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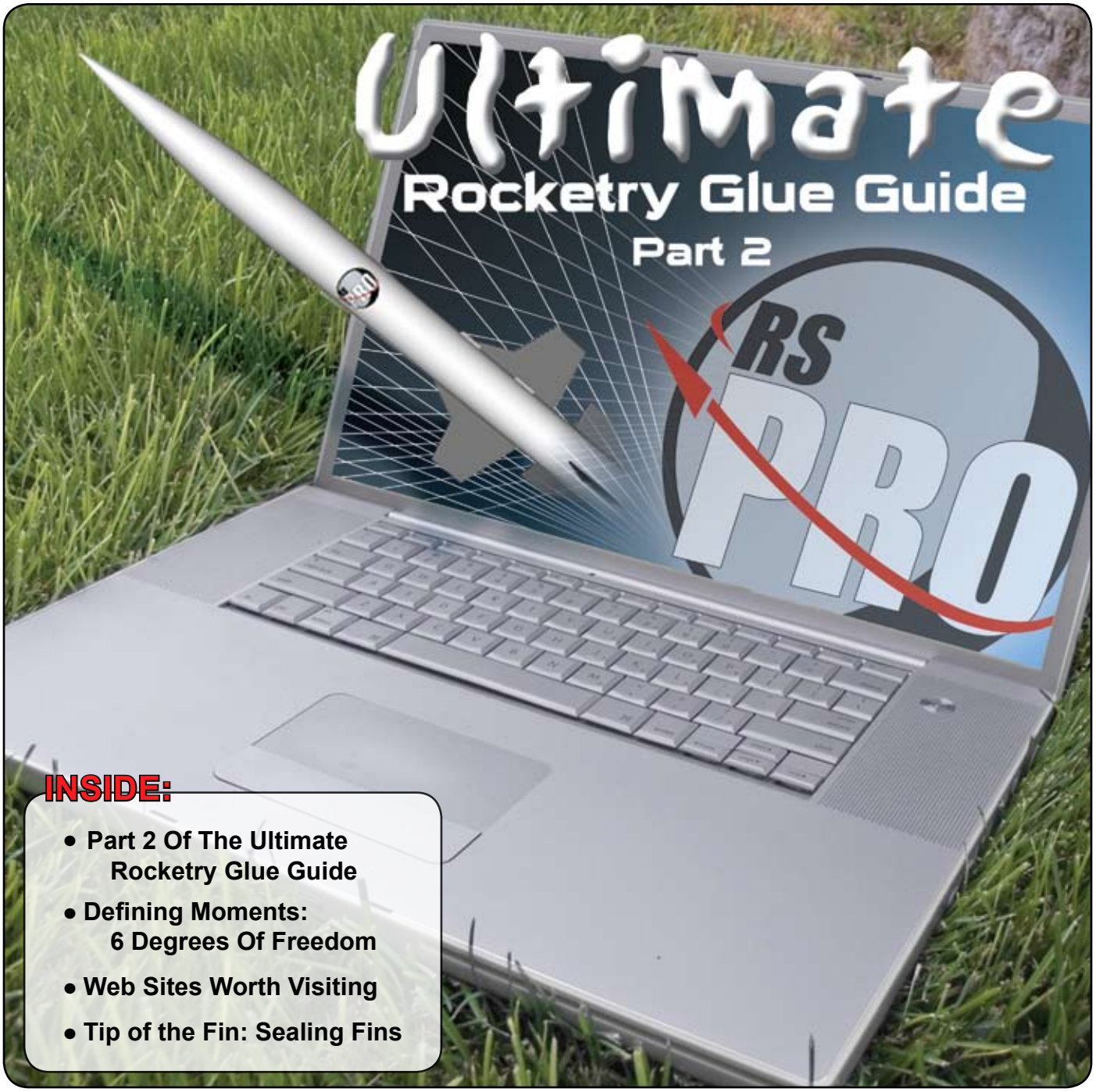
APOGEE PEAK OF FLIGHT NEWSLETTER



INSIDE:

- Part 2 Of The Ultimate Rocketry Glue Guide
- Defining Moments: 6 Degrees Of Freedom
- Web Sites Worth Visiting
- Tip of the Fin: Sealing Fins

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The Ultimate Rocketry Glue Guide - Part 2

By Dave Virga

In Part 1 of this article, I presented an overview of adhesives. I explained how they work at a chemical level, and the different ways that they actually bond to materials. I included an in-depth look at wood glue, as it is the predominant adhesive used in rocketry. You've surely gathered that there's no such thing as the one perfect adhesive. The goal of this guide is not to tell you which glue to use for every situation; there are simply too many possible combinations to list them all. Rather, this guide will tell you everything that you need to know to make informed decisions about what glue to use for each situation.

