and sewing through all three layers. The doubled over seams protect the raw edges of the fabric from the force of the passing air during descent and add strength to the parachute's edges.



X-Ray View of Top and Bottom Parachute Seams

Twill Reinforcement

The eight gore seams of the parachute canopy will be overlaid with twill tape. The twill tape will add reinforcement to the seams, and will also form loops at the bottom edge of the canopy where the shroud lines will connect. Only four pieces of twill tape are used, each covering one seam, crossing over the spill hole, then covering the seam directly opposite. Therefore, you will need to cut four strips of 1/2" wide twill tape to a length that begins at one end of the parachute, crosses over the top (apex) and back down to the opposite side, plus an additional twelve inches for shroud line loops.

Twill tape

- √ To calculate the required length, multiply the radius (one half the diameter) of the parachute by π and add twelve inches.
- √ Cut four lengths of ½ inch twill tape to the calculated length.
- √ Mark each tape at four inches and at six inches from each end. Note: Ideally, the six-inch mark on the twill tape will align with the bottom edge of the canopy. The four-inch mark is where the twill doubles back on itself and gets sewn to the underside of the canopy
- √ Use the gore pattern to determine the radius of the canopy's spill hole.
- √ Find and mark the center of each tape.
- √ From the center of each twill tape, place two diameter marks on the twill tape at a distance equal to the spill hole radius plus an additional couple of inches for slack. Note: These marks are where the twill tape begins to be sewn to the canopy.

The table below gives the expected spill hole radii. However, since sewing skills vary, the diameter of the spill hole never comes out as expected. The better your sewing skills, the less slack the twill tape requires. The author recommends two inches of slack for the first parachute (the excess is tied off at a later time).

Parachute Diameter	**Spill Hole Radius**
5 ft	4.7 in.
6 ft	5.6 in.
7 ft	6.5 in

Note: A second method to determine the placement of the diameter marks is to measure the current diameter of the spill hole. To do so, grab two opposite ends of the spill hole and pull them a part as far as they will go. This collapses the spill hole. Measure the distance between the extreme points, which is half the circumference of the spill hole. Divide this distance by π to calculate the radius of the spill hole.

- √ Lay the tape on top of the canopy and over a seam (between two gores).
- √ Align the spill hole radius markings with the top edge of the canopy.

- √ Starting at the spill hole, sew along one edge of the twill tape.
- √ About 4 inches before sewing to the edge of the canopy, fold the end of the twill tape two inches past the edge of the canopy. Ideally, the edge will line up with the six-inch mark, and you can fold the tape under at the 4 inch mark.
- √ Align the end of the tape with the underside of the seam.
- √ Continue sewing the twill tape to the end of the canopy, making sure you sew the end of tape to the underside of the canopy. This will leave a two inch loop at the bottom of the canopy.
- √ Turn the canopy around and continue sewing up along the other edge of the twill tape, returning to the beginning position at the edge of the spill hole.
- √ Examine the twill tape loops at the bottom of the canopy to make certain that the ends are secured firmly underneath. It the tape spilled out of place and was not sewn down properly, resew the ends of the twill tape from the inside.
- √ Reinforce the area were the twill tape meets the edge of the canopy at top and bottom by sewing crosswise over and slightly beyond the tape several times.
- √ Repeat for the three remaining twill tapes.

Twill tape after being sewn to canopy.

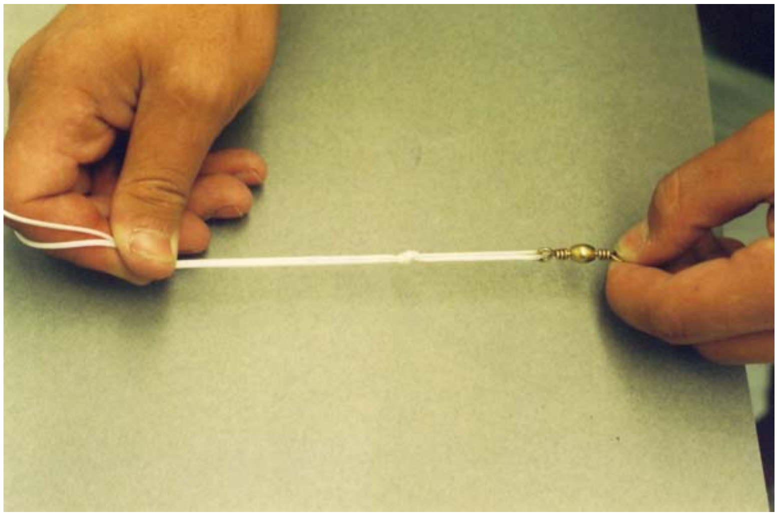
- √ Gather together the twill tapes at the top of the canopy (over the spill hole).
- √ Align the center marks of each tape.
- √ Cut a twelve-inch length of woven Dacron kite line and tie on a strong, 200# bearing swivel in its center.
- √ Tie the other ends of the line around the center of the twill tapes.
- √ Take out the slack in the twill tapes by tying a knot in the twill tapes between the bearing swivel and spill hole edge. The position of the knot depends on the amount of slack in the twill tape, so be prepared to experiment with the knot placement.

3.2.3. Shroud Lines

Each shroud line begins at twill loop on the canopy, drops to a bearing swivel at the parachute ring, and returns to the next twill loop on the canopy. Shroud line knots are covered with heat shrink tubing to reduce the chances of the knot from coming undone. Make the shroud lines from 150# woven Dacron kite string. Use kite line rather than purchasing the twisted nylon cord, as the woven kite line stays together as a unit better than the twisted cord does.

- √ Cut four shroud lines, each with a length four times the parachute's diameter.
- √ Mark the center of each shroud line.

- √ Run the shroud line through one loop of a 100# bearing swivel.
- √ Center the mark in the loop and tie an overhand knot, trapping the bearing swivel inside the loop formed by the knot. The bearing swivel will be used to attach the parachute ring.



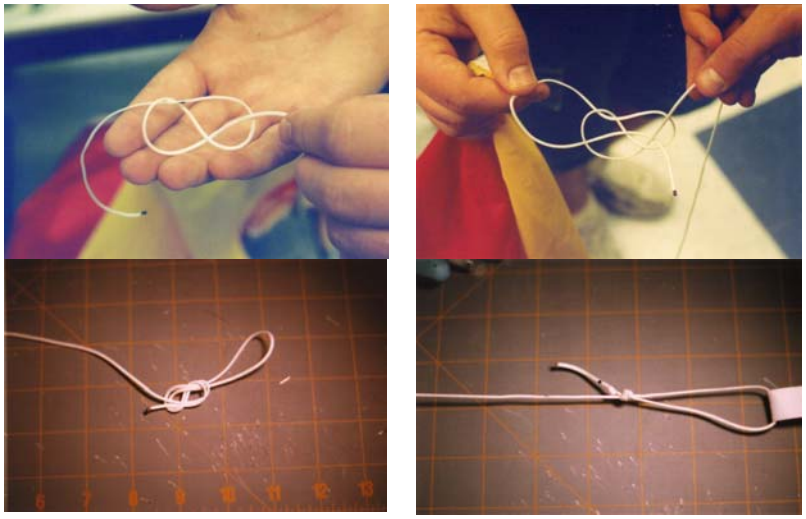
The end of the shroud line. It terminates in a bearing swivel.

- √ Mark each end of the line 6" from the end
- √ Cut eight two-inch lengths of thin heat shrink tubing, a little more than twice the diameter of the shroud lines.

- √ Slip two pieces of tubing on each shroud line (from opposite ends) and push them toward the center of the shroud lines where they are temporarily out of the way.
- √ Tie one end of a shroud line to a twill loop at the bottom of the chute, matching up the knot with the mark that was made 6" from the end of the line. Use a blood knot as it will resist pulling loose of the parachute during descent.
- √ Tie the other end of the Dacron line to a neighboring twill loop, again aligning the knot with the mark on the line.
- √ Repeat this for the other three Dacron loops.
- √ Do not yet shrink the tubing over the knots until the shroud lines are checked.

Test the parachute as follows:

- √ Take the parachute outside and grab the shroud lines at their bottoms, on the center marks you made.
- √ Run as fast as you can and the parachute should open, making it difficult for you to continue running. You should do this when the neighbors aren't looking.
- √ Look at the opened parachute and make sure it looks symmetrical and that none of the shroud lines are grossly slack.
- √ If the shroud lines do not match, then untie the longest shroud line and retie it to match the others, and then repeat the parachute test again.
- √ If the parachute looks good, cut the excess string from each knot back to about 1/2" and carefully use a lighter to melt the ends slightly.
- √ Slide the heat shrink tubing over the knots and shrink it down, taking great care not to damage the nylon lines with the heat gun.



Tying the Knot –
Step 1 - Top Left
Tying the shroud line to the canopy. Start by making this "figure 8".
Step 2 - Top Right
Pass the free end of the shroud line though the canopy, then loop the end back through the knot, exactly as in came through originally.
Step 3 – Bottom Left
Without canopy to make it clearer
Step 4 – Bottom Right
Knot tightened and an overhand stopper knot added

3.2.4. Documentation

At least two items should be recorded on the canopy (where they can't get lost). Document the following items on the canopy:

- Diameter of parachute
- Weight of the parachute

Either write these measurements on the canopy with a fabric marker, or have the measurements embroidered onto a cloth label and sew the label to the canopy.

Along with the previous two, there are three other recommended markings. The first is useful when untangling the shroud lines and the other two are just nice to know items. To simplify untangling the shroud lines, label the bottom of each shroud line with a tag. The tag contains the number of the shroud line. The numbers are written in either clockwise or counterclockwise sequence, as are the positions on the parachute ring. The shroud lines are disconnected from the parachute ring while they are being untangled. Labeling the shroud lines and parachute ring makes quicker work of reattaching the shroud lines to the parachute ring.

The author labels the gores in the canopy. The numbers on the gores uniquely identify each gore. If the canopy is damaged during a mission, the damaged gore can be recorded using its identification number.

Finally, I personally like to record the number of missions the parachute has been used on. I set aside an area of the canopy and label it with the word, "Flights". After each flight or mission, I draw another hash mark. Use a permanent ink fabric marker to make the parachute's hash marks.

Recording the number of missions

4.0 The Parachute Ring

The parachute ring keeps the shroud lines of the parachute from twisting up during a near space mission. The ring does not take the stress of the weight of the near spacecraft pulling down and the balloon trying to lift up, the parachute shroud lines do that. Instead, the parachute ring only forces the shrouds lines apart so they don't tangle. Described below are two methods of making parachute rings. The simplest design uses a needlepoint ring and has been tested by KNSP and TVNSP. The more elaborate design uses mini-capsule containing recovery aids and had not been adequately tested yet at the time of this writing.

4.1. Needle Point Loop Design

Needle point parachute ring

This is the fastest method to create a parachute ring.

