PEAK OF FLIGHT NEWSLETTER

ISSUE 505 / OCTOBER 1ST 2019

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THE "MARS" PARACHUTE!

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PEAK OF FLIGHT

The "Mars" Parachute!

By Dave Flanagan

Introduction

Invented in the early 1960's, the Disk-Gap-Band parachute (DGB) has a very unique place in the history of space exploration [1]. When the Huygens probe (which used three DGB's) went ripping through the thin atmosphere of Saturn's moon Titan, it was the greatest distance from earth that any parachute had ever been deployed [2]. Closer to home a DGB was used in the re-entry phase of the Stardust Sample Return Capsule (SRC), the mission that captured and returned comet particles in 2006. A spacecraft called OSIRIS-REx is now visiting the asteroid Bennu and will use a DGB as part of its SRC recovery system [3]. However, the DGB's main claim to fame is all of the Mars missions it has supported. All of NASA's Mars Lander missions dating back to the Viking Program in the 1970s have used Disk-Gap-Band parachutes at some point during their entry, descent and landing (EDL) phase. Most recently the Mars InSight mission that landed on Mars in November 2018 required a DGB, and one has been selected for the upcoming Mars 2020 mission [3], [4].

Smaller rockets don't function in the high velocity and low-density conditions that are found during a planetary probe's EDL phase (at least not on purpose!). However, the Disk-Gap-Band parachute is a very unusual and historic parachute, and it is a fun parachute to build and fly.

The Disk-Gap-Band Parachute

The main components of a disk-gap-band chute are best described by its name – there is a Disk on top that looks much like a normal parachute, a Band wrapped around the upper part of the suspension lines, and a Gap between the two. Think about a tin can. The Disk would be one end of the can. Then a small distance away from the end of the can a band would be wrapped around the can. The gap in between is, well, the gap. Figure 1 shows the basic layout of the canopy components. However, when inflated the DGB looks much different – see Figures 2 and 3.

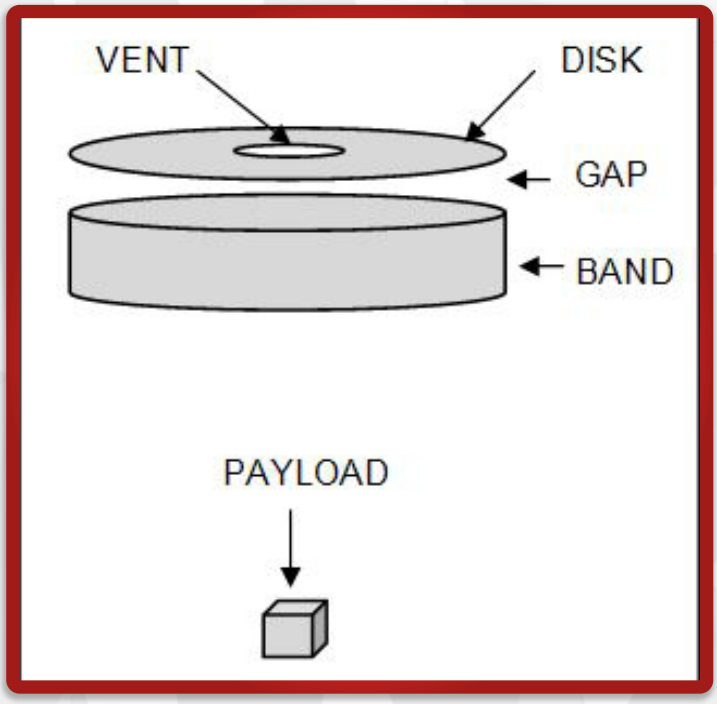

FIGURE 1 - THE BASIC GEOMETRY OF THE DISK-GAP-BAND PARACHUTE IS SHOWN. SUSPENSION LINES ARE NOT SHOWN. NOT TO ANY SCALE.

