PEAK OF FLIGHT NEWSLETTER

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IN THIS ISSUE

GUIDE CHUTE FOR SMALLER ROCKETS

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PEAK OF FLIGHT

Guide Chute for Smaller Rockets

By David Flanagan

Guide chutes are small, very stable, non-gliding, low drag parachutes. They support dual deployment when a parachute release mechanism is used. A guide chute is ejected from the rocket at apogee along with the rest of the recovery system and opens immediately. Used properly, it keeps the main parachute (contained in a parachute release) in "clean air" above all other components so the main chute can deploy without fouling. The high speed descent (sometimes called "droguefall") that occurs before main chute deployment limits the distance the rocket will drift during recovery.

Without guide chutes bad things can happen. Figure 1 is a frame grab from a video of the recovery sequence of a Super Big Bertha. Clearly the parachute was "below" the rocket when it was released and some part of the rocket fell into it. The resulting mess then fell freely until impact.

FIGURE 1: RECOVERY SYSTEM FAILURE OF A SUPER BIG BERTHA

It is surprising that this doesn't happen more often. Each rocket has a minimum of three aerodynamically active components (air frame, nose, and the parachute in its release) connected by tethers (e.g., shock cords, bridles) all tumbling freely. Inevitably there will be times the main parachute package is below some other component or perhaps a tether when the parachute is released.

A guide chute prevents this. See Tim Van Milligan's Peak of Flight article for an introduction to guide chutes. https://www.apogeerockets.com/education/downloads/Newsletter451.pdf

The Problem

The only commercially available guide chute is one called the Truncated Cone Decelerator (TCD) made by Dino Chutes. It is a smaller version of a TCD designed by Dr. Jean Potvin of St. Louis University. Dino Chute's TCD is sewn from nylon and the smallest size available is about 30 cm in diameter and 80 cm long. It is too large for smaller rockets. When Tim Van Milligan first flew the smallest Dino Chute TCD it slowed the rocket down much more than necessary during droguefall – to about 36 ft/s (11 m/s). In contrast NASA's Student Launch Initiative (SLI) guidelines suggest 70-100 ft/s (21-31 m/s) for droguefall.

So no small guide chutes are currently available for lower power rockets that also use the chute release. If you want to launch a smaller 2" or 3" diameter rocket under, say 'E' or 'F' power no reasonably sized guide chute is available – until now.

The Original TCD

Let's call Dr. Potvin's Truncated Cone Decelerator as manufactured by Dino Chutes the "Original TCD." Mathematically it is a cone, but it has a square base. We would normally consider it a pyramid. It has four triangular sides and an

Continued on page 3

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Guide Chute for Smaller Rockets

Continued from page 2

oddly truncated (removed) apex. The gore pattern consists of two adjacent isosceles triangles modified by the truncation (see Figure 2).

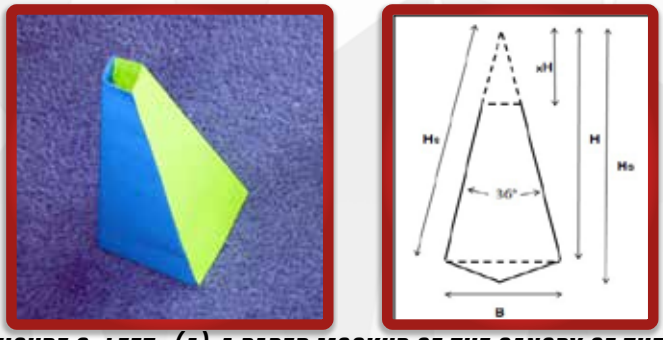

FIGURE 2: LEFT: (A) A PAPER MOCKUP OF THE CANOPY OF THE ORIGINAL TCD IS SHOWN. ALTHOUGH GEOMETRICALLY A PYRAMID, IN-FLIGHT THE PARACHUTE APPEARS CONICAL. RIGHT: (B) THE GORE PATTERN AS ADAPTED FROM REFERENCE 3 (NOT TO SCALE.) THE RATIO H/B IS 63/41 OR 1.5366. THE RATIO HS/H IS 1.0516. THE VALUE OF 'X' SHOULD BE 0.2 OR LESS. TWO GORES ARE REQUIRED TO FORM THE CANOPY. SUSPENSION LINES, ONE ON EACH CORNER, ARE 'H' LONG.

