PEAK OF FLIGHT NEWSLETTER

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PEAK OF FLIGHT

How to Make Your Own Annular Parachute

By Dave Flanagan

Introduction

The term "annular parachute" actually applies to a whole category of parachutes. The main characteristic of an annular parachute is a giant vent at the apex. Any parachute with a comparatively large apex vent might be termed an annular parachute.

Annular parachutes have been around since World War II but have not seen wide use. Their main claim to fame came in the mid 1970's when an annular parachute was incorporated into a Mid Air Retrieval System (MARS) for air launched cruise missiles and satellites. [1]

Each specific annular parachute has its own set of aerodynamic characteristics, but generally they open more slowly than a normal parachute and oscillate less. The drag coefficient of full scale annular parachutes is reported to be about 0.9 based on total area [2]. It is not known if this value would apply to the small models presented here.

Full scale annular parachutes are "shaped" parachutes – they are sewn from individual gores and the canopy cannot be laid flat. Annular parachutes can also employ several different complex suspension line systems. However the annular parachutes presented here are simple "sport scale" versions that are very easy to build and fly.

Design

The Canopy

As noted, annular parachutes are characterized by large apex vents. But how large is large? One way to quantify this is to use a parameter called "geometric porosity" or just "porosity." Porosity is the ratio of all the area removed from a canopy (apex vents, drive windows, turning slots, etc.) to the original total area of the canopy. Parachute experts use the lower case Greek letter lambda (λ) to indicate porosity. It theoretically ranges from zero (no vents or openings) to one (no canopy)! Porosity is also sometimes expressed as a percent. A regular parachute such as the C9 military emergency personnel parachute has just a small apex vent and its porosity is very low (λ=0.003). The porosity of annular parachutes can be as high as 50% (λ≤0.5). The annular parachute used in the MARS system mentioned above had a porosity of about 43% (λ≈0.43) [1].

The outside diameter (Do) of the sport scale annular parachute is chosen by the modeler based on payload weight. Given this and the desired geometric porosity (λ) the diameter of the vent (Dv) can be calculated.

$$Dv = \sqrt{\lambda}\, Do, \quad 0 \le \lambda \le 1$$

The Suspension Lines

The sport scale annular parachute uses continuous suspension lines. Modelers know these as "over the top" suspension lines. They start where the lines are connected to the payload (called the "suspension line confluence point" by parachute engineers) then go all the way up and over the top of the parachute and back down the other side to the payload. This approach is often used to reinforce regular model rocket parachutes. Annular parachutes described here require continuous suspension lines. Annular parachutes of any significant porosity (λ) will simply not inflate if continuous suspension lines are not used. The result is a streamer with a very low drag coefficient.

Shroud line length should be equal to the outside diameter (Do) of the parachute.

Building an Annular Parachute

The model presented here uses the canopy from a commercial parachute kit (Apogee's 12"/8" kit) for raw material. Using a canopy from a kit is often an advantage when building unusual parachutes. Sometimes much of the geometry is already done for the modeler by the design printed on the canopy. For example the canopy used here has a star pattern on it with 24 points – this makes it easy to locate the attachment points for the eight suspension lines that will be installed on this chute (every third point). The canopy from the Dynastar 32" kit has 36 gores printed on it. Printed patterns may make construction easier.

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The outside diameter of the model in this build is Do=31.6 cm. The value chosen for porosity is a conservative 35% (λ=0.35). Therefore the vent diameter is Dv=18.7 cm.

The first step is to trace the outside and vent diameters on to the canopy stock. It helps to tape the canopy stock to the work surface during this process. To draw the circles the author used a Sharpie marker taped to a machinist's scribing compass, but there are many ways to draw circles – modeler's choice. Line attachment points are also marked. See **Figure 1**.

Figure 1: The outside diameter and the vent diameter are marked on the pattern. The star pattern printed on the canopy makes it easy to locate the line attachment points (black dots).

Next cut the canopy from the stock material. When dealing with polyethylene canopy material a good pair of scissors works well enough on the outside circumference but a hobby knife is better for cutting along the vent circumference. See **Figure 2**. Note – if the vent material is removed cleanly it can be used as a canopy for another parachute!

Suspension lines are installed one by one. On small polyethylene models such as this each continuous line is taped to the canopy in four places – at each vent boundary and at each outside boundary. See **Figure 3**.

