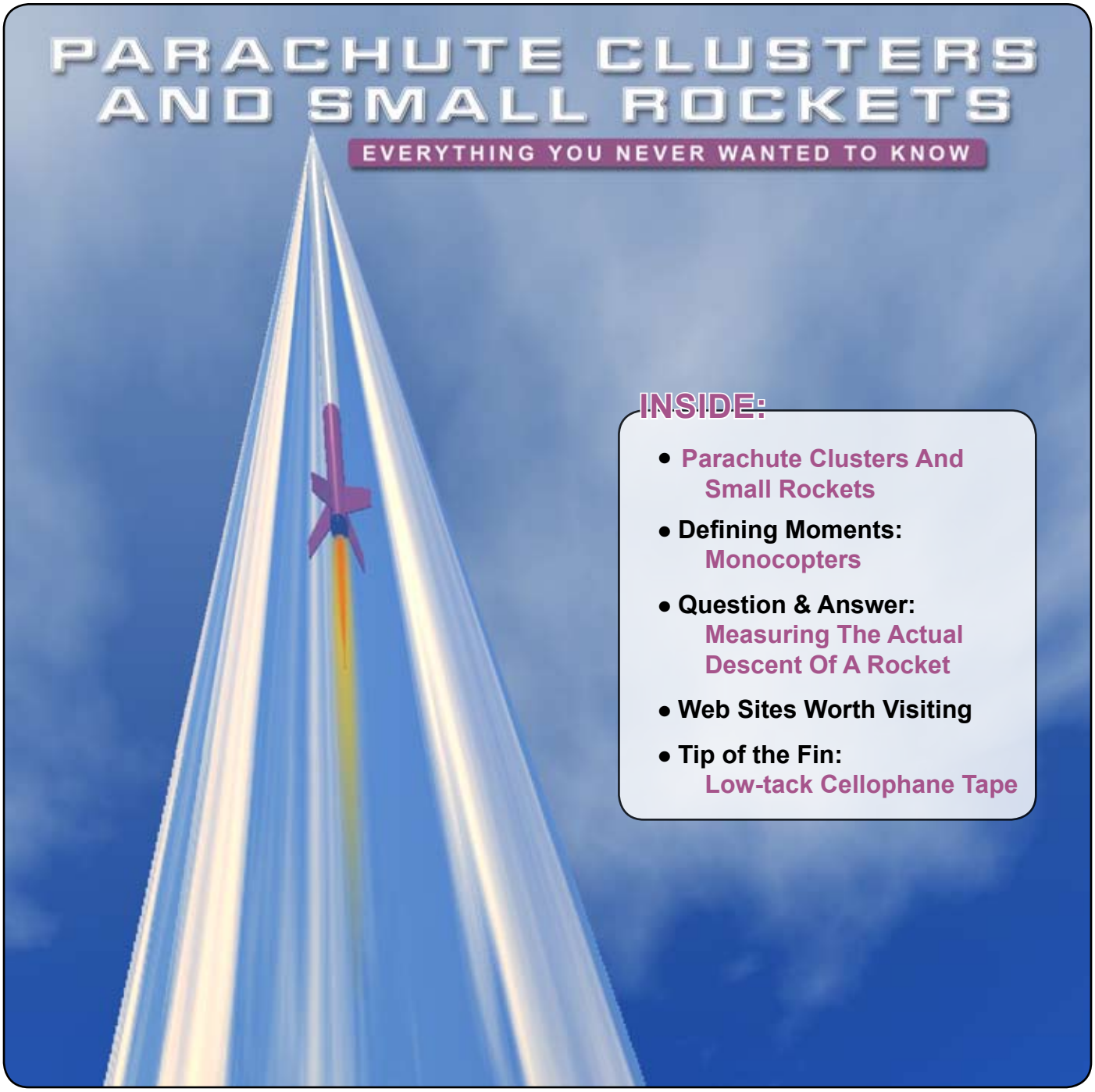
ISSUE 187 - JULY 3, 2007

APOGEE PEAK OF FLIGHT NEWSLETTER

PARACHUTE CLUSTERS AND SMALL ROCKETS

EVERYTHING YOU NEVER WANTED TO KNOW



INSIDE:

- Parachute Clusters And Small Rockets
- Defining Moments: Monocopters
- Question & Answer: Measuring The Actual Descent Of A Rocket
- Web Sites Worth Visiting
- Tip of the Fin: Low-tack Cellophane Tape

APOGEE COMPONENTS

3355 Fillmore Ridge Hts
Colorado Springs, Colorado 80907-9024 USA
www.ApogeeRockets.com e-mail: orders@ApogeeRockets.com
Phone: 719-535-9335 fax: 719-534-9050

Parachute Clusters and Small Rockets

Everything You Never Wanted To Know

By David T. Flanagan

Introduction

Most amateur rocketeers know something about parachutes used in clusters. Many know that all of NASA's Apollo command modules returned to earth under a cluster of three parachutes. NASA also uses three canopies to land each Shuttle solid rocket booster. Some rocketeers may even be familiar with military systems which use multiple canopies to supply ground troops. However, clustered parachute systems aren't used much in the small rocket world. True, normally clusters are not needed, but sometimes they are useful, and they are fun to experiment with!

Figure 1. Apollo 16 returns under a cluster of three parachutes.
Photo courtesy of NASA-JSC

Advantages

Clusters have several advantages over single parachute recovery systems. Two that may apply to small rockets are:

Redundancy

If each canopy in a cluster is individually attached to the payload, then the structural failure of one parachute may not result in the total loss of the payload. The Apollo 15 mission is probably the best known example of this benefit of clusters. After reentry one recovery parachute collapsed shortly after opening. The capsule and crew landed safely under the remaining two chutes [1].

Figure 2. Apollo 15 lands safely under two of the three recovery parachutes. One parachute failed as a result of being burned by RCS fuel vented during the nominal overboard dump. Photo courtesy of NASA-JSC

Stability

There are also occasions in which a payload needs to be very stable during descent. Oscillation might affect pictures or video taken with a camera mounted in the payload. Or stability during descent might be needed to insure the proper orientation of the rocket (a "lander" of some sort) at touchdown. A cluster of three or more parachutes will provide improved stability [3].

Disadvantages

There are some disadvantages to using clustered parachute systems that may affect modelers.

Cost

One disadvantage of clusters is the cost. Generally a cluster of two or more parachutes is more expensive than an equivalent single parachute.

Continued on page 3

About this Newsletter
You can subscribe to receive this e-zine FREE at the Apogee Components web site (www.ApogeeRockets.com), or by sending an e-mail to: ezine@apogeerockets.com with "SUBSCRIBE" as the subject line of the message.

Newsletter Staff
Writer: Dave Virga
Layout / Cover Artist: Dave Curtis
Proofreader: Michelle Mason

Continued from page 2

Weight and Volume

Clusters also weigh more, and take up more space in a payload (rocket) than an equivalent single parachute.

Rigging and Deployment

Clusters are more complicated than a single parachute. They also have problems during opening. Canopies of a cluster usually do not open at the same time – some lead while others lag. The leading chute(s) bear the worst of the opening shock. There is no way to predict which canopy will open first so all chutes have to be strong enough to open first. This adds to the weight and volume of the system. Much research has been performed trying to cure "lead-lag" but it is still a problem [4]. Also, the methods of reducing lead lag that do exist are very complicated and not easily adapted to small systems.

Figure 3. This view looks straight up into a deploying cluster of six chutes. One of the three white chutes has taken the lead and is blanking out the other two white chutes and the three orange ones. Photo by author.

Drag Loss

Parachutes in a cluster interfere with each other. Instead of flying directly over a payload like a single parachute does, canopies of a cluster fly "tipped over" at some angle of attack. This reduces their efficiency. One study showed an 8% decrease in drag coefficient in a cluster of four canopies of a full scale system [3]. No one knows by how much efficiency is reduced in small systems. Drag loss could be even worse. The author has noted that in small systems with light payloads (e.g., small rockets) the canopies appear to fly at much greater angles of attack than the canopies in full scale clusters (compare Figure 4 or Figure 5 with Figure 1 to see this.) Parachutes are generally less efficient at such high angles of attack.

Figure 4.

Figure 4. In this backyard "toss test" the canopies of this tricluster fly at high angles of attack, probably due to the low canopy loading of the system. Photo by author.