I was able to make several Original TCD's that were much smaller than the Dino Chute versions. I used that special high tech parachute material we all know as GBP (garbage bag plastic) and also common parachute nylon (F-111). Figure 3 shows one built from GBP.

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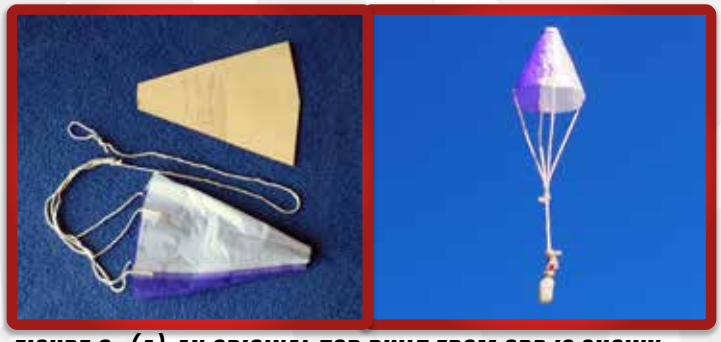

FIGURE 3: (A) AN ORIGINAL TCD BUILT FROM GBP IS SHOWN WITH ITS GORE PATTERN, AND (B) TOSS TESTING AN ORIGINAL TCD. ITS DIAMETER IS ABOUT 13 CM.

Original TCD's work well. If you want to build one all the design information you need is in Figure 2, and you can use the construction techniques described below. There is even a computer program to help you design an Original TCD. It is found at https://www.pcprg.com/tcdcprog.htm. It can be used on the website or downloaded to your computer.

However there is a simpler method of creating a Truncated Cone Decelerator. It is based on a concept very familiar to most experienced rocketeers. I call it the "Shroud TCD".

The Shroud TCD

Any time a rocket design uses body tubes of two different diameters on the same axis, a transition piece must be used. The transition piece connects the two different diameters and creates the desired shoulder or reducer or boat tail. Many times a solid adapter is available for this but often a custom shroud must be made of cardboard or similar material. The formulas for making a shroud are well known

Continued on page 4

Guide Chute for Smaller Rockets

Continued from page 3

(see Figure 4 below).

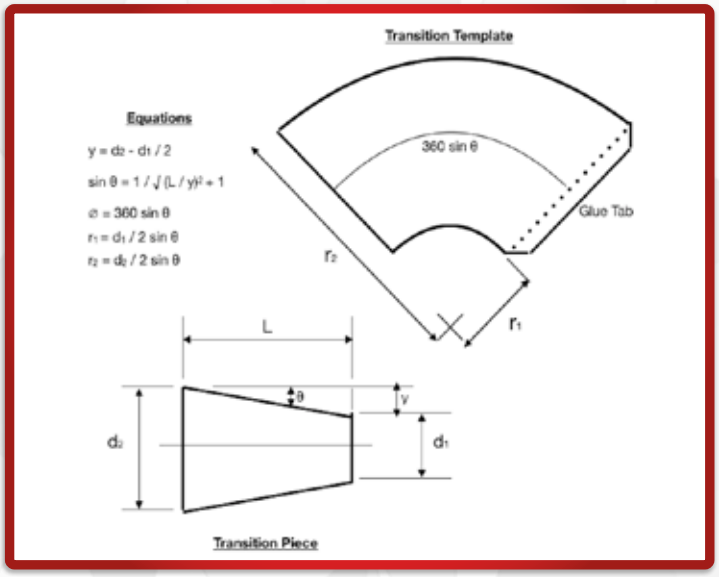

FIGURE 4: FORMULAS FOR MAKING A SHROUD BASED ON THE TWO DIAMETERS AND THE LENGTH OF THE TRANSITION PIECE [4.]

However, it turns out that the shroud formulas can also be used to make a parachute canopy!