4.1.1. Materials

- Twelve-inch diameter wood needlepoint loop
- Epoxy
- 1/8” thick Basswood stock
- Woven Dacron kite line (150# recommended)
- Twelve bearing swivels (at least 100# test)
- Eight one-inch split rings
- Heat shrink tubing 1/8” diameter
- Heat shrink tubing 1/4” diameter
- Fine tip fabric marker

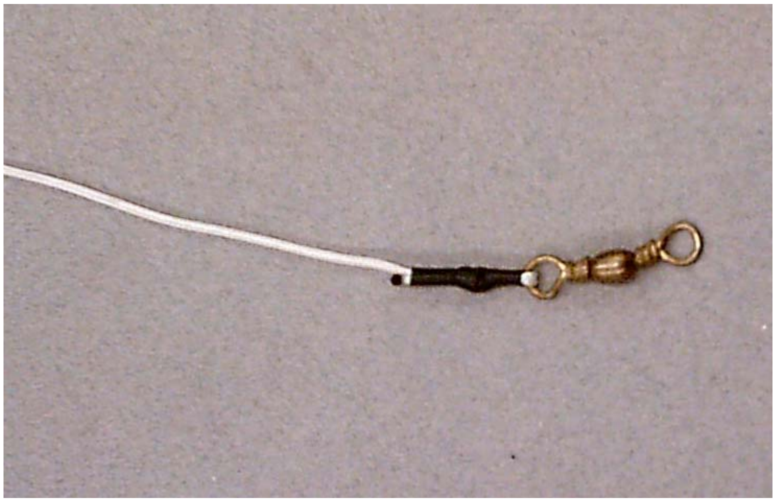
4.1.2. Procedure

The loop actually consists of two rings. The inner ring is a solid piece of wood and the outer ring is split with a clamping mechanism. Assembling a parachute ring requires that the individual rings be epoxied together to make a single, stronger ring. After the epoxy is set, the clamp is removed and the remaining gap filled. The parachute ring is completed after adding loops of Dacron kite line.

A needle point ring before it is converted into a parachute ring. Opened ring shows the clamp and rivets

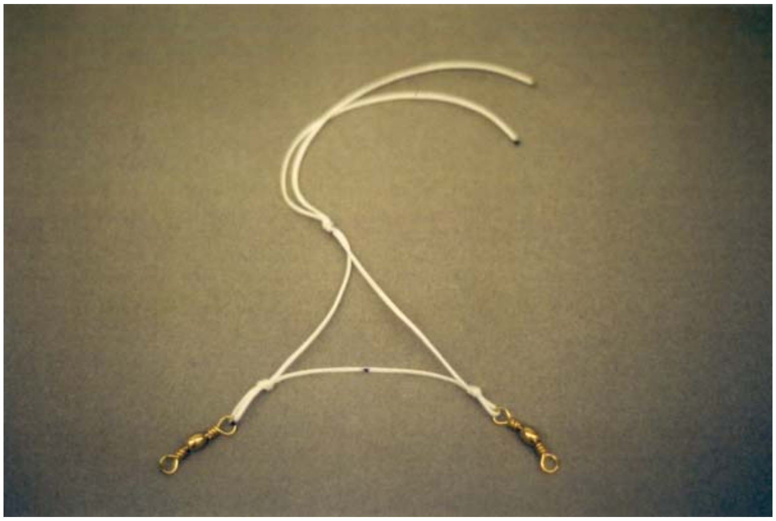
√ Loosen the outer ring of the needlepoint loop.
√ Separate the inner ring from the outer ring.
√ Coat the outer surface of the inner ring with epoxy.
√ Slip the two rings back together and tighten down the clamp.
√ Let the epoxy set overnight.
√ Remove the clamp by grinding off the rivet heads with either a metal file or a Dremel with an abrasive cutting wheel. Note: leave the metal rivets in the ring; just grind off the heads of the rivets.
√ Cut and epoxy a piece of basswood to fill the gap left between the clamps.
√ Clamp the basswood into place until the epoxy sets.
√ Drill four equally spaced holes (1/8” diameter) in the parachute ring.
√ Cut a length of woven Dacron kite line, ten feet long.
√ Melt the cut ends of the Dacron line with a lighter, carefully.
√ Slide eight bearing swivels on the Dacron line.
√ Slide a one-inch length of 1/4” heat shrink tubing on the Dacron line.
√ Lay the ends of the Dacron line together and tie a doubled, overhand knot.

√ Slide the heat shrink tubing over the knot and shrink it.



***Heat Shrink Tubing –** Securing the knot.*

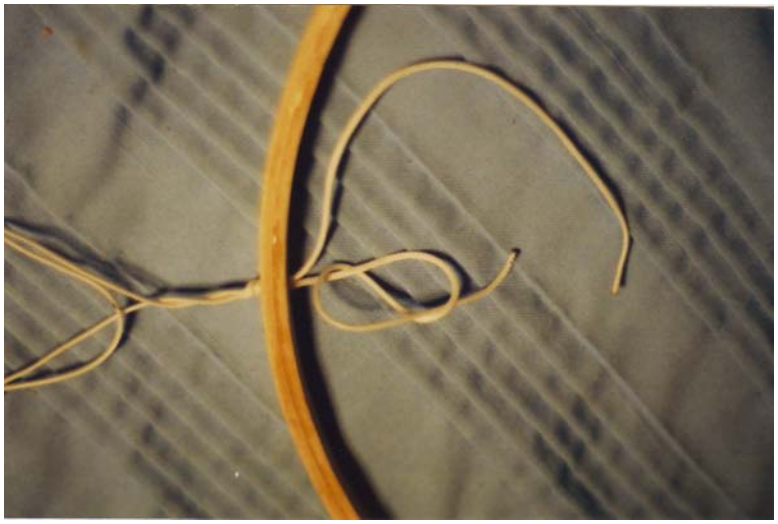
√ Stretch out the loop of Dacron into a straight line, positioning the covered knot about 6 inches from one end.
√ Mark the opposite ends with a fabric marker.
√ Stretch out the loop again, this time by placing the marks together.
√ Mark the new ends. This will make four marks on the loop.
√ Use these marks to find the midpoint between each pair, making 8 equally spaced marks on the loop.
√ On each mark, position a bearing swivel and tie a knot, trapping the bearing swivel.
√ Now there should be eight bearing swivels tied around the Dacron loop, equally spaced.



Trapped bearing swivel

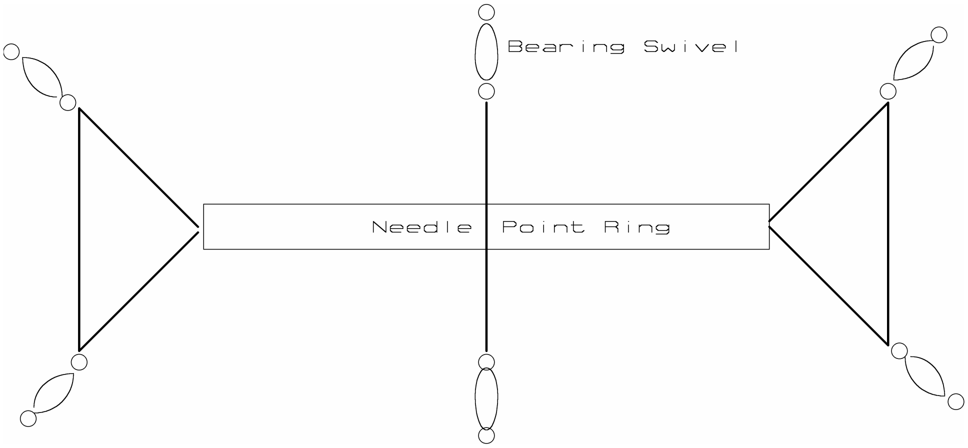
√ Cut four lengths of woven Dacron, 14” long.
√ Perform the following steps on each piece:
√ Mark the midpoint of the Dacron cord (this is point “B”).
√ Mark two more locations on the 14” Dacron; two inches in each direction from the previous mid-mark (Label these marks as “A” and “C”).
√ Slide one bearing swivel on the Dacron at mark “A” and tie an overhand knot, trapping the bearing swivel at mark “A”.

- √ Slide a short length of heat shrink tubing over the knot and shrink the tubing to prevent the knot from loosening.
- √ Slide a second piece of heat shrink tubing over the Dacron and push it up against the first knot temporarily; do not shrink this tubing yet.
- √ Slide a second bearing swivel on the Dacron to mark "C" and tie an overhand knot, trapping the bearing swivel at mark "C".
- √ Slide the second piece of heat shrink tubing from its temporary location to cover the second knot and shrink the tubing.



Line gong through the needlepoint loop

- √ Pass the two free ends of each 14" Dacron line through a hole in the needlepoint loop from the outside of the needlepoint loop.
- √ Lay the free ends of the 14" Dacron line together and tie a doubled overhand knot on the inside of the ring.



Parachute ring and lines.

- √ At this point the needlepoint loop has four small loops of woven Dacron tied to it, with each tiny loop containing two bearing swivels.
- √ Connect every other bearing swivel of the ten-foot Dacron loop to the bottom bearing swivels of the parachute ring with split key rings.
- √ When completed, the ten-foot Dacron loop forms a zigzag beneath the parachute ring. The alternating bearing swivels are connected to the top module of the near spacecraft.

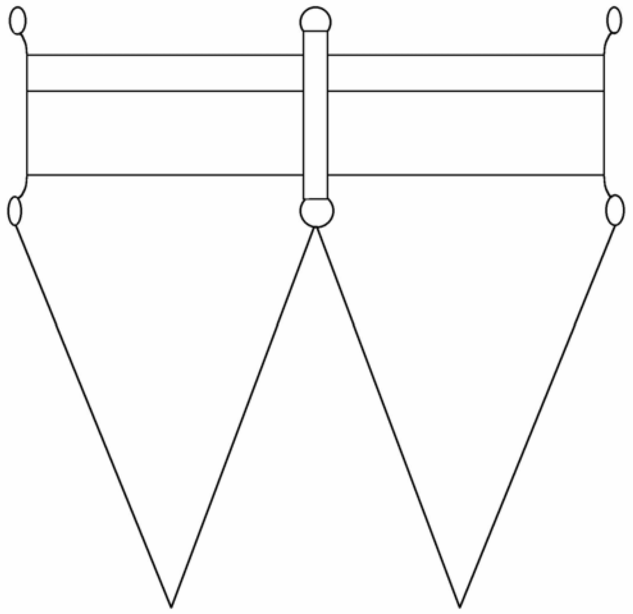
- √ Connect the top bearing swivels to the ends of the parachute shrouds with one-inch split rings.

4.2. Mini-Capsule Parachute Ring

An alternative to a simple wooden hoop is to construct a mini-capsule in place of the hoop. The mini-capsule keeps the shroud lines apart while allowing recovery aids and flight termination systems close to the parachute. This should be considered an experimental design. The author has constructed one mini-capsule, but it has not been thoroughly tested at the time of this writing.

4.2.1. Mini-Capsule Design

Build a near spacecraft module as described in Chapter One, but only a few inches tall. Add the normal abrasion jacket and link loops. Add the same 10-foot Dacron loop used in the parachute ring to the bottom link loops of the mini-capsule.



Mini-Capsule Design

4.2.2. Electronics For Mini-Capsules

Good electronics to incorporate into a mini-capsule are recovery aids, like trackers and beacons, and flight termination systems.

Mini-Trackers

A good recovery aid is the Tiny Trak II based near space tracker, as described in Chapter Two, Section Three. A flexible 2 m or 70 cm dipole antenna, with the top element tied loosely to a shroud line or a 70 cm wire dipole makes good antenna choices. Let the bottom element of the flexible dipole antenna dangle free.