FIGURE 2 - THE MARS INSIGHT DGB DURING TESTING IN THE WORLD'S LARGEST WIND TUNNEL. THE TUNNEL HAS AN 80 FT X 120 FT TEST SECTION ABOUT 300 FT LONG. (CREDIT: NASA/JPL-CALTECH/LOCKHEED MARTIN AS OBTAINED FROM REFERENCE 4)

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FIGURE 3 - THE PHOENIX MARS LANDER DGB DURING A DROP TEST. NOTE THE VERY LONG AND LARGE NUMBER OF SUSPENSION LINES. (CREDIT: NASA/JPL CALTECH)

Just looking at the geometry it seems there are many combinations of disks, gaps, and bands that can be arranged to create a DGB parachute, and this is true. However, with the exception of the Mars Pathfinder program and the Mars Exploration Rover program [5], the major changes to the DGB from program to program have mostly involved the size of the DGB and the materials used in its construction. The general geometry of most DGB's today remains quite similar to that of the same old successful Viking DGB. This article will focus on that Viking DGB.

Advantages/Disadvantages

Generally speaking a full scale DGB has a slightly lower drag coefficient than a regular or "flat circular" parachute (as they are technically called). The drag coefficient for a DGB is about 0.6 as opposed to 0.8 for the flat circular parachute. However it is a bit more stable - a flat circular parachute can oscillate up to 40 degrees from vertical while a DGB generally will oscillate less than 25 degrees. DGBs open more softly as well, having an "opening force coefficient" of about 1.3 as opposed to a value of 1.7 for a flat circular chute [6]. But as always, remember that these numbers apply to full scale parachutes used in harsh environments.

Building the Disk-Gap-Band Parachute

Building a DGB is straightforward. The Disk, like most model rocket and full scale parachutes, is based on a regular polygon (n-gon), and the Band is just a strip of material like a streamer. The Gap between them requires no material at all.

In the following, the names of the important components (Disk, Gap, Band, and Vent) will continue to be capitalized to make it clear the author is referring to a specific component of a DGB.

The Disk of the full scale Viking DGB is almost 40 ft in

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diameter. As noted it is actually not circular – it is a regular polygon with 48 sides (n=48, or a 48-gon). It would be difficult to scale this down to a size suitable for low or even medium power rocketry. Even the Disks of many of the Viking DGB wind tunnel models (about 4 ft in diameter) were made from polygons with only 24 sides (24-gons) [7]. For use in low to medium power rocketry, polygons of 6 to 16 sides (6 ≤ n ≤ 16) will work fine. The modeler must choose a value for 'n' keeping in mind that, as will be shown below, larger values of 'n' produce more realistic results.

For this parachute the best reference dimension for scaling is the inscribed radius of the polygon that makes up the Disk. In geometry, the inscribed radius of any regular polygon has a special name - the "apothem" – which is symbolized by 'a'. Given a value for 'a' and the modeler's selection of 'n' all the other necessary dimensions for construction are readily calculated from Table 1.

Parameter	Value
Inscribed Diameter of Disk	2*a
Diameter of the Apex Vent of Disk	0.193*a
Height of the Gap Between Disk and Band	0.116*a
Height of the Band	0.333*a
Length of Band (Disk Perimeter)	2*n*a*tan(180/n)
Length of Suspension Lines (Below the Band)	4.6*a

TABLE 1 - BASIC DIMENSIONS OF THE VIKING DGB (ADAPTED FROM REFERENCE 7).

Although it is not required, with model parachutes (or any other model) it is often very convenient to develop a spreadsheet that will calculate all the necessary dimensions for construction given a selected input. This will help the modeler plan the project. See Table 2.

Viking DGB Design Spreadsheet - Based on AIAA 73-454	
Inputs:	
16	=Number of Sides of the Disk Polygon (n>5)
25	=Length of Apothem (a) of Disk Polygon
Outputs:	
22.50	=Apex Angle of Single Gore
2.4100	=Radius of the Apex Vent
4.8200	=Diameter of Apex Vent
2.8950	=Height of the Gap
8.3250	=Height of the Band
9.9456	=Edge Length of Band - Single Gore
4.9728	=One Half Edge Length
159.1299	=Total Length of Band - All Gores
115.0000	=Suspension Line Length

TABLE 2 - DESIGN SPREADSHEET FOR THE BLACK DGB MODEL FEATURED IN THIS ARTICLE IS SHOWN. THE YELLOW CELLS ARE INPUTS. LINEAR DIMENSIONS IN THIS EXAMPLE ARE IN CENTIMETERS.