Parachute Cluster Guidelines

Dispite these disadvatages, clusters are still useful and experimenting with them is fun. When building and using a clustered parachute system the following information might help. Much of it is taken from literature which describes research on *full scale systems*, and some of it comes from the author's model experience. To the best of the author's knowledge no real research has been done on cluster systems used in small rockets. It is a new frontier, so please use these guidelines cautiously.

Parachute Type

All parachutes in a cluster must be identical. Parachutes must be of the same size and type and be made of the same material. They should be of the ballistic (non-gliding) type but other than that there is no restriction on type.

Effective Rigging Line Length (ERL)

Effective rigging line length (ERL) is the British term for a very important concept. It can be defined as *the distance between the payload attachment point (or riser confluence point) and the skirts (hems) of the parachutes in the cluster when the recovery system is stretched out flat.*

The purpose of the ERL is to reduce the amount of interference between the chutes in a cluster. Yes, two or more parachutes can be hooked directly to a pay-

Continued on page 4

Continued from page 3

load but they will interfere with each other very badly. Efficiency will be lost. If more than five are connected in that manner at least one collapses [3]. A proper ERL is needed to avoid this.

Generally the ERL is calculated by

$$ERL = \sqrt{n}\,D$$

where D is the diameter of a parachute in the cluster.

The British use the inflated diameter for "D" which is about 65% to 70% of the constructed or "flat" diameter, but for small systems it is definitely better to use the flat diameter [5][3].

The mathematically inclined might notice that the ERL is the diameter of a parachute having an area equivalent to the total parachute area in the cluster.

$$ERL = \sqrt{\frac{4}{\pi}\left(n\frac{\pi}{4}D^2\right)} = D_{equivalent}$$

The ERL is a minimum value. Longer is OK, shorter is not.

Another reason to maintain a proper ERL is something called "forebody wake effect." This can apply to single parachutes as well, if they are rigged too close to the payload. Basically the air flowing past the payload (forebody) produces a wake which can interfere with the parachute(s). Up to 25% of parachute drag can be lost [6]. Keeping a sufficient distance between the payload and the parachute minimizes this risk. Notice in Figure 5 the separation between the canopies and the payload.

Riser Systems – To Cascade or Not to Cascade?

The member parachutes of a cluster each generally have suspension line lengths equal in length to their diameter. These lines are gathered at the suspension line "confluence point." When a single parachute is used its confluence point might be attached directly to the payload. However, in a cluster there must be a riser that connects the confluence point of each individual parachute to the payload in order to maintain the minimum ERL.

If the cluster has more than three parachutes, there are two choices for the type of riser system. Each parachute can be connected to the payload individually using a single long riser, or the parachutes can be divided into smaller "subclusters" which are in turn connected to the payload by other risers (cascaded risers). The former provides greater redundancy, the latter is a little easier to handle and may be a bit lighter.

One test showed that with clusters of five or more canopies, cascaded riser systems are needed to prevent riser "wrap-up" during long descents [3].

Examples

Below are examples based on clusters made with parachutes twelve inches in diameter (D=12".)

If we use two chutes we apply the ERL formula for n=2 and D=12".

$$ERL = \sqrt{2}\,12'' = 17.0''$$

So the distance from the payload to the skirts of the parachutes must be about 17". The suspension lines of the parachutes already provide 12" of this length, so we really need only a 5" length of riser between the payload and each of the line confluences of the parachutes.

For a cluster of three parachutes (a tricluster) the answer is similar. We use n=3 instead of n=2 in the formula and our ERL for the tricluster is ERL=20.8". Again, 12" of this is supplied by the parachute suspension lines so our risers need only be 8.8" long.

For a cluster of six 12" chutes we would need much longer risers. By the same method, the ERL is 29.4", but again subtracting the contribution of the 12" suspension lines, the riser length needed for each of the six chutes is 17.4."

Continued on page 5

Continued from page 4

Since the cluster has more than three parachutes, a "cascade" riser system can be selected. For the six parachutes it works like this: Divide the six chutes into two "subclusters" of three chutes each. Treat each subcluster as an independent cluster. Thus we would need three bridles 8.8" long to join the three chutes together in the subcluster, just like we calculated above. Each of the two subclusters is then connected to the payload by another riser. The total ERL for the cluster of six parachutes is still ERL=29.4". However, the subclusters account for 20.8" of this, so the remaining two risers need only be 8.6" long.