The aerodynamic characteristics of the Original TCD are known, so I wanted to develop a Shroud TCD that was as close to the Original TCD as possible. There were several ways to mathematically convert the geometry of an Original TCD to a Shroud TCD. I made several paper mockups of the canopies produced by different approaches and built several models. The differences among the Shroud TCD "candidates" were extremely minor. The paper canopy mockups were all nearly identical to each other. During toss testing of models the various candidates looked identical to each other and to the Original TCD (see Figure 5). So I chose the adaptation which seemed mathematically the closest to the Original TCD.

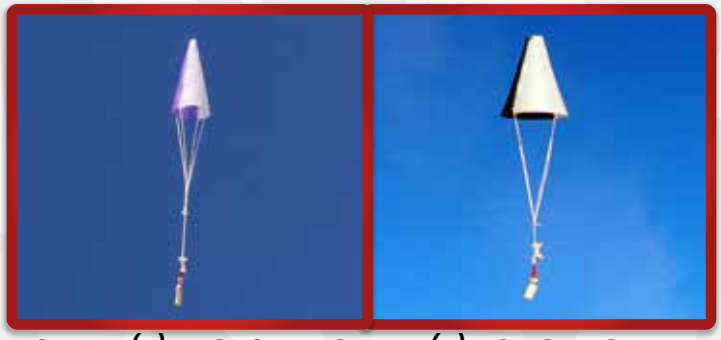

FIGURE 5: (A) AN ORIGINAL TCD, AND (B) A SHROUD TCD DURING TOSS TESTING.

To design a transition piece for a rocket we need the two diameters and the length of the piece (Figure 4). The same is true for the Shroud TCD canopy. The "design data" for large diameter (main opening), the smaller diameter (apex vent), and the length (height) of the Shroud TCD canopy are given in Table 1 for the selected adaptation of the Original TCD. These dimensions are given in terms of the larger diameter (d2) which I chose as the reference dimension for the Shroud TCD.

However, since the canopy geometry here is fixed, the "build data" produced by the shroud calculations is also directly related to the reference dimension (d2) and is included in Table 1. Your shroud pattern data can be directly calculated from the build data.

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Continued on page 5

Guide Chute for Smaller Rockets

Continued from page 4

Design Data	
Larger Diameter (d_2)	$1.0*d_2$
Smaller Diameter (d_1)	$0.20*d_2$
Length (L)	$2.00*d_2$
Build Data	
Shorter Radius (r_1)	$0.51*d_2$
Longer Radius (r_2)	$2.55*d_2$
Angle (ϕ)	70.6°

TABLE 1: SHROUD TCD DESIGN AND BUILD DATA. THE MINIMUM LENGTH OF THE FOUR SUSPENSION LINES IS EQUAL TO R2. REFERENCE FIGURE 4.

Building a Shroud TCD

It is very easy to make small Shroud TCD's from garbage bag plastic. First select a size for your Shroud TCD by choosing a value of d2. This is the diameter of the main opening. A good value of d2 for your first Shroud TCD made from GBP is between 10 and 15 centimeters. Then calculate build data using Table 1 and construct a pattern. I use old file folders for pattern stock. Remember that the angular value phi (ϕ) is for a shroud that wraps all the way around a rocket. Since you need two gores (for symmetry) this value must be divided by two when making your pattern. (You can actually use as many gores as you want by dividing ϕ appropriately).

Then two gores are then traced out on stock canopy material. Add a "seam allowance" along one edge of each gore. See Figure 6.

FIGURE 6: TWO GORES AND THEIR PATTERN FOR A SMALL SHROUD TCD ARE SHOWN. NOTE THE EXTRA "SEAM ALLOWANCE" ALONG THE RIGHT EDGE OF EACH GORE.

Gores of a plastic TCD are joined together with (believe it or not) a single strip of…..tape. Use "invisible" tape. This tape has a frosted appearance until it is applied after which it becomes clear. I use the cheap tape from the dollar store. Don't use thick tape or clear tape or cellophane tape or packaging tape. Light, flexible, "invisible" tape is required. Selecting the correct tape is important to avoid undue stiffness.