It is often very useful to make some kind of pattern to guide construction. The needed dimensions can be written on the pattern, or the output from a design spreadsheet can simply be taped to it.

Construction should begin with the Disk. For the n=16 polygon of the Disk presented here, stock polyethylene material was folded over and then folded again to produce four layers. Then the pattern was used to trace and then cut out just one quarter of the Disk. Unfolding the resulting product yielded the completed Disk.

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FIGURE 4 - THE PATTERN FOR ONE GORE OF THE DISK IS SHOWN. ONE SIDE (LEFT) SHOWS GAUGES FOR THE BAND HEIGHT AND THE GAP HEIGHT. THE OUTPUT FROM A DESIGN SPREADSHEET IS TAPED TO THE REVERSE SIDE (RIGHT). THE HOLE DESCRIBES THE APEX VENT.

FIGURE 5 - THE COMPLETED DISK WITH PATTERN IS SHOWN. THE INSCRIBED DIAMETER OF THE DISK IS 50 CM (2*A = 50 CM).

The Band of a model DGB resembles a streamer – long (the length when wrapped around the suspension lines) and narrow (the height). Unless the modeler is fortunate, limitations of stock material will require that the Band be installed in sections. Calculate the total length required (see Table 1) and figure out how many sections are needed. Cut them to length but allow for a little overlap between sections.

FIGURE 6 - THE DISK OF THE MODEL DGB IS SHOWN WITH THE FOUR SECTIONS OF MATERIAL THAT WILL MAKE UP THE BAND.

There are two ways to complete the construction of the DGB. One is to first install all the suspensions lines on the Disk, then go back and install the Band. The other is to install the Band as you install the suspension lines on the Disk. In the author's opinion the latter is the better option.

Figure 7 shows the start of the process.

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FIGURE 7 - THE FIRST SUSPENSION LINE IS ATTACHED TO THE DISK WITH TAPE. THE GAP GAUGE ON THE PATTERN IS USED TO POSITION THE BAND BELOW THE DISK WHICH CREATES THE GAP. THE SUSPENSION LINE IS THEN TAPED TO THE BAND AT THE TOP AND BOTTOM.

This process continues until the end of the section of the Band is reached. The next section of the Band is attached to the installed section with a slight overlap. Both sides of the splice are taped at the top and bottom.

As the process continues, the completed sections of the parachute's Disk and Band become tangled and wadded up and difficult to control. The best way to manage this is with a series of weights (whatever is handy). First stabilize the section of the Disk. Then stabilize the section of the Band in the correct orientation with respect to the Disk using the gap gauge on the pattern. Ignore the rest of the parachute – it can be untangled later. Once all the parts are stable the suspension line can be correctly installed. See Figure 8.

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FIGURE 8 - THE DISK AND BAND ARE CONTROLLED DURING ASSEMBLY WITH WEIGHTS. THE GAP GAUGE ON THE PATTERN IS USED TO POSITION THE BAND WITH RESPECT TO THE DISK.

One option for easier assembly of the Band that is as yet unexplored by the author would be to use a cylindrical form of some sort. As noted the DGB components can be considered part of a right circular cylinder (see Figure 1). Perhaps a large coffee can or waste basket or something with a similar cylindrical shape could be installed horizontally on some type of stand. The Gap height could be marked on cylinder at the correct distance from one end. The suspension lines would then be installed on the Disk. The Band could then be draped over the cylinder and then installed on the suspension lines one by one.

Once the suspension lines and the Band are installed gather the lines together, and making sure they are all the same length, tie an overhand knot. Technically, the suspension line length of a Viking DGB is supposed to be 2.3 times the diameter of the Disk (4.6*a), and this measurement starts at the bottom of the Band. This is much longer than the sus-

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pension line length of a regular parachute and can be inconvenient when preparing the DGB for use in a rocket. Although long lines are necessary to reduce both the opening shock and the oscillation of the parachute at full scale they are not needed here. Feel free to shorten them. After all, this is a sport scale project, not a scale project. How much? Modeler's choice, but the author likes 1.5 times the inscribed diameter of the Disk, or 3*a.