Audio Beacons

Another recovery aid, although of a different nature from the previous one, is the audio locating beacon. Commercial models are available through high power rocket dealers. Quite a serviceable one can be constructed for about $6 from Radio Shack. Check Section Seven of this chapter for details.

Flight Termination Systems

Since the HT's receive capability isn't used in the Tiny Trak based near space tracker, a programmable DTMF decoder can be incorporated into the mini-capsule. This keeps the flight termination system close to the parachute. Again, consider this experimental, as there are no formal plans in this book for DTMF-controlled Flight Termination Units. Complete Flight Termination Systems are discussed in Section 6 below.

4.2.3. Wrapping Up

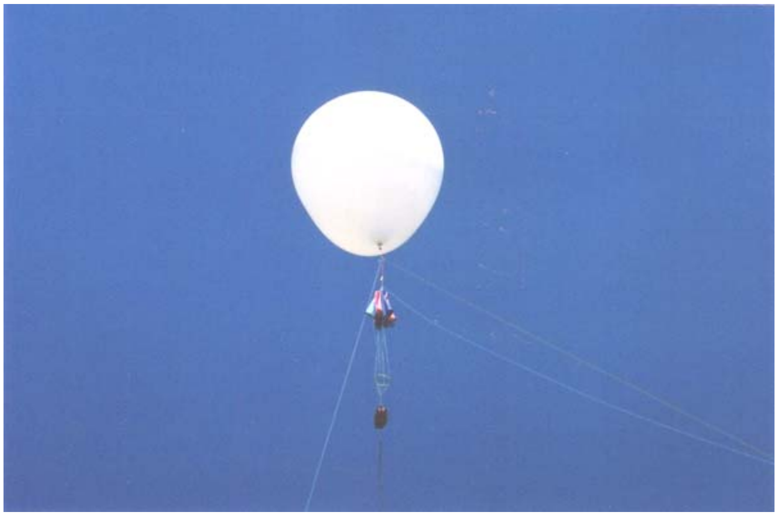
Your parachute and parachute ring is complete. The authored tested his first parachute by dropping it from a tall building, but found this hard to do successfully. Below, a different way to test the parachute for proper opening, drag, and stability is explained. The testing lets you characterize the parachute's performance.

5.0 Parachute Testing and Proper Storage

I recommend that you test your completed parachute before use; don't rely on the parachute to work properly (although it probably will) during a mission without first testing it. Testing ensures the parachute opens without tangling, and determines the landing speed of the parachute for different payload weights. With the landing speed of the parachute and knowledge of air pressure at various altitudes you can generate a descent profile of the parachute. Proper storage of the parachute between missions increases the reliability of the parachute. A parachute that is stored wadded up in a tight ball may not function properly during descent.

5.1. Parachute Testing

One way to test the parachute at various air speeds is to rent time on a wind tunnel. This author assumes this is not a realistic option. Instead, to accurately measure the descend speed of the parachute, you'll perform drop tests. The drop test measures the parachute's performance under various payload weights and records the descent speed of the parachute.



Parachute and near spacecraft raised beneath the tethered balloon.

This test is fun. The TVNSP crew performed this test in a soccer field in Boise and attracted quite a bit of attention. This test requires the use of a tethered helium-filled weather balloon to carry the parachute and capsule over 100 feet above the ground for a drop test.

Parachute away! *The release pin was pulled loose and the parachute descends.*

5.1.1. Materials

Collect the following items for the parachute drop test:

- Latex balloon (the balloon can be used for a mission if handled carefully)
- Two rolls of strong nylon twine
- 2" – 3" metal ring
- ½" wood dowel, cut six inches long
- Hard hat(s)
- Completed parachute
- Near spacecraft modules
- Small, soft weights and/or packing material
- Duct tape
- Gloves
- Scale to weigh capsules and balloon lift
- Helium
- Ground-based APRS tracker
- Camcorder or camera (you'll want to record this test as it is awesome fun)

5.1.2. Construction

√ Construct the release mechanism
√ Drill a hole perpendicularly through the dowel near one end, with a diameter large enough to pass the nylon line through. This is the release pin.
√ Taper the other end of the release pin to a dull point.
√ Tie a nylon cord through the hole in the release pin.

Release Pin *- Round the end to help prevent snagging.*

- √ Prep the near spacecraft
- √ Program the tracker or flight computer to transmit the GPGGA sentence every couple of seconds. The time and altitude data will be recorded in this test.
- √ Move the HT off the APRS frequency so the test does not interfere with local APRS traffic.
- √ Test that the tracker/flight computer is transmitting properly.
- √ Attach the second module to the tracker module.
- √ Test that the weights fit inside the empty module and are secure.

Parachute Prep

- √ Tie a large loop (about six inches in diameter) to the top of the parachute with sisal line.

5.1.3. Procedure

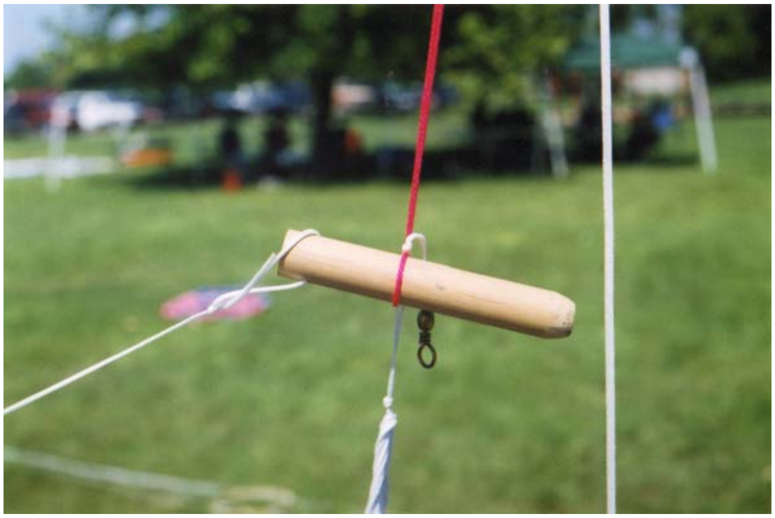
- √ Weigh and record the near spacecraft. Include the parachute's weight in the total.
- √ Attach the parachute to the near spacecraft.
- √ Power up the near spacecraft.
- √ Start up a mobile APRS tracker (this is a good opportunity to test a chase vehicle's tracker).
- √ Start logging APRS data (see Chapter 11, Sections 1.1.3 through 1.1.5 for directions on setting up the TNC and APRS).

Consult Chapter 10, Section 3 for directions on filling and sealing a weather balloon. In place of the 30-foot long load line, use a line over 100 feet long. In this test the lanyard ring is used as the parachute release. After filling the balloon, but before beginning the test, tie the free end of the load line to a car or other object that the balloon cannot carry away. Select several people as the Balloon Crew to operate the balloon. It is their task to raise and lower the balloon for each test. All of them must wear gloves for protection against string burn.

Raising the tethered balloon *- It's safest to wear a hard hat, as there's stuff falling from the sky in this test!*

The release line is a separate line from the load line and is operated by a single individual, the Release Operator. It is best that this person be separate from the Balloon Crew to prevent the load line and release line from tangling. This person must wear gloves and a hard hat as the release pin is overhead when they release the parachute from the tethered balloon.

√ Pass the loop of sisal at the top of the parachute through the lanyard ring on the weather balloon and lock it into place with the release pin.



Release Mechanism *- Release pin connecting the line to the balloon and the loop on the parachute's apex together. Next stop, 100 feet AGL.*

- √ The Balloon Crew raises the balloon on the load line. Note: keep tension on the parachute until the weight of the capsule is pulling on the parachute.
- √ After the balloon is at altitude, confirm the parachute and release line are not tangled.
- √ Have the Release Operator call "HEADS UP!" before pulling the release pin loose.
- √ Observe that the parachute opens properly.
- √ Under no circumstances attempt to catch a falling capsule when its parachute has failed as the risk of injury is too great in comparison to the cost of the capsule.

- √ Repeat the Parachute Test with various weights inside the empty module, recording the total weight of the capsule in each test.

After completing the tests, carefully lower the balloon and remove the tape wrapped around the nozzle. It will take a while to dump the helium out of the balloon. However, if the balloon is handled with care, it can be repacked inside the bag it came in and used for your first flight. **CAUTION: The interior of the balloon is filled with talcum powder, so be sure no one attempts to breathe the helium being vented.**

A Final Observation to Make

Mirages occur when pockets of air warmer than the surrounding atmosphere bend or refract light from its original path. One effect is the shimmering observed over warm pavement of more distant objects as pockets of warm air rise and mix with the cooler air higher above the pavement. Helium is a very low-density gas and is capable of refracting light in just the same fashion. As you vent helium from the balloon, observe the scene behind the helium stream leaving the balloon nozzle and look for shimmering.

5.1.4. Analysis of Drop Test Data

- √ Change HT frequency back to 144.390 MHz.
- √ Confirm that the parachute opened promptly when released and did not collapse.
- √ Look for asymmetries in the canopy if there is a problem. Make sure the shroud lines look even and are under the same amount of tension.
- √ The time and altitude are the two most important fields during the drop test. Use only the last few GPGGA sentences, when the capsule is descending at a constant rate.
- √ Record the capsule weight and last three or four GPGGA sentences from each drop.

- √ Calculate a descent speed for the parachute. Note: As an example, use the last three GPGGA altitudes and UTC times.
- √ Calculate the change in altitude by subtracting the last altitude from the third altitude.
- √ Convert the change in altitude from meters to feet by multiplying meters by 3.28.
- √ Calculate the change in time by subtracting the last UTC time from the third UTC time, being sure to take into account any roll over in minutes. You want the results in seconds.
- √ Divide the change in altitude by the change in time.
- √ Record the descent speed and capsule weight in a spreadsheet.
- √ Record the same data for each drop test.
- √ Create a graph of parachute descent speed as a function of payload weight (use best fit).
- √ The graph should be close to a straight line (linear).

Why Are There Errors?
The descent speed of the parachute may not be as low as calculated. Factors that affect the true descent speed of a parachute includes sewing errors, variations in parachute diameter or spill hole size, and canopy porosity.

5.1.5. Generating a Descent Profile

You just measured the characteristic descent speed of a parachute at your local elevation. The Descent Profile determines the speed of the recovering near space capsule as a function of altitude.

- √ Begin by creating a spreadsheet with altitudes for every 1000 meters, starting at your elevation.
- √ Add a second column with the Standard Atmosphere density at those altitudes (found in the table below).
- √ Create a third column of altitude in feet by multiplying the first column by 3.28.
- √ Create a fourth column of the inverse, square root of air density.
- √ Create a fifth column of predicted descent speeds by multiplying the fourth column by the landing speed of the parachute and divide by the inverse air density at the elevation the drop test was performed.
- √ Graph the third (altitude in feet) and fifth columns (descent speed in feet per minute).