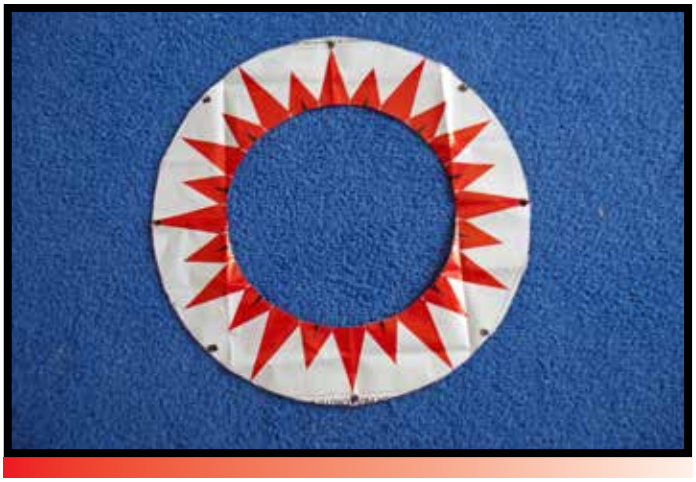

Figure 2: The canopy is cut from the stock material and is ready for installation of the suspension lines. Thirty five percent of the area has been removed.

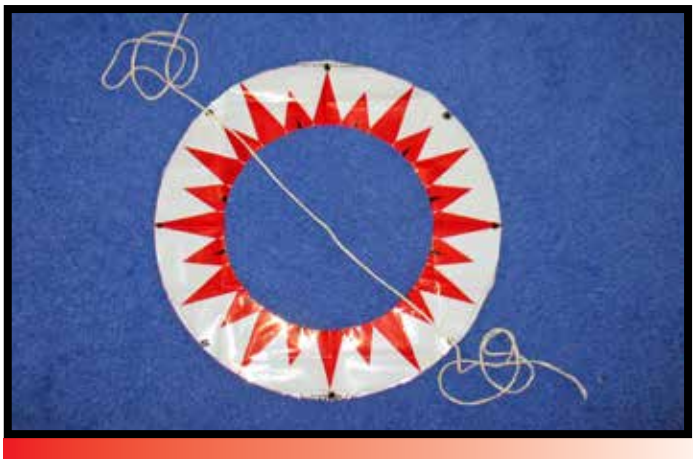

Figure 3: The first of four continuous suspension lines is installed.

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Figure 4 shows all lines installed. The four continuous suspension lines provide eight "shroud lines." The parts of the lines spanning the vent are called "crown lines."

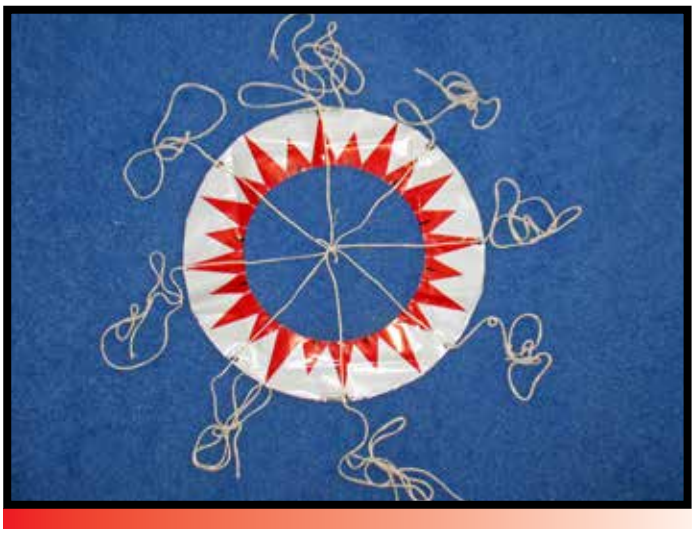

Figure 4: All lines are installed. A short piece of line is tied around the crown lines where they cross in the center of the vent. This helps to control the crown lines during packing and deployment.

Once all the lines are installed they are gathered together and, in the case of small models, secured with an overhand knot. Shroud line length is equal to the outside diameter (Do=31.6 cm). The completed annular parachute is shown in **Figure 5**.