Preparing the DGB for launch is similar to preparing a regular parachute. However, when holding the DGB up by its apex Vent before "s-folding" it, it is a good idea to make sure that at least most of the "loops" of the Band are pulled outside of the lines.

FIGURE 9 - THE KEY FEATURES OF THE DGB (DISK, VENT, GAP, AND BAND) ARE CLEAR IN THIS PHOTO.

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FIGURE 10 - TWO VIEWS OF THE DGB DURING TOSS TESTING. (TOSS TESTING IS ALWAYS A GOOD IDEA WHEN DEALING WITH A NEW PARACHUTE DESIGN!)

The Disk of the black DGB shown above has 16 sides (n=16) and its inscribed diameter is 50 cm (a=25 cm). It is possible to make DGBs with fewer sides but these will not appear quite as realistic. The red DGB shown below is very small and its Disk has only half the number of sides as the black DGB shown above. It is still interesting to build and fly but it is not as realistic as the black DGB. Nevertheless, for a modeler's first DGB it might be a perfect size.

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FIGURE 11 - THE DISK OF THIS SMALL RED DGB HAS 8 SIDES (N=8) AND AN INSCRIBED DIAMETER OF 20 CENTIMETERS (A=10 CM).

The Disk of the white DGB shown below is slightly larger than the red DGB but has even fewer sides. It is not very realistic.

FIGURE 12. - A DGB WITH A DISK HAVING ONLY 6 SIDES (N=6) AND AN INSCRIBED DIAMETER OF 30 CM (A=15 CM).

Clearly, the greater the value of 'n', the more realistic the resulting DGB will be.

Alternate Approach

Modelers that do not care to bother with polygons and their geometry can simply use a circular Disk as opposed to a polygonal Disk. The diameter of the Disk would be 2*a as shown in Table 1. The Gap height and Band height would also be as shown in Table 1. However, the length of the Band as wrapped around the suspension lines would be the same as the circumference of the circular Disk, i.e., 2*π*a. One advantage of this approach is that the modeler doesn't have to decide ahead of time how many suspension lines to use. A disadvantage of this approach is that it is more difficult to use the "gap gauge" to position the Band when the Disk is circular. The Disk and Band sections for one such model are shown in Figure 13.

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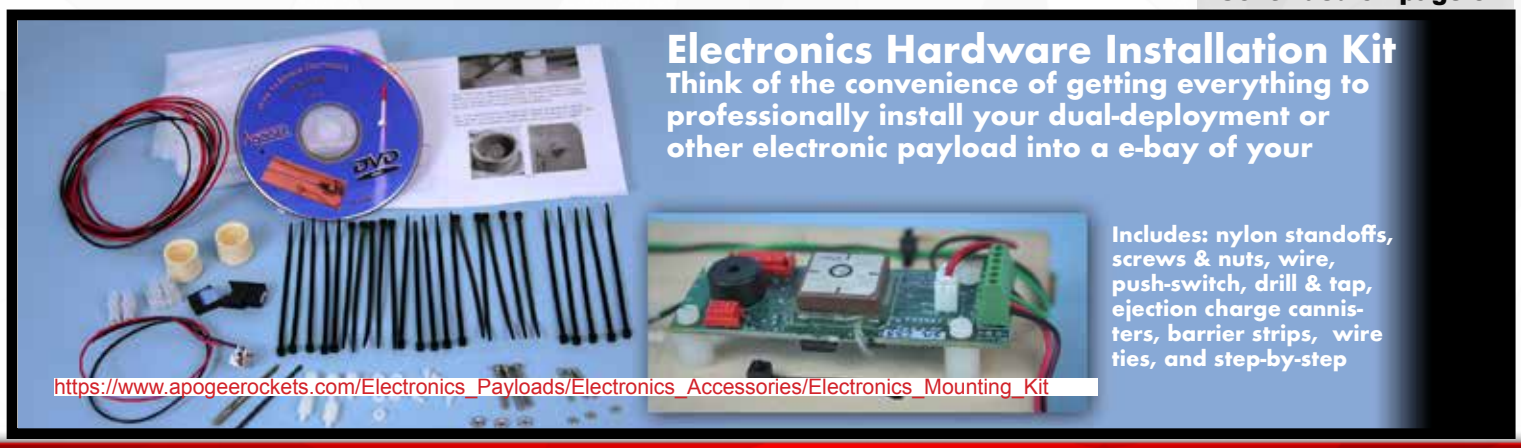