Spreadsheet Commands

	A	B	C	D	E
1	Altitude	Density	Altitude	1/Density$^{1/2}$	Descent Speed
2	meters	newtons/meter^2	feet		feet/second
3	1000		= +A3*3.28	= 1/SQRT(+B3)	= +D3*15

Standard Atmosphere	
Altitude (m)	**Density (kg/m^3)**
0	101325.0
1000	89874.6
2000	79495.2
3000	70108.6
4000	61640.2
5000	54019.9

6000	47181.0
7000	41060.7
8000	35599.8
9000	30742.6
10000	26436.3
11000	22632.1
12000	19330.4
13000	16510.4
14000	14101.8
15000	12044.6
16000	10287.5
17000	8786.7
18000	7504.8
19000	6410.0
20000	5474.9
21000	4677.9
22000	3999.8
23000	3422.4
24000	2930.5
25000	2511.0
26000	2153.1
27000	1847.5
28000	1586.3
29000	1363.0
30000	1171.9

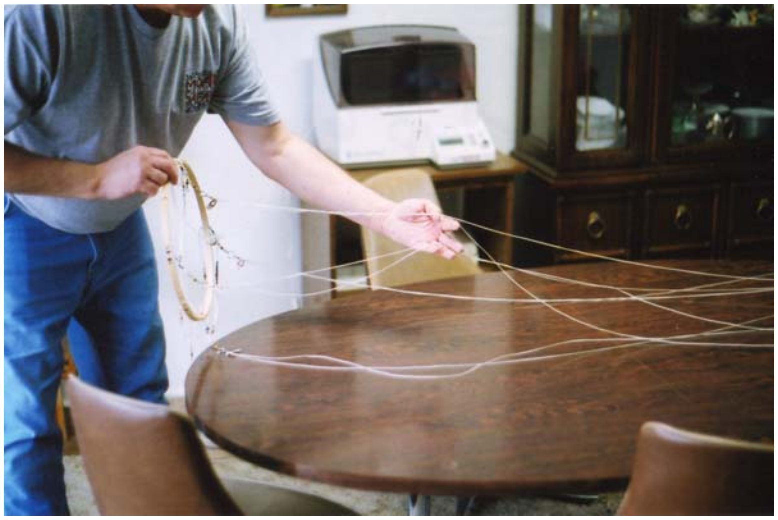
The resulting graph predicts the descent profile for this particular parachute for a given weight. The descent speed of a parachute above 100,000 feet is usually greater than 150 feet per second, or 100 miles per hour. Again, don't let this worry you. The air pressure at this altitude is so low that high speeds are necessary to generate enough drag. As far as the parachute is concerned, it appears that the force of the rushing air on the parachute at this altitude is equal to the force of the slower rushing air at a lower altitude. The force on the parachute is constant all the way down. One test to perform is to calculate the actual descent of the parachute during a mission and comparing the results to the predicted descent speeds.

5.2. Storing And Transporting Parachutes

5.2.1. Storing Parachutes Between Missions

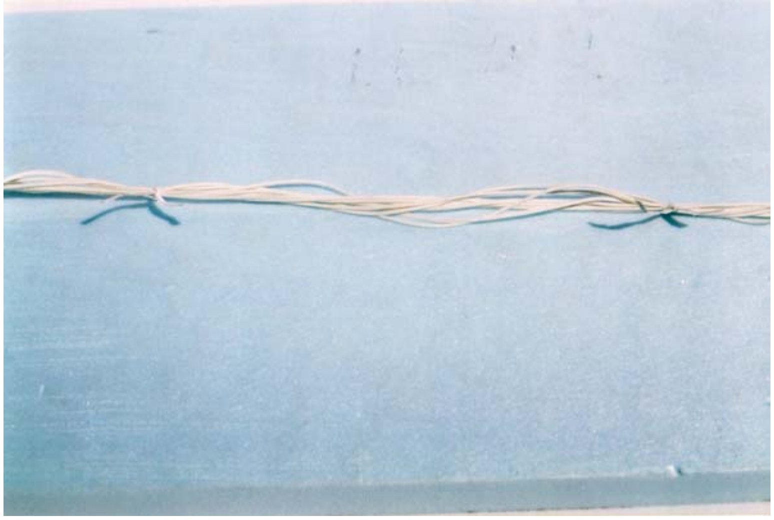
Parachutes should never be stored folded up. Instead, let the parachute’s apex hang from a nail in the wall or ceiling. Place the parachute where it is protected from direct sunlight and drafts of cold or hot air.

5.2.2. Untangling Shroud Lines



Oh joy! Untangling shroud lines!

Someone must have responsibility for untangling the shroud lines during a mission's Flight Readiness Review (FRR). Link the split rings at the ends of the shroud lines together with a fifth split ring to keep the lines from tangling again. Mike Manes of EOSS recommends wrapping the stretched-out, untangled shroud lines with several twist ties. That's such a good idea that I wish I had thought of it.



To keep shroud lines under control, wrap wire twist ties around the bundled shroud lines. (A suggestion from Mike Manes of EOSS)

Alternatively, a parachute transport bag also helps keep shroud lines from tangling during transport.

5.2.3. Transporting a Parachute to a Launch

Only on the night before a flight should the parachute be folded into a transporting bag. One good bag for transporting a parachute is a laptop case (after the shroud lines are tied together).

Another option is to sew a transport bag from a heavy-duty nylon fabric. Below are directions for making one type of transport bag. This bag is a long, narrow tube sewn closed at both ends. A Velcro[B] closure along the length of the bag makes it easy to lay out the parachute inside, and avoids snagging the parachute in a zipper. A flap of fabric inside the opening protects the parachute's shroud lines from making contact with the Velcro. Small gaps at the top and bottom of the Velcro closure allow the ends of the parachute to protrude, preventing it from sliding down and tangling inside the bag.

Materials

- Two yards of heavy cloth like a nylon canvas
- Several sheets of poster board
- Five feet of ¾" sew-on Velcro tape

Procedure

- √ Determine the dimensions of the rectangular bag pattern:
  Lay out the parachute and measure its length. The length of the pattern is two inches longer than parachute's length.
- √ Determine the circumference of the canopy when it is wrapped in a tight roll. The width of the pattern will be 7 inches wider than this circumference.
- √ Make a pattern on poster board and cut out.
- √ Trace the cardboard pattern onto the cloth and cut out.
- √ Fold over all four sides by one inch, then fold again to form a hem that is one inch wide.
- √ Sew the hems down; you will be sewing through three layers of fabric.
- √ Cut the Velcro strip six inches shorter than the length of the bag. This leaves a small opening at each end of the tube.
- √ Sew one face of the Velcro furry side up on the face-up side on the right hand hem, equidistant from both ends.
- √ Flip the cloth over and sew the other side of the Velcro strip on the opposite side of the cloth, with its edge two inches from the edge of the cloth. These two inches of overlapped fabric will be on the inside of the bag, forming a flap to protect the parachute from coming in contact with the Velcro.
- √ Fold the rectangle length-wise, forming a tube with the Velcro strips sealed together, and with the two-inch overlap inside.
- √ Sew the tube closed across both ends. This will leave a small opening between the Velcro and the end seam at both ends of the bag.

Directions for Use

- √ Untangle the parachute during the FRR and tie shroud lines with twist ties.
- √ Open the tube and place the parachute inside at the top.
- √ Lay the shroud lines inside the bag, keeping them straight.
- √ Cover the parachute and shroud lines with the inner flap, leaving parachute's apex ring and the ends of shroud lines extending from the bag.
- √ Fold the tube closed by first folding the inner flap over the parachute, then folding the outer flap over to line up the Velcro.
- √ Seal the Velcro closure
- √ Fold bag in half and link parachute's top and bottom rings together.
- √ Roll the tube into a ring.

You can either buy a bag or sew your own.

6.0 Flight Termination Systems

The function of the flight termination system is to cut the balloon and load line away from the parachute during descent. Cutting away the balloon lets the parachute lower the near spacecraft in a gentler manner than when the burst balloon is swinging around the parachute apex at the end of a thirty-foot load line. As long as the near space capsule meets the weight limits imposed by FAR 101, the stack doesn't require a flight termination device. But in the long run, you should carry one of these to prevent losing an expensive near space capsule in case the balloon becomes neutrally buoyant or if a main battery begins to fail during a mission.

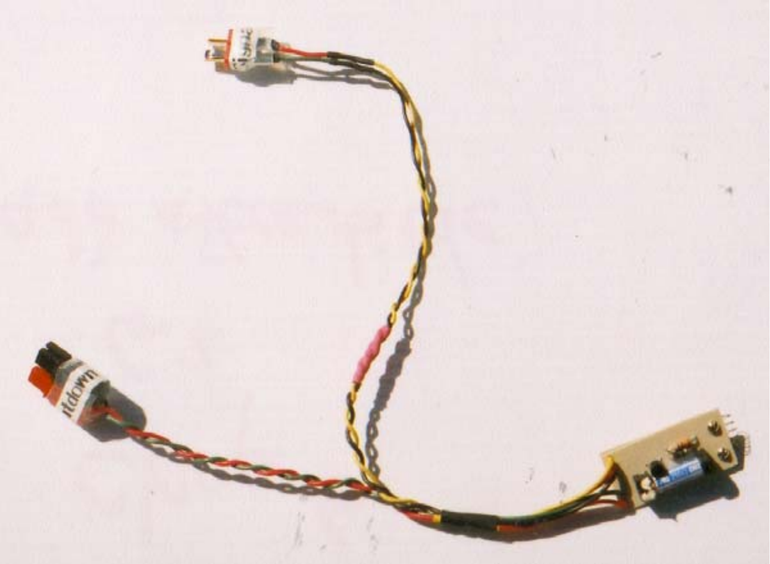
6.1. Types of Failures Requiring Flight Termination

There are two broad categories of failures requiring flight termination, Near Spacecraft Emergencies (NSEs) and Flight Path Violations (FPVs). NSEs occur when some event compromises telemetry, such as when flight cells fail and telemetry is no longer being sent. FPVs occur when the course of the near space capsule deviates substantially from the predicted flight path and it risks landing in hazardous areas, like tall mountains, great lakes, or restricted areas. Another FPV is when the stack becomes neutrally buoyant. When events like these occur, you have no other option than to terminate the flight early. By terminating missions early, the near space capsule lands sooner and closer to its current position.

This section describes the construction of a Flight Termination Unit (FTU). The FTU uses a thermal knife to sever the load line between the balloon and parachute. At flight termination the near spacecraft drops from the balloon, the recovery parachute deploys, and the balloon begins rising much more rapidly. Since near space missions described in this book are flown on latex balloons, the balloon is guaranteed to terminate, meeting the requirements of the FAA (a balloon capable of lofting a near spacecraft does not become neutrally buoyant when the near spacecraft is released). The FTU design in this section allows one or more sources to terminate a mission. Using separate batteries and termination signals lets the FTU meet the FAR 101 requirement for multiple, independent, and redundant termination methods for larger payloads. At the time of this writing, the FTU described in this section has only been tested in flight with timers and on the ground with a pager.

6.2. The Near Space Flight Termination Unit (FTU)

The FTU is an electronically controlled thermal knife designed to cut the load line between the parachute and the balloon.