Figure 5a. This rear engine ejection model is recovered by a 6:3,2 cluster of D=12" nylon chutes. Notice each parachute's high angle of attack possibly due to the low canopy loading. Photo by author.

Figure 5b. Sketch of the 6:3,2 cluster shown in Figure 5a

Figure 5 shows a cluster of six parachutes with this arrangement. Note that the single long riser connecting the riser system confluence to the model does not count as part of the ERL. Remember that the purpose of the ERL is to allow the canopies to separate. The single long riser does not help this. It does count towards eliminating any forebody wake effect.

The parachutes in this system could also be arranged as three subclusters of two chutes each instead of the two subclusters of three chutes each discussed above. This would be a 6:2,3 array. The key is the ERL.

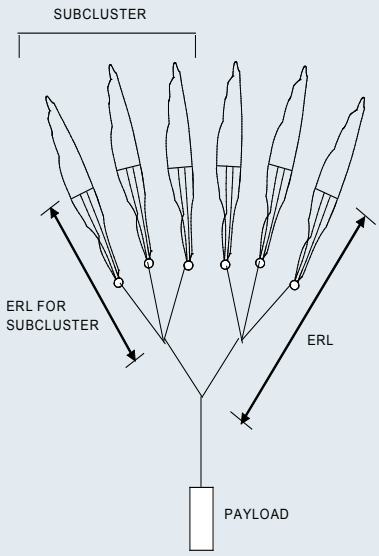


Figure 5b.

In all cases the skirt or hem of the chutes is 29.4" from the payload (or riser system confluence point.)

This can get wild and crazy. By way of demonstration, many years ago the author used a cluster of eight 8" diameter polyethylene kit chutes (n=8, D=8") arranged in a three level cascade riser system to recover a 5 N-sec powered stock Estes Arcas model. Each pair of chutes was connected together as a terminal subcluster. Each pair of terminal subclusters was joined together as an intermediate subcluster (four chutes). Finally the two intermediate subclusters of four chutes each were joined together and attached to the rocket. The ERL's were maintained at all three levels. This assembly can be referred to as a 8:2,2,2 cluster array. Eight chutes total, 2 in the terminal subcluster, 2 terminal subclusters in each of 2 intermediate subclusters, and 2 intermediate subclusters joined together and attached to the rocket. A rather poor photo (scanned from a print) of this assembly is shown in Figure 6.

The strange nomenclature (e.g., 8:2,2,2, and 6:3,2) is the author's way of keeping track of large, complex clusters and is not used to describe full scale systems.

Continued on page 6

Continued from page 5

Note the product of all the numbers to the right of the colon must equal the number to the left of the colon.

The largest known cluster (in terms of the number of canopies) had 19 parachutes! This was a special test performed by the British early in the development of clustered parachute systems around World War II. Member parachutes were of an unusual design and each parachute was attached to the payload by its own riser [5].

Figure 6. A cluster of eight D=8" kit chutes used to recover a stock Estes Arcas. A three tiered cascade riser system was used. Photo by author.

Rigging and Deployment

One cause of malfunctions in any parachute system is an *out of sequence deployment*. This happens when parts of the parachute system are exposed to the air before they should be. Generally the canopy portion of the parachute should not be allowed to start filling until the lines are already fully deployed. This is why the Carlisle method of folding chutes works for modelers – we wrap the canopy up in the lines and it cannot fill until the lines are already deployed [7]. Keep this in mind when working with any parachute system

Stack and Pack

Smaller, simpler clusters don't require much more effort to prepare for use than single parachutes. The easiest way to rig a small cluster is to stretch the system out taut, stack the canopies together and S-fold them to fit the rocket. Wrap the suspension lines *lightly* around the canopies. Then S-fold most of the risers onto that package and finally, wrap a just a little of the remaining riser material around the whole assembly. After ejection the package will unroll first, then the S-folded riser will stretch out, and finally the suspension lines will unroll from around the canopies, allowing them to fill. The author has successfully deployed clusters of four chutes like this.