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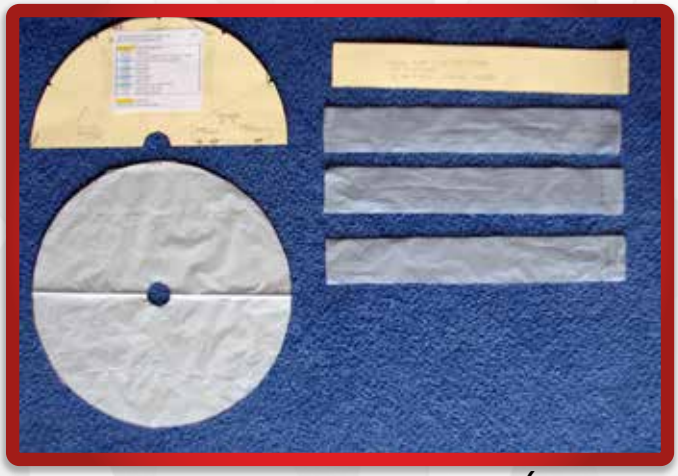

FIGURE 13 - THE DISK AND BAND COMPONENTS (AND THEIR PATTERNS) FOR A DGB HAVING A TRULY CIRCULAR (INSTEAD OF POLYGONAL) DISK ARE SHOWN.

Extra for Experts

The DGB is one of the most thoroughly studied parachutes of all time. Reference 8 describes one of many studies. However, most studies did not focus on models for use in the recovery systems of small sport rockets at low speeds, so there still might be a few things to look at.

For example, much wind tunnel testing has been done on models constructed with as a many gores and suspension lines as possible given the test facility in order to reflect as closely as possible the design of a larger full scale DGB. Would a model with as few suspension lines as possible have a higher drag coefficient than one with more lines? After all, to recover today's model rockets, large "real" parachutes with many suspension lines are modeled with as few as six or eight suspension lines. Parachute models (of all types) with fewer lines do not resemble their full scale counterparts very well but may actually be more efficient.

Also, parachutes that recover model or amateur rockets usually suspend two interconnected masses (nose and airframe.) Coupled with the parachute this is essentially a compound pendulum with an unsteady suspension point. Does this affect the performance of the parachute compared to a single mass payload such as a Mars lander?

Finally, two construction approaches are given above, one in which the Disk is a polygon and one in which the Disk is circular. If the two types of DGBs were built with the same number of lines which would have the higher drag coefficient?

It might be useful for researchers to have the equation for the area of a polygon on hand. In terms of the number of sides 'n' and the apothem 'a' the area of a regular polygon is:

Eq.1 $$S=a^2 n \tan(180/n)$$

The equation for the perimeter of a regular polygon (for determining Band length as wrapped around the suspension lines) is:

Eq.2 $$P=2an \tan(180/n)$$

The equations for the area and perimeter of a circle are well known.

Have fun!

Acknowledgement

The author is greatly indebted to Mr. Allen Witkowski for his review of this article. Mr. Witkowski is founder and Princi-

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pal of Katabasis Engineering, LLC, a firm specializing in aerospace engineering and management with focus on planetary probe decelerators. He has over 30 years of experience with Disk-Gap-Band parachutes and has designed and qualified all NASA probe decelerators over that period. The DGB used for the InSight mission that landed on Mars in November 2018 was Mr. Witkowski's 8th DGB supporting Mars landings.

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About The Author

Dave is a professional engineer with well over twenty years of aerospace experience at NASA's JSC and MSFC. He holds bachelors and masters degrees in engineering avnd 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 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 very weird parachutes.