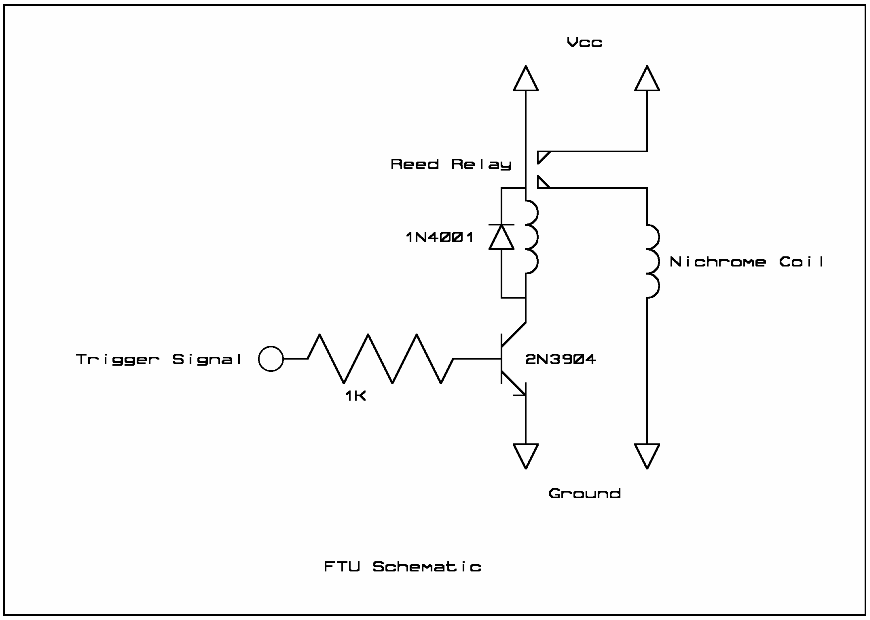


The FTU

Several signaling sources can operate the FTU. The first method described in this section is with a stopwatch. With a stopwatch, the FTU acts as a stand-alone device that ensures the termination of a flight in cases where the balloon becomes neutrally buoyant. The second termination method is a telecommand method and uses triggering devices like a pager, flight computer, or DTMF decoder. Flight computer connection to the FTU allows a software command to terminate the ascent when events like when balloon burst is detected, a low main voltage alarm occurs, or telecommands to the flight computer are transmitted from ground stations. Pagers and DTMF decoders allow telecommands from ground stations to terminate near space missions at the detection of a failure. The stopwatch method is described in detail, while other methods of triggering the FTU are described only in general details. I have not had the time to complete my tests of telecommanding the FTU, so I leave it as an exercise for the reader.

6.2.1. Theory of Operation

Refer to the schematicbelow. The resistance of a three-inch length of 30-gauge nichrome wire is less than one ohm.



Schematic of FTU

According to Ohm's and Watt's Laws, when sufficient voltage is present on the nichrome wire, the voltage creates enough current and power to make the nichrome wire glow incandescently. Nichrome is also designed to tolerate such high temperatures without melting or otherwise failing. Temperature sensitive cords, like nylon or Dacron, melt from the heat produced by a glowing nichrome wire coil. According to Ohm's Law, when six volts is present on a 0.75 ohm nichrome wire, it generates a current of:

I = V/R (Ohm's Law)
I = 6/.75 (substitute the voltage and resistance into the equation)
I = 8 Amps

According to Watt's Law, when eight amps of current flows through a volt difference of six volts, the current generates a power of:

P = I*V (Watt's Law)
P = 8*6 (substitute the current and voltage into the equation)
P = 48 Watts

Dissipating a power of 48 watts within a coiled three-inch length of nichrome wire generates enough heat to make the nichrome wire coil glow orange hot within a second. Any nylon or Dacron cord threaded inside of this glowing coil melts the cord into two pieces very quickly.

However, a stopwatch, microcontroller, pager, or DTMF decoder is incapable of sourcing or sinking enough current (8A) to operate a coil of nichrome wire. The FTU uses a reed relay to sink the necessary amount of current. This creates a new problem. Not every stopwatch, microcontroller, pager, or DTMF decoder can source or sink enough current to ensure the reed relay operates reliably. To ensure reliability, a bipolar, NPN transistor triggers the reed relay. External signaling devices can provide sufficient current to saturate the transistor when the proper base resistor is used. When the proper value is used, the current from the signaling device is low enough not to damage it, but high enough to saturate the transistor.

The entire FTU sequence of operation goes as follows: initially there is no current flowing into its base. With no base current, the resistance between the transistor's emitter and collector is so high that effectively, no current flows, so the transistor behaves like an opened switch. When triggered, a small current flows from a signaling device into the transistor's base, saturating the transistor. The resistor (R1) limits the amount of current flowing into the base of the transistor (Q1), protecting the transistor from excessive current. However the value of R1 must be small enough to allow sufficient current to flow into the base of Q1 to saturate it. When saturated, there is virtually no resistance between the transistor's emitter and collector. The transistor now acts like a closed switch, letting current flow from between the battery and the coil of the reed relay. When the relay's coil is energized, contacts inside the relay close, letting several amps of current flow through the nichrome wire coil. The current flowing through the coil produces enough heat to melt the load line passing through the coil. When the signal to the transistor ends, the transistor is no longer saturated, completely cutting off current to the relay's coil. As a result, the contacts in the relay open, stopping the flow of current to the nichrome coil. Diode (D1) protects the transistor, Q1, from current induced by the coil (inductor) within the relay. When current stops flowing through the relay, the magnetic field created by current flowing through the coil collapses, generating a new current flowing in the opposite direction. It's this current that the diode protects the transistor from.

6.2.2. Materials

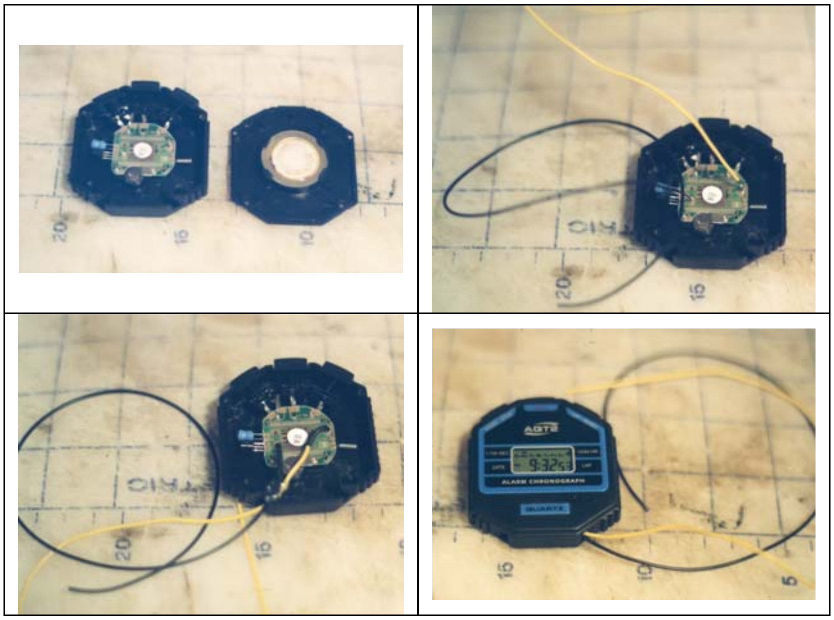
- FTU PCB
- One resistor, with a value between 330 ohms and 10k ohms[C]
- One 1N4001 diode
- One 5-volt reed relay, Radio Shack 275-232
- One 2N3904 transistor
- Three inches of 30 gauge nichrome wire
- #2 mounting hardware (nuts, bolts, and washers)
- One pair of Powerpole[D] connectors
- Stopwatch or other triggering device[E]

6.2.3. Construction

Modifying the Stopwatch
Locate on the back of the stopwatch the four small screws that hold the two halves of the stopwatch's case together. Use a small jeweler's Phillips screwdriver to remove them. They're small, so set them in a safe location where they can't drop or roll out of sight. Inside the back of the stopwatch you'll notice a one-inch diameter brass disk with the piezo crystal. Use small cutters or an Exacto knife to trim the plastic lip holding the piezo speaker down. Remove the speaker. Save the speaker for fun science experiments. Now turn your attention to the front half of the stopwatch case. Keeping the face of the stopwatch face down, rotate the stopwatch so that the buttons are at the top. Be careful not to knock the three stopwatch buttons loose. They are spring-loaded and are easily replaced should they come loose. Remove the lanyard from the stopwatch.

√ Notice that the piezo speaker received its power from two spring contacts mounted to the back of the stopwatch PCB. These two springs provide the connection to the timer signal (and power). Use either 26 or 24 gauge stranded wire to extend the springs.
√ Cut a six-inch length of two pieces of wire, red for positive and black for ground.
√ Strip back ¼ inch of insulation from one end of both wires.
√ Stick the stripped end of the bright wire into the right spring and stick the dark wire into the spring on the left side.
√ Get a soldering iron hot and heat up one spring and its wire.

- √ Use solder sparingly and solder the wire into the spring. Do this as quickly as you can, and don't let the soldering iron touch the stopwatch PCB.
- √ Repeat this to the other spring.
- √ After the soldered has cooled, cut short lengths of 1/16" heat shrink tubing and slip them over the soldered springs.
- √ Shrink them down, increasing the strength of the wires' connection to the springs.



Find the springs connecting the piezo speaker and solder wires inside the springs.

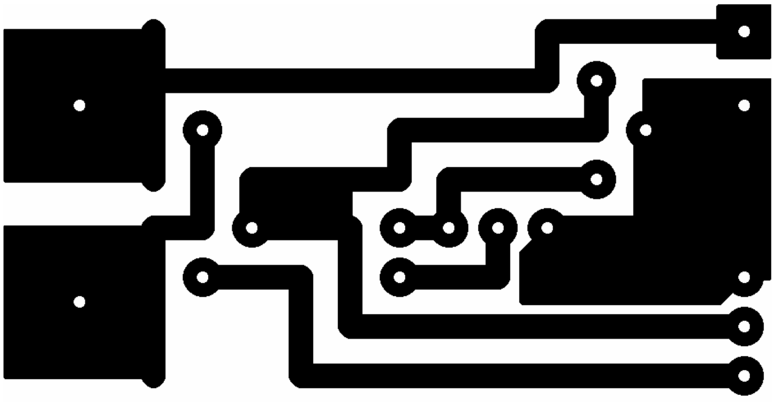
- √ Fold the wires down and pass them outside the stopwatch case through one of the lanyard holes.
- √ Use a small amount of hot glue and seal the wires to the opening of the stopwatch, to provide a strain relief.
- √ Close the back plate of the stopwatch and screw it back on.

Now, instead of ringing, the stopwatch sources a current when the alarm rings.

Assembling the PCB

Soldering Discrete Components

Refer to the folllowing diagram when placing components into the FTU PCB. Only the diode and transistor are sensitive to orientation. With the PCB turned with the nichrome pads at the top, the transistor is mounted with its flat face to the right. The diode is mounted so that the band of the diode is at the top.



Top Silk of FTU

Solder the components in this order.