Align the gores to be joined very carefully and immobilize them (see Figure 7). You get one and only one chance to tape a seam correctly – no "do overs." Use an extra-long piece of tape. I basically tape the canopy to the work surface at the top and bottom of the seam during this process. Once the tape is firmly in place on the gore seam I trim the excess tape from both ends using a hobby knife.

Continued on page 6

Guide Chute for Smaller Rockets

Continued from page 5

FIGURE 7: A GORE SEAM IS READY FOR TAPING. GORES ARE ALIGNED CORRECTLY AND SECURED. FOR THIS SEAM THE ORANGE GORE (RIGHT) OVERLAPS THE SEAM ALLOWANCE OF THE BLUE GORE.

When both seams are complete the canopy should look like Figure 8. Inspect the inside of the canopy to make sure no sticky surface of tape is exposed. This could cause the TCD to fail. Talcum powder can be used to foul any sticky areas.

FIGURE 8: THE COMPLETED CANOPY IS SHOWN. TO SEE HOW WELL YOU DID SLIDE YOUR PATTERN FULLY INTO THE COMPLETED CANOPY. THERE SHOULD BE NO SERIOUS WRINKLES OR DEFORMITIES.

Now install the four suspension lines. Minimum suspension line length is equivalent to r2 in Table 1. Two lines are installed, one line on each taped gore seam, and two others are installed one each on the middle of each of the two gores. Use tape, not sticky dots. Make one of the four lines very long so after knotting the lines at the payload end, the long one can be used as a bridle. See Figure 9.

FIGURE 9: THE COMPLETED SHROUD TCD. NOTE THE LONG BRIDLE SO THAT THE MAIN CHUTE WILL OPEN ALONGSIDE THE BRIDLE AND NOT TANGLE WITH THE SHROUD TCD ITSELF.

Shroud TCD's can also be sewn from parachute nylon (e.g., F-111) in small sizes. I made one prototype with a diameter of d2=10 cm but had to ignore certain standard practices of parachute construction to do so. I believe that an expert with a sewing machine (which I am not) could make one as small as d2=15 cm using accepted best practices for making model rocket parachutes.

Flight Preparation

The bridle of a TCD is connected to the same location as the main parachute riser. A TCD is packed for flight much

Continued on page 7

Guide Chute for Smaller Rockets

Continued from page 6

like any other parachute – spike it, s-fold it, and place it in the rocket. It is important that it be on top of the rest of the recovery system. Do not wrap any lines around the s-folded canopy unless absolutely necessary. The TCD must be the first thing out and must open quickly.

Cold Weather Deployments

Parachutes made from GBP sometimes take a "set" in cold weather which can interfere with full deployment. Adding tape to one (to make gore seams) might aggravate the problem. To test this I prepared a TCD made of GBP for toss testing and packed it very tightly, even wrapping the lines around the s-folded canopy (not recommended for flight). I placed it in my freezer for a couple hours, carried it outside in a frozen koozie, and immediately tossed it upwind. It opened within just a few feet and was not deformed upon landing. See Figure 10.

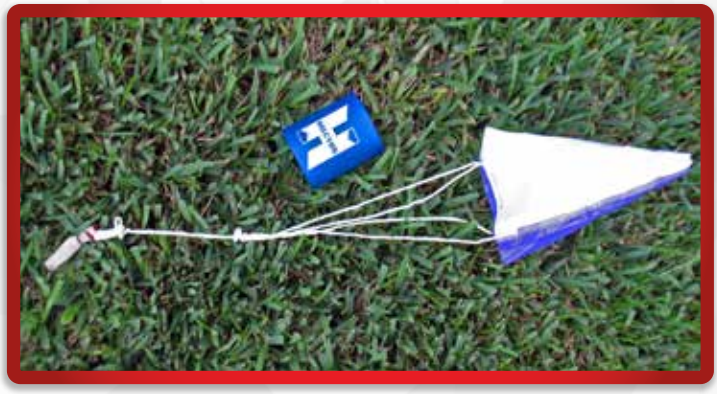

FIGURE 10: THIS PICTURE OF A TCD MADE FROM GBP WAS TAKEN SECONDS AFTER LANDING FOLLOWING A COLD WEATHER DEPLOYMENT TEST. THERE WERE NO INFLATION ISSUES.