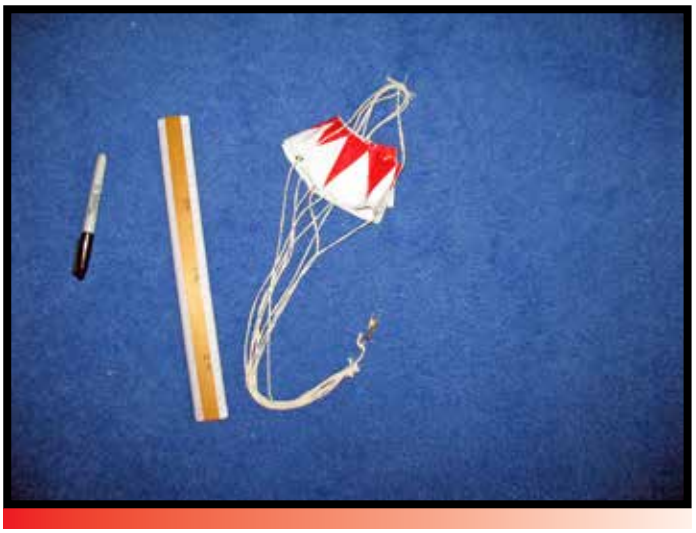

Figure 5: The completed annular parachute.

There is an alternate way of installing the suspension lines that some modelers might prefer. Rather than continuous lines spanning the vent area, each line can be installed individually. Excess line material is provided in the vent area during line installation. Once all the lines are installed the excess line is gathered and knotted at a distance of one half the diameter of the vent (Dv) to create the crown lines. This technique is useful when the parachute is large compared to the available work area. See **Figure 6**.

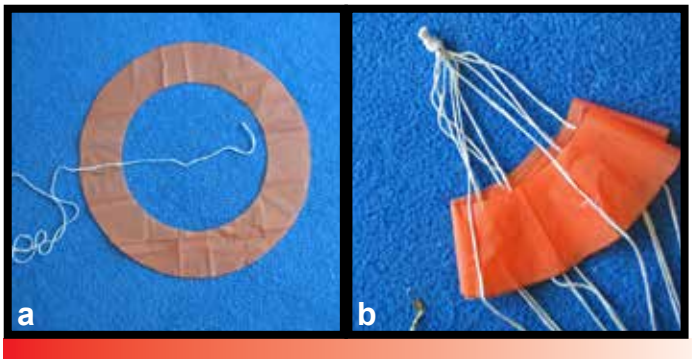

Figure 6: The alternate method of installing the lines is shown. (a) The first line is installed. Note the extra line material in the vent area. (b) Lines have been gathered, knotted, and the excess trimmed off. This canopy has an outside diameter of Do=40 cm and a porosity of λ=0.4 and was cut from an Apogee 24" parachute kit canopy.

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Packing the Annular Parachute

Lay the parachute on its side and secure the payload attachment point. While holding the crown lines at their apex, clear all of the canopy material from the center of the canopy – none of the gores should be nested in other gores, folded over, or tangled in lines. Clearing the gores is the most critical step. Lay the crown lines onto the stacked gores and fold the stacked gores in half to cover the crown lines. Roll the resulting package up into the shroud lines while keeping the lines taut (the reliability of all parachutes is improved by keeping the lines taut while packing!) See **Figure 7**.