1. The reed relay
2. The 2N3904 transistor
3. The 1N4001 diode
4. The current limiting resistor

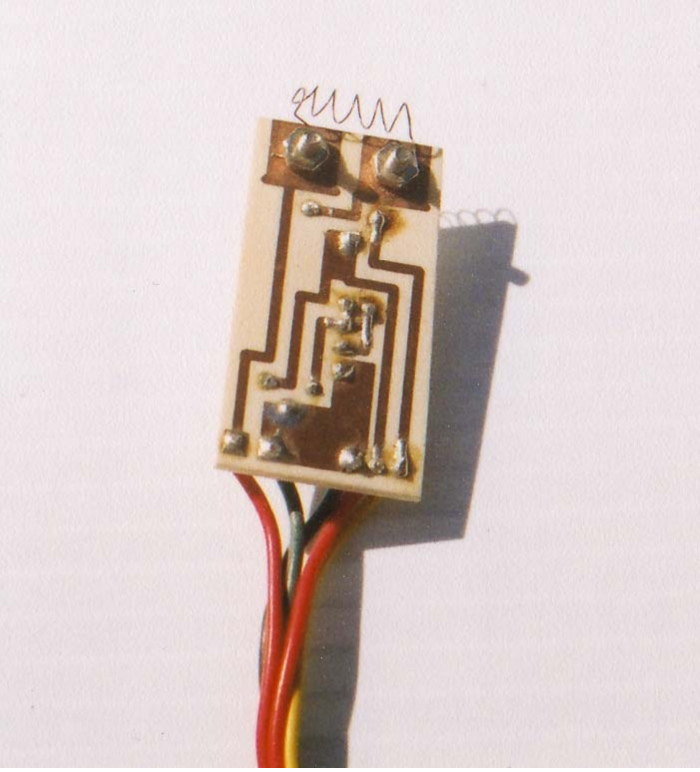
Recommended resistors are:

Pager:	500 Ohm
CC/PS:	10k Ohm
DTMF:	1k Ohm

Coil Power Connection
Power to heat the nichrome coil comes from the two bottom right pads of the PCB (the coil power pads). Depending on the current from the triggering device, the power source for the nichrome coil may be the same power source for the transistor. For example, if a stopwatch is used to trigger the FTU, the nichrome coil battery must be used to also operate the transistor. However, if a flight computer that is capable of sourcing several milliamps of current is used to trigger the FTU, then the nichrome coil's battery is not needed to operate the transistor. If using the coil's battery only for the coil, then solder heavy wire, 12 gauge or higher, to the coil power pads. The length of the wires should be as short as realistic for the application. If instead the FTU is sharing the battery between the coil and the transistor, then split the positive wire from the battery into a "Y" and solder one arm of the "Y" to the coil power pad marked POWER and the other arm of the "Y" to the pad marked +5V (on the bottom left of the FTU PCB).

Crimp and solder pins and attach Powerpole housings on the ends of the coil power wires. The polarity of these wires does matter, so use one black and one red housing. Backfill the Powerpole housings with hot glue for additional strength.

Making and Mounting the Nichrome Coils
Wrap three inches of 30-gauge nichrome wire around a 1/8" dowel, like a jeweler's screw driver, leaving ½" to ¾" of wire sticking straight out from the ends of the coil. These ends are connected to the FTU coil pads (not the coil power pads), located at the top center of the FTU PCB. Nichrome does not solder well, so 2/56 hardware is used to bolt the coil to the FTU. Bend a kink into the ends of the coil arms to lock the bolts around. Enlarge the coil pads if necessary to get the mounting hardware into the PCB. Tighten the bolts securely, locking the ends of the coil to the FTU



The nichrome coil.

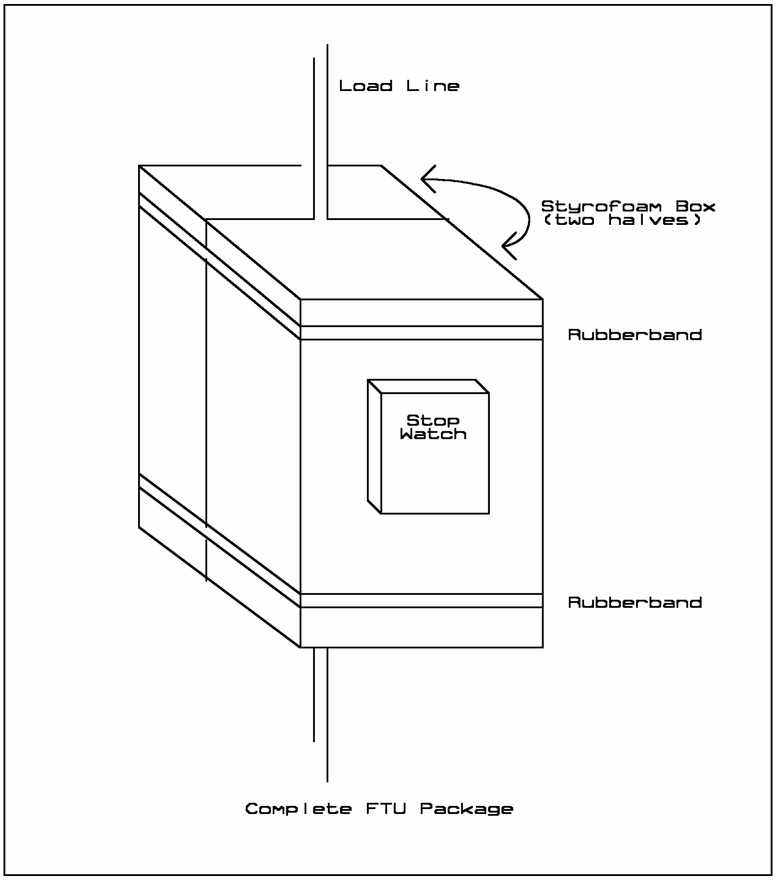
Triggering Device
If using a stopwatch or pager, solder the wires extending from the stopwatch to the FTU to the bottom pads marked SIGNAL and GROUND (the stopwatch does not connect to the +5V pad). If instead of using a stopwatch, you use a triggering device that provides enough current to operate the transistor, then connect wires from the triggering device to the three bottom left pads marked SIGNAL, +5V, and GROUND. The pad marked +5V will not trigger the FTU until the SIGNAL pad is energized. The length of the triggering wires depends on the application. If using a lightweight triggering device like a stopwatch or pager, then the wires can be short and the triggering device kept close to the FTU. If the triggering device is a flight computer or DTMF decoder from a radio, then the wires must terminate in Powerpole connectors. A wire cable, like 20-gauge zip wire (speaker wire) can make the run from the flight computer or radio to the FTU. Finally, there is no reason the pager or stopwatch must be permanently connected to the FTU PCB. A set of Powerpole connectors on the pager/stopwatch and a second set on the PCB will let you disconnect the triggering device from the FTU.

Mounting the Flight Termination Unit
Securely mount the FTU PCB to a base that is fire resistant. A 1/8” thick sheet of polystyrene plastic works well. Make the backing large enough to hold the FTU, its battery, and the stopwatch, if used. Tie everything down to the plastic base with nylon wire ties.

To protect against fires, the FTU and its nichrome coil must be mounted inside a block of Styrofoam[F]. Also, any device triggering the cutdown must limit its signaling time to only a few seconds. However, in the case of the stopwatch, it has such a low duty cycle that it can ring for a minute without significant fire risk.

Make the Styrofoam block in two halves so that the two halves trap the FTU between them. Cut a notch into the top and bottom of both halves where the load line enters and exits the nichrome coil.

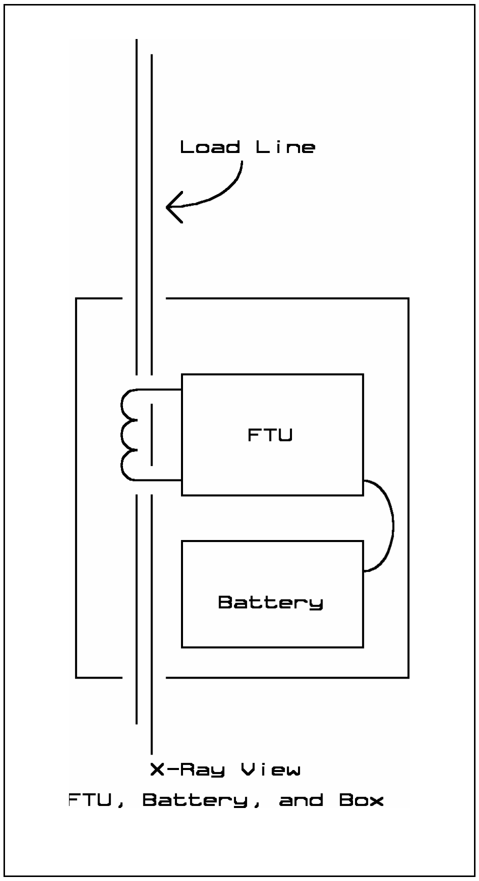
Epoxy dowels or Popsicle sticks to the foam halves so that rubber bands can clamp the foam halves around the FTU. On one of the foam halves, tie a heavy cord and a split ring. This line and ring secures the FTU to the apex of the parachute after the load line is cut free.



The closed FTU on a load line.

6.2.4. Operation

The night before a launch, test that the nichrome coil battery has sufficient capacity to make the coil glow. Then cut 12" of load line and thread it through the cooled nichrome coil. Tie loops into both ends of the line. Close the foam halves around the FTU PCB, leaving the ends of the load line sticking outside the block. Clamp the foam halves together with rubber bands, trapping the FTU inside. Test that the load line can slide within the block, but be careful not to pull the load line out of the block. Secure the FTU to the apex of the parachute with the split ring and the bottom end of the load line coming out of the FTU. The parachute now has two attachments to the FTU, one being the FTU's load line, and the other is the split ring.



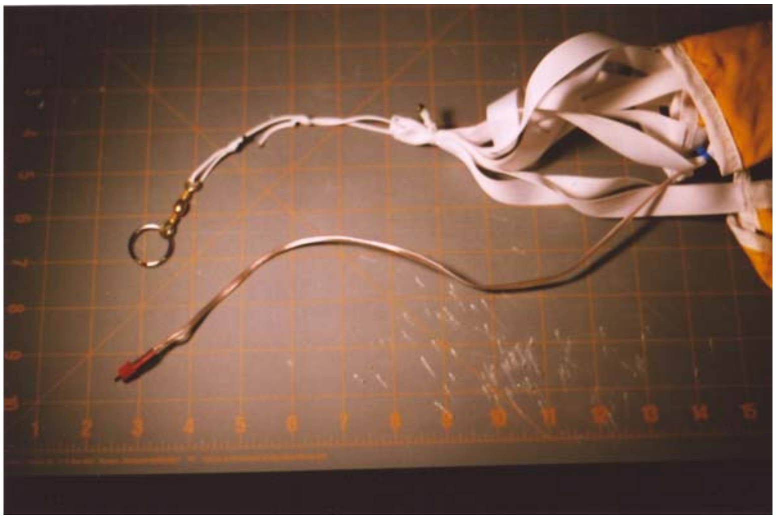
X-Ray View *- FTU, battery, box, and load line.*

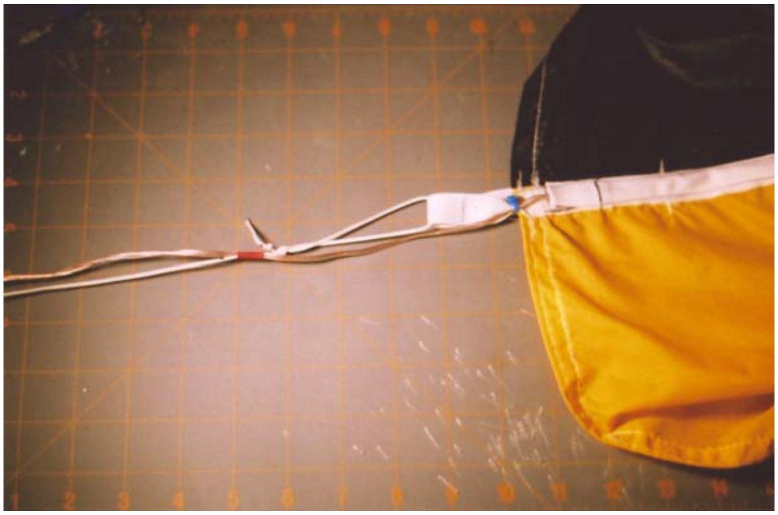
The next morning, during balloon fill, tie one end of the load line to the loop at the top of the FTU and the other end of the load line to the balloon. Tape all knots.