Deployment Bags

Modelers with intermediate size systems might want to use a cheap, expendable deployment bag to better control the deployment sequence. They are not difficult to make. The author has used a simple tube taped up from a piece of garbage bag plastic and open at both ends to contain the canopy portions of the parachutes of a cluster. On the top end of the tube a small chute called a pilot chute is attached. The size of the pilot chute is unimportant but is generally smaller than the canopies in the cluster. Once the parachute canopies are stacked together and contained in the plastic tube, S-fold the pilot chute on top of the tube. Fold the tube in half to cover the pilot chute. Wrap the suspension lines of the cluster and as much of the risers as you are comfortable with around the folded tube and place it in the rocket.

Upon ejection the risers and suspension lines unwrap completely, finally the tube of canopies is exposed and unfolds. This frees the pilot chute to inflate which pulls the plastic tube from the canopies, exposing them to the air stream all at once. Note that the deployment bag and pilot chute assembly is so light it is seldom recovered.

Please note that this system, which is technically more of a deployment sleeve than a deployment bag, bears only a small resemblance to the method used to deploy "full scale" cluster systems. However, the author has deployed a cluster of twelve 12" diameter nylon chutes using this method.

Truly large (e.g., high power) systems will need to resemble full scale systems. The canopies of the cluster

Continued on page 7

Continued from page 5

might be contained in a deployment bag with the lines stowed in rubber bands on the side of the bag. In such a system the drogue parachute is ejected at high altitude and stabilizes the rocket for most of the descent. At the proper lower altitude a pyro would fire, releasing the drogue chute. A "lazy leg" bridle connecting the drogue chute to the deployment bag would then deploy the bag from the airframe and serve as a pilot chute for deployment of the cluster.

An advantage the modeler sometimes has that is not available to the parachute engineer working with large full scale chutes is the availability of the toss test. If there is any doubt about how the system is rigged, attach a dummy payload and do a toss test.

Summary

Clusters can provide redundancy and stability to model rocket systems although they add complexity, weight, volume, and cost to that system. Until more research is performed on very small systems, guidelines for designing clusters used in full scale systems as adapted and presented here should be followed cautiously.

Acknowledgement

The author thanks Dr. Calvin K. Lee, Ph.D., of the U.S. Army's Natick Soldier Research Development and Engineering Center. A research and development specialist on parachute opening aerodynamics, clustered parachute systems, improved methods for parachute performance, and personnel landing dynamics, Dr. Lee's insight was extremely valuable in preparing this article.

About The Author

Mr. Flanagan holds degrees in life sciences and mechanical engineering and is a registered professional engineer in several states. He has held both research and engineering positions with contractors at NASA -JSC, and is currently with Jacobs Engineering at NASA - MSFC supporting the Experimental Fluids and Environmental Test Branch. He is a licensed airplane pilot, ultralight pilot, an expert scuba diver and a former Army paratrooper. He has had a life long interest in parachutes and made his first sky dive at the age of 17. He has made several hundred parachute jumps, holds a master parachute rigger certificate from the FAA, and has completed the University of Minnesota Parachute Technology Short Course. He continues to monitor developments in the field of "aerodynamic decelerators", has made models of most types of parachutes, and has flown most of them in model rockets. He lives in Madison, Alabama, with his wife and two cats.

References

1. *Apollo Experience Report – Earth Landing System*, R. B. West, NASA TN D 7437, November 1973.

2. *Space Shuttle SRB Light Weight Recovery System*, R. E. Runkle and D. F. Wolfe, AIAA Paper 95-1594, 1995.

3. *An Experimental Study of the Performance of Clustered Parachutes in a Low Speed Wind Tunnel*, B. K. Baca, AIAA Paper 84-0822, 1984.

4. *Controlled Opening Method for Clustered Parachute Systems*, C. K. Lee and J. E. Sadeck, Journal of Aircraft, Vol 29, No 2 March-April 1992.

5. *Parachutes*, W. D. Brown, Sir Isaac Pitman & Sons, London, England, ca. 1942 - 1948.

6. *Reduction in Parachute Drag Due to Forebody Wake Effect*, C. W. Peterson and D. W. Johnson, AIAA Paper 81-1939, 1989

7. *Handbook of Model Rocketry*, G. Harry Stine, 6th ed., John Wiley & Sons, New York, NY 1994

DEFINING MOMENTS

Monocopters

A monocopter is a very unique type of aircraft that was inspired by a maple seed. While a typical helicopter rotor design has two or more equal blades to balance the rotational forces, the monocopter employs a single rotating blade as its source of lift. To offset the inherent asymmetry of the design, the propulsion pod is attached opposite the blade, and is of sufficient mass to balance the spinning blade in flight. Weighted stabilizing bars are often added perpendicular to the wing, centered on the balance point.