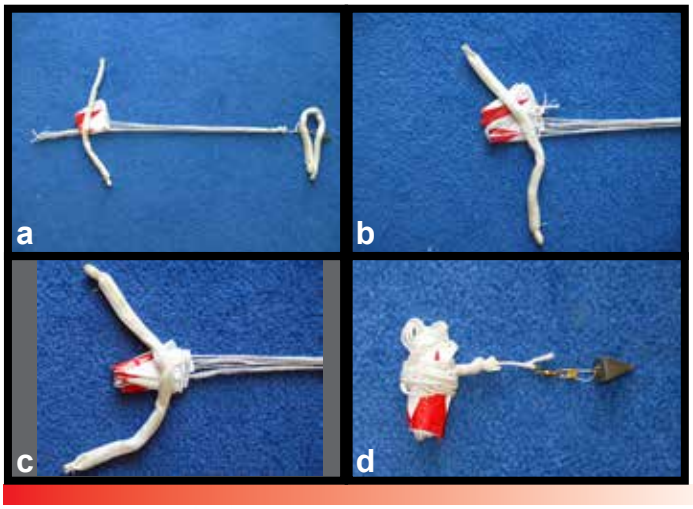

Figure 7: (a) The payload end is secured and (important!) all eight gores are cleared from within the canopy and lines, straightened, and stacked to one side on top of each other. (b) The crown lines are folded down onto the stacked gores, (c) the stacked gores are folded over the crown lines, and (d) while keeping the lines taut the canopy is rolled up into the lines. Note: The white tubular item seen in the figures is a small version of the "shot bags" used by parachute riggers to control a canopy during packing. These shot bags are made by filling small sections of tubular nylon with lead shot and tying off the ends. They are very useful tools!

There is a packing shortcut: It begins by securing the payload attachment point by stepping on it. Then while holding the crown lines in one hand use the other hand to straighten, clear, and stack the gores. The stacked gores are then folded in half over the crown lines as noted above. From that point it is easy to roll the canopy into the main suspension lines while keeping the lines taut. See **Figure 8**.

Figure 8. A shortcut particularly useful for larger models in the field begins by securing the payload attachment point by stepping on it. Hold the crown lines with one hand, clear the gores with the other hand, then continue the packing process.

When building a new type of parachute, "toss testing" the model is highly recommended. Toss testing will show the modeler the unique characteristics of the parachute particularly as they relate to reliable deployment. With the annular parachute the most critical step is to clear all of the gores. No gore should nest within another gore or be folded up or be tangled in any lines.

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Figure 9 shows the completed Do = 31.6 cm. λ = 0.35 annular parachute during toss testing.

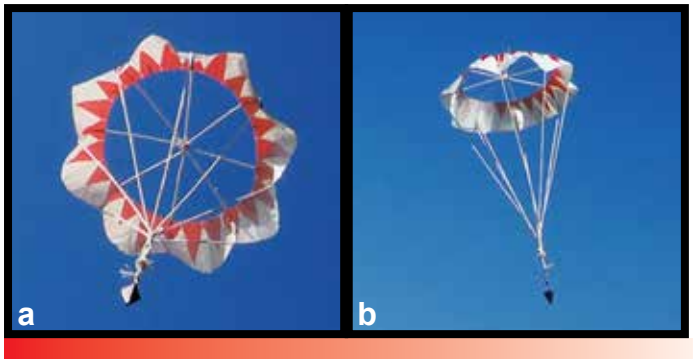

Figure 9a and 9b. Thirty five percent of the area of this parachute has been removed.

Figure 10. The annular parachute with suspension lines installed using the alternate method is shown during toss testing. No difference in performance was noted. Forty percent of the area of this parachute has been removed (λ=0.40).

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Figure 11. A Do=40 cm annular parachute model with half of the area removed (λ=0.50).

Extra for Experts

To the best of the author's knowledge, sport scale annular parachutes have never been studied. No one knows anything about them, even simple data like an approximate drag coefficient. There is ample subject matter for many research projects. The following observations and remarks may help guide future work.

In addition to several other annular parachutes made over the years the author fabricated and "toss tested" four sport scale models specifically for this article. Some are shown in the **Figures 1-11**. The models are described in **Table 1**.

Stock Canopy Material	Do (cm)	λ	Dv (cm)	Lines	Observations
Apogee 12"/8" Kit	31.6	0.35	18.7	8	Works great. Open reliably
Apogee 24" Kit	40.0	0.40	25.3	10	Works great. Open reliably
Dynastar 32" Kit	76.0	0.50	53.7	12	Hard toss test due to size.
GBP*	40.0	0.50	28.3	10	Opens ugly but reliably

Table 1: Summary of models. *GBP: A hi-tech polymer sometimes known as "garbage bag plastic."

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Porosity, Suspension Lines, and Canopy Loading

In general the sport scale annular parachute does not inflate quickly or in an orderly fashion (this is also true of full scale annular parachutes). There may be a correlation between porosity, the number of suspension lines, and the filling time of the parachute. More suspension lines may allow higher porosities by providing more support for the canopy material. However more lines may also slow the deployment since more lines create more gores which seem to individually flutter, inflate, and deflate several times during the parachute inflation process. See **Figure 12**.