Initial Flight Tests

Eight initial flight tests were completed. Flying field constraints dictated only low altitude tests. The test vehicle was a scratch built rocket constructed from BT80 and powered by 18 mm motors ("C" series in this case). It has a huge parachute compartment, is extremely lightweight, and has large fins for stability. I normally use it for low altitude tests of main parachute designs. Figure 11 shows the test configuration during terminal descent.

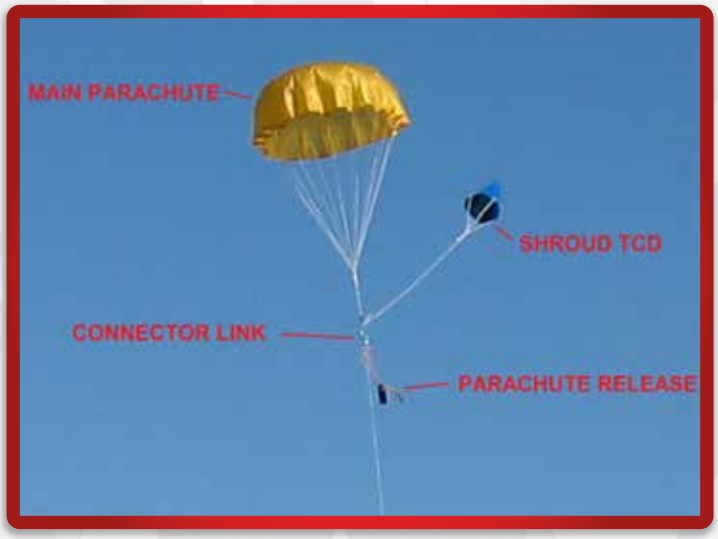

FIGURE 11: DETAILS OF THE FLIGHT CONFIGURATION ARE SHOWN. FOUR ITEMS ARE INDIVIDUALLY SECURED TO THE MAIN CONNECTOR LINK – THE MAIN PARACHUTE RISER, THE LONG BRIDLE LEADING TO THE SHROUD TCD, THE SHOCK CORD LEADING TO THE ROCKET NOSE AND AIRFRAME, AND THE SAFETY LANYARD THAT SECURES THE PARACHUTE RELEASE.

In all flights the deployment of the guide chute was successful but due to the small size of the Shroud TCD (d2=10 cm) and/or the light weight of the airframe, there were times that the airframe floated above the other components during droguefall. However all recoveries were successful and lessons were learned.

One lesson is that a minimum size for a Shroud TCD is probably greater than d2=10 cm. The Shroud TCD used here was the largest model available at the field (d2=10 cm), but it did not quite get the job done because of the light weight of the rocket airframe. Had a more typical (heavier) rocket been used (e.g., a BT70 airframe with a 24 mm motor) this small Shroud TCD would probably have worked fine. See the "Extra for Experts" section on page 9 if you want to get deeper into the weeds on this subject.

Another observation involves the behavior of the Shroud TCD in droguefall. The payload of a TCD is the main parachute constrained in its release. It is connected to the rest of the rocket. Any time this payload experienced a horizontal force from another rocket component via the shock cord it appeared to induce an angle of attack to the TCD. This seemed to make the TCD and main chute subassembly momentarily "glide" away from the rest of the falling com-

Continued on page 8

Guide Chute for Smaller Rockets

Continued from page 7

ponents. Again because of the low altitude of these tests droguefall periods were very short, so this needs further investigation.

Future Work/Research

The Shroud TCD presented here has a fixed geometry based on one mathematical interpretation of the Original TCD's geometry. However the shroud formulas (Figure 4) provide for infinite variations. Some variations might provide different desirable aerodynamic characteristics. Note there are pitfalls. If the area of the apex vent exceeded 25% of the area of the main opening, the Original TCD either did not inflate or executed a series of inflation/collapse cycles during descent. Also, if the cone is too "flat" (indicated by larger values of ϕ) the TCD becomes too much like a regular parachute. If it is too "tall" (smaller values of ϕ) perhaps the TCD becomes a streamer due to the vent issue noted above. Toss test all models before flying.