COSROCS Launch

The monocopter concept has been around for about a century, but the first actual flying models weren't made until the 1950's. The concept has languished until recently, when rocket-powered versions gained popularity several years ago. Since then, monocopters have appeared in all sizes from Micro-Maxx to more than J impulse!

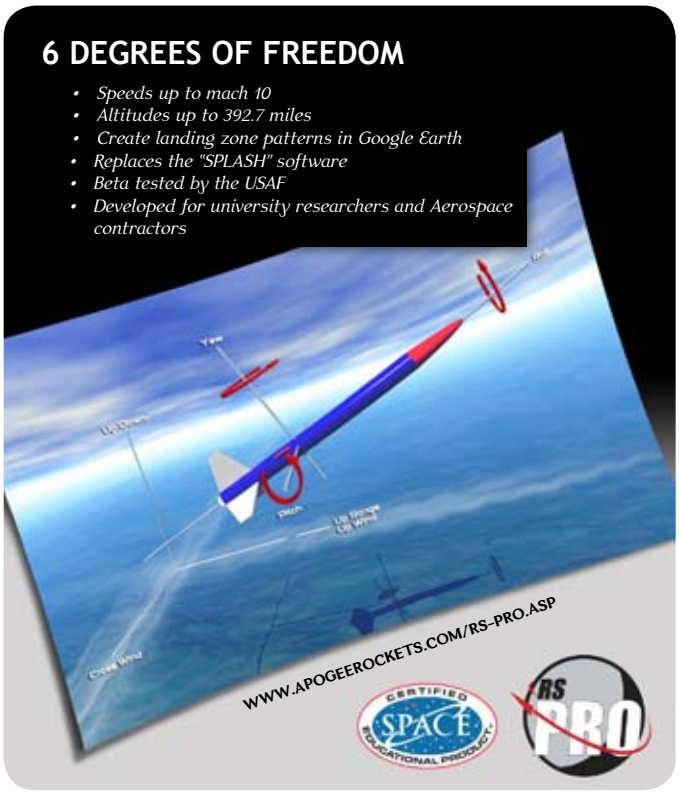
(Photo courtesy of Alien Enterprises, http://www.rocketreviews.com)

There is a video of a monocopter flight on the Apogee website:

www.apogeerockets.com/monocopter_movie.asp

Are you interested in learning more about monocopter design? Check out the book *Monocopters* by Francis Graham:

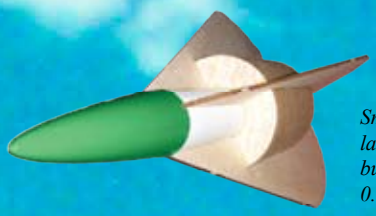
www.apogeerockets.com/monocopter_book.asp



SUNWARD AEROSPACE GROUP LIMITED

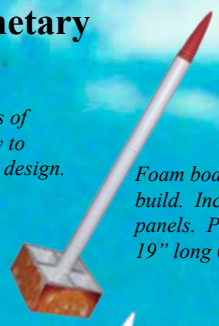
Available Worldwide through Quality Hobby Shops and Online Retailers

New designs NOW available at you local retailer:



Interplanetary Shuttle

Small rocket with lots of laser cut balsa. Easy to build with distinctive design. 0.976" dia 11"long



Box Racer

Foam board fins for a different build. Includes pre-printed side panels. Plastic nose cone. 19" long 0.976 dia.

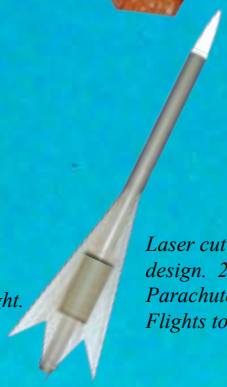
Space Speedster

Printed body with foam board fins. Preprinted fins. Laser cut foam mounting rings.

Flechette

3 fins 6 piece laser cut balsa. Flights to 1000'/ 300m. Parachute recovery.