If using the stopwatch, set the timer. Be sure the time is long enough for the balloon to reach its predicted max altitude. If using a pager instead of the stopwatch, then be sure to disconnect the pager from the FTU before switching on the pager. Pagers test their alarms when first powered up and the pager self-test will trigger the FTU if the pager is attached (it's embarrassing to launch a balloon without the near spacecraft). After the pager self-test, attach the pager to the FTU signal connectors. If using a flight computer to trigger the FTU, then make sure the signal from the flight computer is low at power up. If there's a risk the signal may be high momentarily, then disconnect the signal line from the FTU at flight computer power up. Also, make sure the flight code loaded into the flight computer will not trigger the FTU before launch. While the stack is still on the ground, GPS altitude errors may fool the flight computer into thinking the balloon has burst. It's best if the flight computer will not check for balloon burst until several minutes after launch.

6.2.5. CC/PS as Flight Termination Signals

The Block 1 and Block 2 CC/PS are capable of sourcing 20 mA of current. This is sufficient current to trigger the FTU's NPN transistor with a 1k resistor in series with the base. The command cable should be sewn into the parachute's canopy, then tied to a shroud line on the parachute ring. Create a "tube" from twill tape along a previously sewn twill tape. Pass the cable through the tube after it is sewn. The tube lets the parachute canopy flex without binding from the command cable. From there a cable can connect the CC/PS to the command cable. A command cable that drops through the spill hole of a parachute risks tangling shroud lines. Make the command cable from thin speaker cable. The cable contains two stranded wires, enclosed in flexible insulation.





A parachute with the signal lines for the FTU sewn in –

Top – Cutdown signal line at apex of canopy

Bottom – FTU Signal line at bottom of canopy

If the CC/PS has control of the FTU, then it should terminate the flight when the main battery voltage drops too low. Experiment with low voltage conditions on the ground before giving the CC/PS control of the FTU.

To terminate the flight, use the following BS2p commands (assuming the FTU signal is connected to I/O pin 8)

```
FTU    con    8

high FTU
pause 5000
low FTU
```

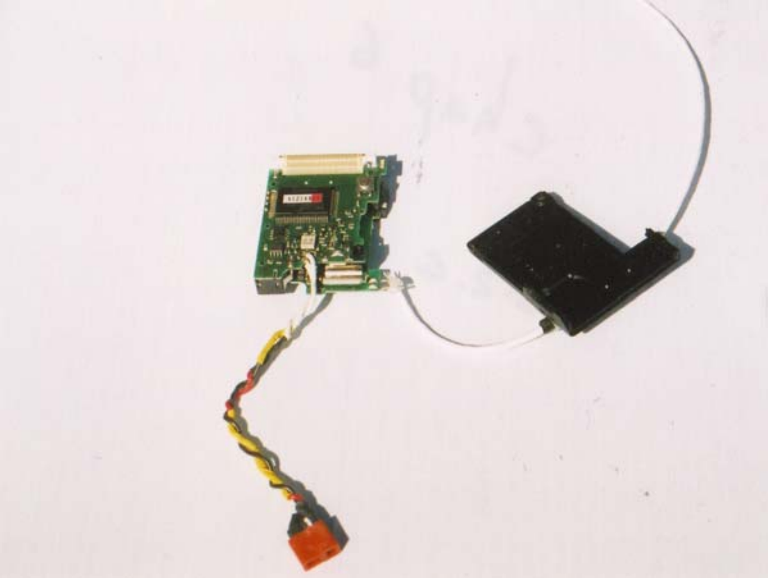
6.2.6. Pagers as Flight Termination Signals

The simplest independent receiver you can use to terminate flight is a pager. Pagers have thousands of hours of development and testing to insure reliability and are durable and inexpensive. The following directions explain how to modify a $20 pager so that it can terminate a near space flight.

There are two types of pagers in use. The first kind uses a five number cap code as an ID. When this type of pager is called, a set of five tones is sent over the radio. Only the pager with that specific cap code will respond to the signal and all other pagers will ignore it. The typical frequency used for these pagers is 152.24 MHz, just above the two-meter band. You can use a scanner to hear these tones. The second type of pager uses a seven digit data string made up of digital tones. The tones are sent FSK (frequency shift keying).

Rather than develop a new radio receiver, which could fail due to construction errors, or use a heavy HT, I decided to experiment with a dependable pager. Software at the Paging Service allows passwords to be required to ring a pager, preventing an accidental or malicious termination event. Pagers operate in two modes, beep and vibrate modes. These directions take advantage of the vibrate mode. The vibrator in a pager is a tiny motor with an off-center weight. When the motor spins, the off-center weight rocks the pager, creating the vibration sensation. In its new life, the pager is used sans motor to operate an FTU.

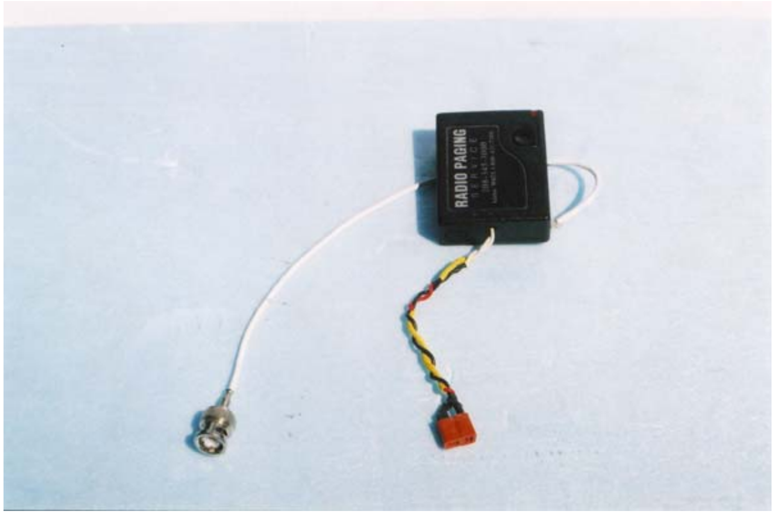
Construction



The opened pager

- √ Purchase a pager (do not modify a rented pager as the Paging Service does look kindly to this).
- √ Open the back of a pager.
- √ Locate the vibrator motor (this is a tiny motor with an off-center weight).
- √ Physically disconnect the motor from the pager case.
- √ Cut the power leads to the motor close to the motor, leaving the leads as long as possible.
- √ Strip about ¼” of insulation from the ends of the motor leads.
- √ Cut two #24 or 26 stranded AWG wires to a length of 12 inches.
- √ Strip ¼” of insulation from one end of the wires and about ½” of insulation from the other ends.
- √ Cut two ½” lengths (at least) of heat shrink tubing large enough to cover the above wires.
- √ Solder the stranded wire to the motor leads and cover the solder joint in heat shrink tubing.
- √ Find a location in the pager case to pass the wire through.
- √ Cut a small notch in the pager case at this location.
- √ Test fit the wires, making sure the pager cover can still close.

- √ Close the pager cover.
- √ Terminate the wires with connectors like Powerpoles or Dean's Connectors. Note: the author recommends using a different style of connector than is normally used for battery connections in the near spacecraft.



The pager after removing the vibrating motor and soldering wires to the motor's pads on the PCB.

Procedure for Using Pager

- √ Before powering up a pager, disconnect the pager from the FTU.
- √ Power up the pager.
- √ Set the pager to vibrate mode.
- √ Wait until pager stops vibrating.
- √ Connect the pager to the FTU.

Note: After powering up the pager, the pager performs a self-test. The test will trigger the FTU if it is connected. To prevent a premature and embarrassing surface termination of the balloon, disconnect the pager from the FTU before powering up the pager. After a few seconds you can reconnect the pager.

During a mission the pager listens for a signal to vibrate. If an FPV occurs, Chase Crews or Mission Control calls the pager number. To protect the flight from being terminated by accident, ask the Paging Service to install a password on the pager. Only authorized individuals are given the password.

TVNSP has performed two tests on pagers in near space. The missions experienced pager failures because the radiating pattern from paging tower antennas is concentrated on the horizon. When selecting a Paging Service, make sure they have antennas several hundred miles from the launch site, as these antennas are located on the horizon during a flight.

7.0 Audio Beacons

A good recovery aid to add to all near space capsule is the audio beacon. Amateur rocketry has used similar devices for years to located model rockets in tall grass. A recovered near space capsule may not be visible one hundred feet away from its last recorded GPS location, but the beeping of the audio beacon can be heard. Check with Adept rocketry for one of their loudest models or make your own (recommended).

7.1. Constructing an Audio Beacon

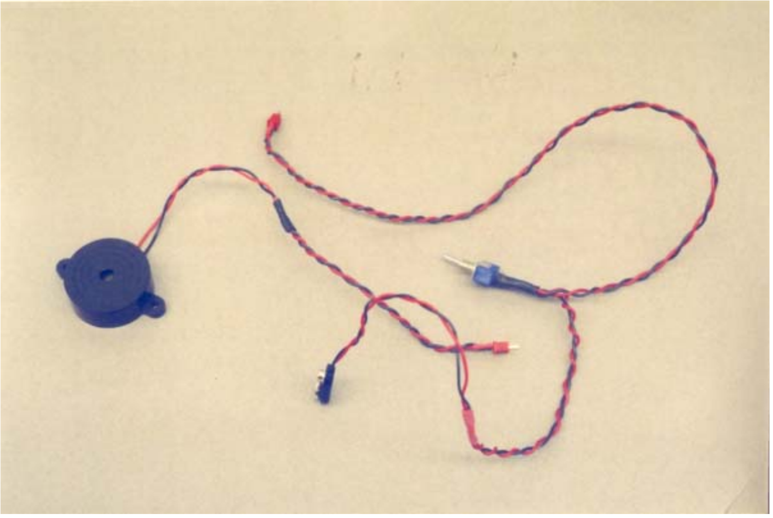
A suitable audio beacon can be constructed from materials available at Radio Shack. In addition to the satisfaction of constructing more of the near space program is the money that is saved.