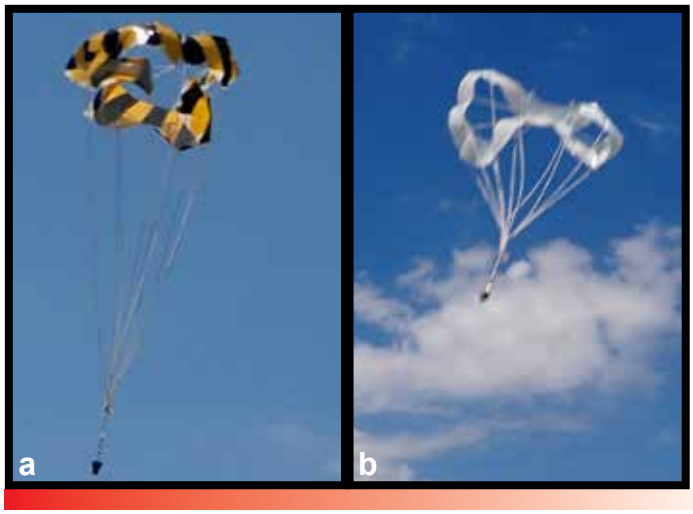

Figure 12a and 12b. Examples of the irregular deployment of annular parachutes as seen during toss testing. Porosity of each parachute is λ λ=0.50.

All of the parachutes in **Table 1** opened reliably during toss testing except for the largest (which also had the most lines). In most cases it was not possible to achieve the altitude required for complete deployment by toss testing. However, this model did eventually inflate when towed outside the window of the author's truck at ~10 mph (about 4.5 m/s). Note that the other parachute with same porosity (λ=0.50) but smaller and having fewer lines opened reliably. **Figure 13** shows both parachutes.

Figure 13. (a) Do=76 cm and the (b) Do=40 cm models are shown inflated in the breeze. Porosity of each model is λ=0.50.

An interesting research project would involve video analysis of the deployment sequence of different annular parachute models.

Clustering

Sometimes parachutes, like rocket motors, are used in clusters. An example is the Apollo capsule which returned to earth under three large parachutes. Can sport scale annular parachutes be used in clusters? Their unique inflation characteristics could cause mutual interference and prevent the canopies from opening. No one knows.

Circular vs. Polygonal Annular Parachutes

Almost all full scale parachutes including annular parachutes are based on regular polygons (n-gons), although these polygons have so many sides that the parachutes appear circular. Model parachutes used for small rockets are also polygonal but have very few

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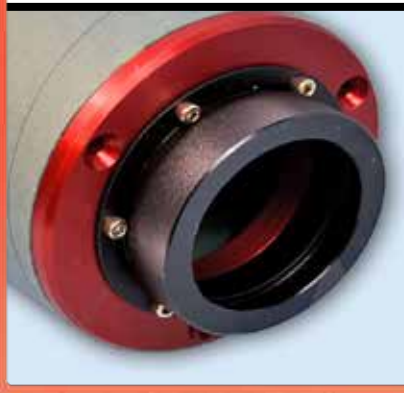
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sides (e.g., hexagonal n=6, octagonal n=8). Can annular parachutes be made from such canopies? Should the vent be circular or polygonal? How large can the vent be? No one knows.

Suspension Line Systems

Suspension line systems differ among full scale annular parachute designs. One variation is an apex line that pulls the crown lines down and partially inverts the parachute. The sport scale annular parachute is very sensitive to apex line length adjustments - too much inversion collapses the canopy (rather quickly!). However, some adjustment may improve the drag coefficient. Again, no one knows.

Canopy Shape

Most annular parachute canopies are not flat. Some are modeled after portions of a sphere: Consider two parallel planes intersecting a sphere in one of its hemispheres – the portion of the sphere between the two planes describes the canopy shape. Another version involves a similarly derived section of a right circular cone. Modelers with a background in geometry and some sewing experience can explore these canopy shapes.

Years ago the author designed a shaped annular parachute. See **Figure 14**.

To see it fly: https://youtu.be/-N9XU1K1YTQ. Also courtesy of Northeast Florida Association of Rocketry NRA 563/TRA35 obtained from www.nefar.net

Have fun!

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1. Fallon, E.J., J. Watkins, & E. Vickery, “The Annular Parachute”. AIAA 86-2449, AIAA Aerodynamic Decelerator and Balloon Technology Conference, October 1986.