Flechette: *The word flechette is French for "dart." In military use, it is a projectile having the form of a small metal dart: a sharp-pointed tip and a tail with several vanes to stabilize it during flight.*



Explorer

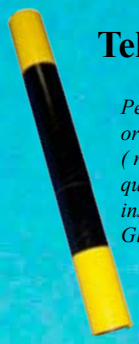
Laser cut 4 fin with distinctive design. 21" long 0.976" dia Parachute recovery. Flights to 750'/ 250m

Bug Me Not!

Great beginner's rocket. Laser cut fins. Streamer recovery. 0.976" dia 11" long.

Lightning Fury

Simple to build. Laser cut fins. Streamer recovery. 0.796" dia, 21" long



Telescope Kit

Perfect for science projects or science fairs. Working telescope (not a rocket). Custom high quality tubing with black coating on the inside. Precoloured - no painting required. Glass lenses.

Check out the rest of our new mounting kits, BT50 nose cone, BT55 tubes - 18" long, 29mm thrust rings

NOW SHIPPING

www.sunward1.com info@sunward1.com

Direct 416-953-1847 fax 416-245-7985

TIP OF THE FIN

BY DAVE VIRGA

Low-tack Cellophane Tape

Masking is a delicate process when painting anything, including rockets. You need a method of protecting the existing painted areas, and doing so in a way that allows for a crisp, clean line between the colors, with little or no ridge. You also need to be aware of the masking material's effect on the underlying paint coat; a strong adhesive can pull paint off when you remove it, or it can leave behind an undesirable residue.

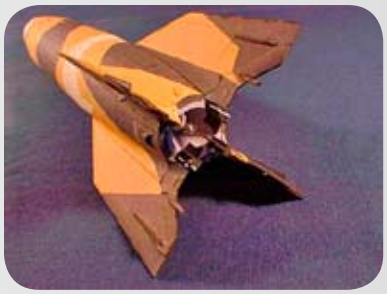
My favorite masking tape is 3M Scotch 811 Removable Magic™ Tape. It is available in both a dispenser and as a refill. This is a cellophane tape with a very gentle adhesive, similar to a Post-It® note. It will not lift the paint under it, and since it is very thin it leaves only a minimal ridge.

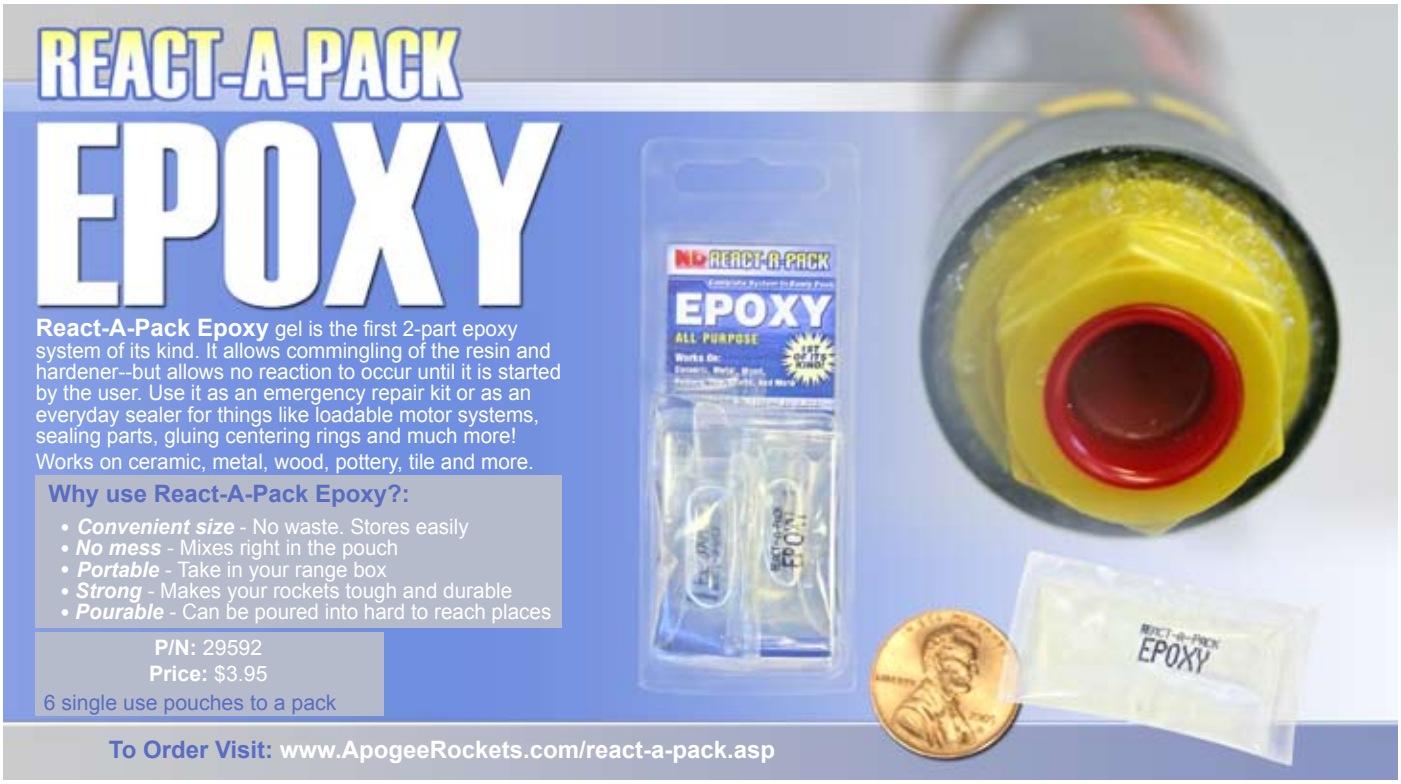
So look for Scotch tape in the blue packaging – it's great for paint masking!