7.1.1. Materials

- One loud, 12V DC piezo buzzer[G] (Radio Shack 273-060 will work)
- Nine-volt battery snap
- SPST (or SPDT) toggle switch
- Two colors of #24 AWG stranded wire (Red and black are good color choices)
- 3/16” diameter heat shrink tubing
- “Remove Before Flight” tag[H]

7.1.2. Procedure

√ Cut 30 inches of both colors of wire.
√ Strip ½” of insulation from both ends of both wires.
√ Twist 30-inch wires to the leads of buzzer and solder. Use a meaningful combination of colors.
√ Cut four pieces of heat shrink tubing, ½” long.
√ Slide two pieces of tubing onto the soldered wires and shrink.
√ Solder battery snap to other end of the 30-inch wires.
√ Cover soldered connection with heat shrink tubing and shrink.
Note: Ensure the red battery lead is connected to the red lead of buzzer.
√ Cut positive (red) lead ten inches from battery snap.
√ Strip ½” of insulation from each wire end.
√ Cut two pieces of heat shrink tubing and slide one onto each cut wire.
√ Tin the ends of the wires and the terminals of the switch.
√ Solder the wires to the switch terminals.
√ Note: If using a SPDT switch, one wire must be soldered to the center terminal; otherwise, the terminals soldered to are not important.
√ Cover exposed solder joint with heat shrink tubing and shrink.
√ Twist wires to keep them neat.

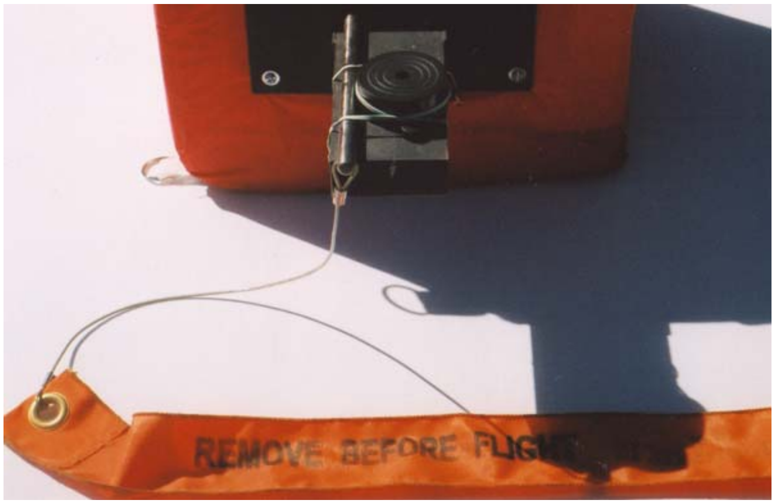


The completed audio beacon

7.2. Recommendations for Audio Beacon

Find a location for the buzzer on the outside of the near space capsule or its recovery system. A good location is on a boom, like the antenna boom. Attach the buzzer to the exterior of the capsule with rubber bands. Then slide the power wires, battery snap and power switch through an opening in an E-Quad Port. Using the pass-through hole for an antenna coax is a good idea. Install the beacon battery where it can't pop loose and then give the capsule a real good shake just to make sure. Since the beacon is loud and annoying, don't power it up until just before launch. Attach a "Remove Before Flight" tag to the beacon power switch to remind launch crews to power up it. A silent beacon is useless dead weight.

Place the audio beacon securely on a boom.



Don't forget a little reminder to start the beacon before launch.

If the mission includes a camcorder, then position the buzzer away from the camcorder. It is best if the buzzer is placed on a different module and on the opposite side from the camcorder lens and microphone. By placing the buzzer as far as possible from the camcorder, the volume of their awful noise is reduced on the camcorder's audio recording. One thing to notice after recovery of the videotape is the change in the audio beacon's volume during the flight because of the reduced air pressure in near space.

Good to Know

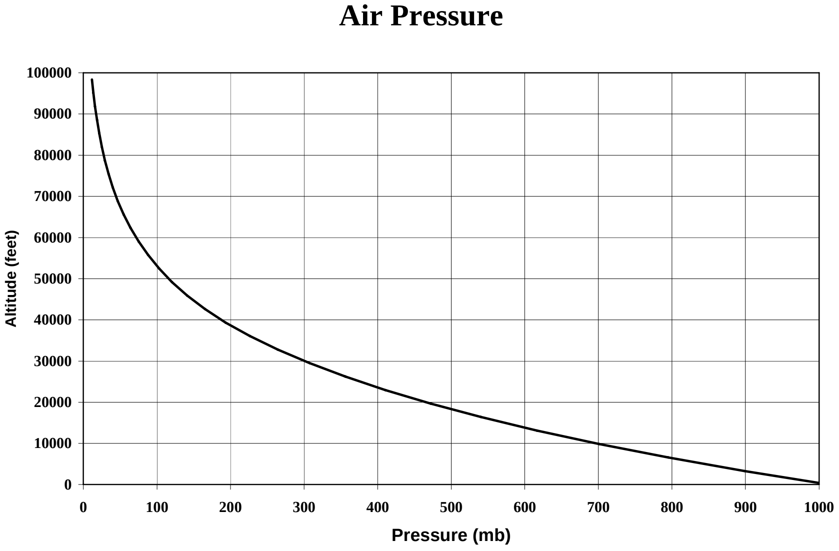
Air Pressure

Air molecules are matter and, like all other forms of matter, have mass. Gravity pulls on anything with mass, giving it weight. What we measure as air pressure is the weight of the air column above us. In terms most Americans are familiar with, the weight of the air column above us is 14.7 pounds per square inch. In the SI, it is equal to 1013 millibars (mb), or 101.3 kilopascals. Think of it this way. Every square inch you can draw on a ground, table, or person has almost fifteen pounds of weight pressing down on it. As seen from above, I measure approximately six inches by twenty-four inches. This gives me a surface area of 144 square inches. At approximately fifteen PSI there is 2,160 pounds of weight pushing straight down on me. I am carrying an automobile's worth of weight on my shoulders. No wonder I feel tired at the end of the day! Since air is a fluid medium it flows around and inside of me, exerting pressure in all directions. The balance of air pressure inside and outside of me keeps me from being crushed by the weight of the air column above me. Without this, I would be crushed just as if there was car placed on my shoulders.

As a balloon ascends into near space, it leaves more air below it and less air above it. So as the balloon climbs higher, there is less weight from the air above the balloon. In the standard atmosphere, air pressure drops by a factor of two every 18,000 feet. The average air pressure at mean sea level is 1013 millibars (mb). A millibar is one thousandth of a bar.

Let's round this figure down to 1000 mb for this exercise in air pressure. If the air pressure is 1000 mb at sea level, then when the balloon reaches an altitude of 18,000 feet, the air pressure will be 500 mb. At 36,000 feet, which is 18,000 feet higher still, the air pressure drops another factor of two. So at 36,000 feet the air pressure is 250 mb. A constant factor of change for one variable for every fixed change in a second variable creates a logarithmic curve.

Here is a second way to state the change in pressure as a function of altitude. For every 50,000 feet change in altitude, the pressure drops by a factor of ninety percent. At 50,000 feet the air pressure is 90% lower than at the surface. Using our first example, the air pressure is 100 mb at 50,000 feet. At an altitude of 100,000 feet, the air pressure is 10 mb, or one percent of surface pressure.



Graph of Pressure vs. Altitude

Vapor Pressure (Boiling Water In Near Space)

According to the book *Chemical Principles and Properties*[I], vapor pressure is the pressure exerted by a vapor when in equilibrium with its liquid. A gas and liquid at equilibrium occurs when the number of molecules evaporating from a liquid in a unit of time equals the number of molecules condensing back into the liquid in the same unit of time.

Vapor pressure for a liquid depends on the temperature of the liquid. When the vapor pressure of a liquid equals the ambient pressure, then the liquid begins to boil. Let us take water as an example. When you bring water to a temperature of 100 degrees C, vapor pressure of the water equals the atmospheric pressure at mean sea level. As a result the water begins to boil. If you try boiling water at the top of a mountain, the water boils at a lower temperature because the ambient air pressure is lower. The water needs to be at a lower vapor pressure, or lower temperature, to boil. Room temperature water (20 degrees C or 68 degrees F) has a vapor pressure of 23.4 mb. This pressure occurs at an altitude of around 82,000 feet. So if you bring room temperature water up to an altitude of just below 82,000, it begins to boil. Body temperature is 37 degrees C. At body temperature, water boils at a pressure of 60 mb. This pressure occurs at an altitude of around 62,000 feet (the Armstrong Line). Before you can reach near space, your blood begins to boil. Of course, the bends will kill you first.

Here is a table from *Chemical Principles and Properties* covering vapor pressures of water at various temperatures.[J]

Vapor Pressure of Water at Various Temperatures

Temperature (OC)	Vapor Pressure (mb)
0	6.03
1	6.48
2	6.97
3	7.48
4	8.03
5	8.61
6	9.23
7	9.89
8	10.6
9	11.3
10	12.1
11	13.0
12	13.8
13	14.8
14	15.8
15	16.8
16	17.9
17	19.1
18	20.4
19	21.7
20	23.1
21	24.5
22	26.1
23	27.7
24	29.4
25	31.3
26	33.2
27	35.2
28	37.3
29	39.5
30	41.9
35	55.5
40	72.8
45	94.6
50	121.7
55	155.3
60	196.6
65	246.8
70	307.5
75	380.4
80	467.2
85	570.5
90	691.8
95	834.1
100	1000.0

Performing Your Own Low Pressure Experiments

Educational Innovations makes a wonderful and affordable vacuum apparatus. However, to make it affordable, it is micro scale. Do not let this be a detractor; it's a great toy. For less than forty dollars you can play with low-pressure effects on water and marshmallows. Order your own micro scale vacuum apparatus, VAC-10, from the Teacher Source, at http://www.teachersource.com.

Near Space Humor

Top Ten Things NOT To Say When the Near Space Capsule Lands in a Homeowner's Yard

1. "You didn't touch that, did you?"[K]

2. "Are you familiar with the movie *The Andromeda Strain*?"

3. "Hello, we're from the UN!" (This is guaranteed to get you shot in some locations in the rural West.)

4. "We're from the government. We will help you recover from this incident." (Something else to say to get yourself shot.)

5. "We're from the FBI. We'd like to discuss with you what we monitored you doing through that capsule that landed in your yard."

6. "It landed here only 20 minutes ago? Good, you should still be safe."

7. "It depends on what you mean when you say 'dangerous.'" [L]

8. "You have ten minutes to pack your most important possessions."

9. "Your homeowner's insurance should cover this event."

10. "Look at the tip of this pen, please."

[A] DACRON® is a registered trademark of INVISTA.

[B] Velcro® is a registered trademark of Velcro Industries B.V.

[C] The value of the resistor depends of the triggering device. You may have to experiment with various resistors to find the appropriate value.

[D] Powerpole® is a registered trademark of Anderson Power Products.

[E] Use Wal-Mart's inexpensive stopwatch, the ATQ2. It costs $4.95

[F] Trademark of The Dow Chemical Company

[G] Do not use a piezo speaker, as they require a driver.

[H] Available at places like the Boeing Surplus Sales store in Seattle, WA.

[I] *Chemical Principles and Properties*, Michael J. Sienko and Robert A. Plane, Second Edition, 1974, McGraw Hill.

[J] Converted from units of atmospheres to mb by the author. Use this data along with the table of the Standard Atmosphere in section 5.1.4.

[K] Suggested by Mark Conner

[L] Suggested by my mother, Erma Verhage