2. Knacke, T. W., “Parachute Recovery Systems Design Manual”, NWC-TP-6575, March 1991.

About the Author

Dave is a registered professional engineer with over twenty years of aerospace experience at NASA’s JSC and MSFC. He holds bachelors and masters degrees in engineering and a bachelors degree in science, and while at MSFC supported NASA’s University Student Launch Initiative. Although no longer actively jumping, he holds an expert skydiver rating and is a former Army paratrooper. Dave is a FAA certified master parachute rigger and has completed the AIAA Parachute Systems Technology Short Course. He is a licensed private pilot and a certified ultralight pilot. Dave is retired and spends most of his time scuba diving and kayaking but does occasionally fly model rockets, usually ones recovered by weird looking parachutes.

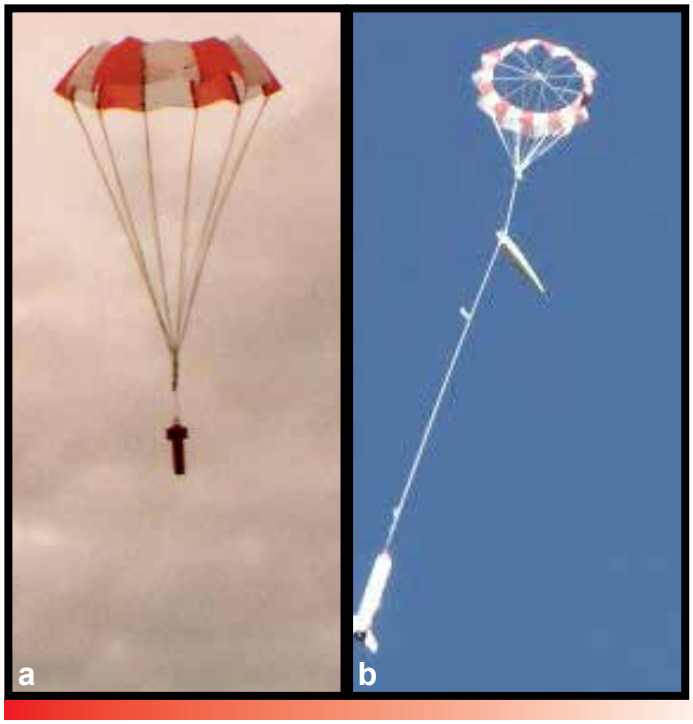
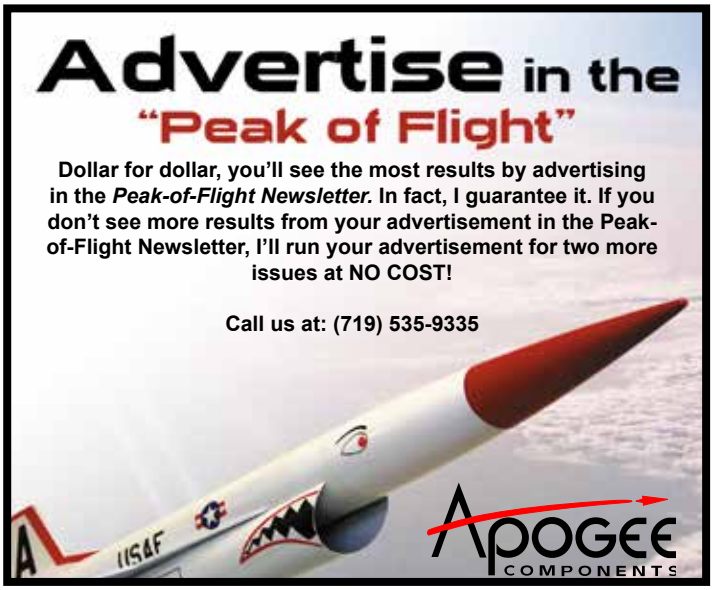
Figure 14. A Do=40 cm annular parachute based on a surface of revolution created by rotating the top surface of the NACA 4424 airfoil oriented at a particular angle of attack around a vertical axis as seen (a) during toss testing and (b) during flight. Figure 14b courtesy of Northeast Florida Association of Rocketry NRA 563/TRA35 obtained from www.nefar.net .