Web Sites Worth Visiting

Want to try your hand at building something completely different? Try cardstock models! This issue's featured website is Ralph Currell's card model plan site – http://www.currell.net/models/index.htm. Of course, he has rocket model plans, as you can see from these pictures. But he has a lot more as well – ships, aircraft, and buildings – nineteen in total – and they're all free! Be sure to look through the photo galleries to see what some enterprising people have done with a few of the rocket models.

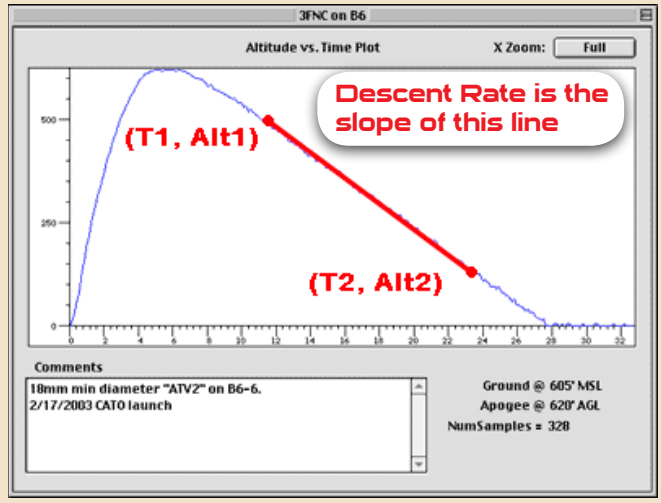
The plans consist of Portable Document Format (PDF) files that you print on heavy paper, then cut out and assemble. Detailed instructions are included that fully explain the building process. All that's needed are basic modeling tools (sharp knives, scissors, straightedge, white glue), a steady hand and some patience, and you can turn out some very impressive models. **Check it out!**





Question & Answer

Question: "How do I measure the actual descent rate of a rocket?"

Answer: An on-board electronic altimeter is the perfect tool to do this. Apogee carries a micro-sized altimeter that is small enough to fit into a BT-20 tube (http://www.apogeerockets.com/altimeter.asp). This altimeter measures barometric air pressure throughout the flight, and stores the data for download to your computer. This image shows a typical flight data plot from the altimeter, with altitude on the vertical axis and time on the horizontal axis. You can clearly see the rocket's rapid ascent to over 700 feet altitude, and then a much slower descent. You can determine the rocket's descent rate by calculating the slope of the line as indicated. Simply pick two data points at opposite ends of the line, and divide the difference in altitude by the difference in time.

$$\text{DescentRate} = \frac{\text{Alt}_1 - \text{Alt}_2}{T_2 - T_1}$$