The actual material ("cloth") area of a Shroud TCD may be needed for some research. Based on the build data r1, r2, and ϕ it is:

$$S = \left(\frac{\phi}{360}\right)\pi\left(r_2^2 - 2r_1^2\right)$$

where ϕ is in degrees.

Extra For Experts

Precisely sizing any TCD for a particular rocket is not a well-established process. We know the TCD and it's payload (the main chute in its chute release) needs to have a slower terminal velocity than any other rocket component in droguefall. However we don't need to haul out the drag equation and individually calculate the terminal velocities of each component. We can use the ballistic coefficient of each component instead to determine relative terminal velocities of the various components. The ballistic coefficient can be obtained from the drag equation. In scalar form the steady state drag equation for each component of the rocket is:

$$D = mg = \frac{\rho}{2}v^2 C_D S$$

where 'ρ' is the air density, and 'g' is the acceleration of gravity, 'm' is the mass of the body, 'S' is its reference area, and 'CD' is its drag coefficient. Solving for the terminal velocity:

$$v^2 = \frac{2mg}{\rho C_D S}$$

Now each component of the rocket in droguefall has its own characteristic mass, area, and drag coefficient, but all of them are affected by the same values of air density and the acceleration of gravity. So define a new constant 'k' such that:

$$k^2 = \frac{2g}{\rho}$$

And the terminal velocity becomes:

$$v^2 = k^2\frac{m}{C_D S} \quad or \quad v = k\sqrt{\frac{m}{C_D S}}$$

The value under the radical is the ballistic coefficient, usually symbolized by the Greek letter beta (β),

$$\beta = \frac{m}{C_D S}$$

so the terminal velocity of a component then becomes:

Continued on page 9

Guide Chute for Smaller Rockets

Continued from page 8

$$v = k\sqrt{\beta}$$

Thus to determine relative steady state fall rates of the various components of our rocket we need only compare their ballistic coefficients. Components with higher ballistic coefficients generally have faster terminal velocities and vice versa. We want β of the TCD with its parachute package to be less than the β of all other components so it remains "above" the rest of the components in droguefall.

Finding β for any Shroud TCD and its payload is straightforward. Drop tests of the Original TCD show the drag coefficient is Cd~1.08 referenced to the area of its main opening. Since the Original and Shroud TCD's are indistinguishable in flight this seems a good approximation of the Shroud TCD's drag coefficient as well. The area 'S' of the Shroud TCD is calculated from its diameter (d2). Finally mass can be obtained by weighing the Shroud TCD, the parachute release, and the main parachute on a small scale.

Estimating a "worst case" (lowest) β for other components is more difficult. While any mass 'm' can be determined by weighing, and worst case (maximum) cross sectional areas 'S' of body tubes and fins can determined, drag coefficients are harder to estimate. This is also true for noses, payload sections and other components. This area needs further work.

Have fun!

Acknowledgements

I am grateful to the developer of the Truncated Cone Decelerator, Dr. Jean Potvin, PhD, for an email exchange regarding some aspects of his TCD as described in his paper (reference 3). I am indebted to the videographers of the Northeast Florida Association of Rocketry (NAR #563, TRA#35) – the "frame grab" in Figure 1 was shamelessly lifted from a video on the Association's public website. Mr. Al Witkowski of Katabasis Engineering provided useful comments regarding the ballistic coefficient. Finally I would like to thank Mr. Pat Butler of Dino Chutes for providing the details of his TCD's.

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About the Author

Dave is a retired professional engineer with over twenty years of aerospace experience at NASA's JSC and MSFC. He holds B.S. and M.S. degrees in engineering and a B.S. 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 was a paratrooper in the Army. Dave is an FAA certified master parachute rigger and has completed the AIAA Parachute Systems Technology Short Course. He is a licensed private pilot and an EAA certified ultralight pilot. Dave lives in Florida and spends most of his time scuba diving and kayaking but does occasionally fly rockets, usually ones recovered by very weird looking parachutes.