Now, I will continue the in-depth discussions of the other adhesives that we use, and also discuss a few that we shouldn't use.

Epoxy

While wood glue is the most widely used adhesive for model rocketry, epoxy holds this honor for high power rocket construction. There have been some quite heated debates as to which of these two adhesives is better; the simple answer to this question is that they are both strong enough for rocket construction – when used properly. The real reason for epoxy's popularity is its versatility, despite its complexity. Epoxy is not just an adhesive – it's an adhesive system.

Chemically, epoxy is classified as a thermosetting epoxide polymer resin. The resin transforms into a solid through polymerization and cross-linking after the addition of a catalyst, which triggers an energy-releasing reaction with the resin. The reaction is irreversible; the resin and catalyst cannot be separated into their original components after curing. Once cured, it also cannot be reshaped. These characteristics, combined with the basic chemical nature of the compound, result in a very stable and hard end product: cured epoxy is solvent and heat resistant. It is sensitive to ultraviolet light though, and so must be coated with a UV inhibitor (i.e., paint) for best longevity. Pure epoxy may soften when heated (but still cannot be reshaped), and may become brittle at freezing temperatures. Additives, as discussed later, can reduce these effects.

In its purest form, epoxy is a simple adhesive made up of a resin and a catalyst; with epoxy, the catalyst is

Continued on page 3

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Continued from page 2

called a hardener. The ratio of resin to hardener (by volume) varies by manufacturer from even 1:1 mixtures to ratios as high as 5:1; higher ratios are usually considered more pure. Mainstream epoxy manufacturers such as Bob Smith Industries, Devcon and Loctite add fillers to their products' hardener to achieve a 1:1 mix ratio for ease of use.

Epoxy goes through three main stages after mixing with its hardener. First is the working stage, where the epoxy is still in its monomer state with very little polymerization having occurred. The epoxy is applied and shaped, and parts are joined while in this stage. Second is the green stage, where much polymerization and cross-linking has occurred and the epoxy has solidified to the point where it is no longer workable; it has not fully polymerized yet, and so has not reached full strength. The green stage is important because, since it has not finished polymerizing and cross-linking, additional epoxy can be added to the first application and a chemical bond will result between the two layers for the strongest bond. Additional epoxy added after the green stage will only result in mechanical bonding. The third stage is full cure, where the polymerization and cross-linking reaction has completed. The time that an epoxy spends in each of these stages is variable; see your specific manufacturer's literature for the exact details.

Cured epoxy often leaves an oily by-product called amine on its surface. Amine is chemically similar to ammonia, which is why curing epoxy sometimes emits an ammonia-like odor. The amine needs to be removed before bonding anything to the cured epoxy beneath it; a wipe-down with isopropyl alcohol does the job quite nicely.

As mentioned above, epoxy is an adhesive system. Rarely do you use just the adhesive itself without adding one or more modifiers to it. However, pure epoxy is used for laminating applications in high power rocketry, components such as body tubes and fins are often given added strength by applying tightly wrapped layers of fiberglass, aramid (Kevlar®) or carbon fiber cloth with pure, thin epoxy as the adhesive. Since the strength comes from the cloth and not the epoxy, the goal when using this construction method is to use as little epoxy as possible to bond the fabric, as the excess epoxy will only add weight to the finished product.

The modifiers that we add to epoxy resin fall into three general categories – fiber fillers, bulking agents and thickeners. Fiber fillers add strength to the epoxy mixture. Chopped or milled fiberglass strands and plastic minifibers are the most widely used additives. These short (1/16 to 1/4 inch) fiber strands give the cured epoxy a structural component, which adds great omnidirectional strength. Fiber fillers are used when a structural fillet is needed.

Bulking agents reduce the density of the epoxy mixture and increase its sandability. Wood flour as well as phenolic and quartz microspheres are common bulking agents. These additives are good for creating lightweight non-structural fillets that will need to be sanded to their final shape after curing.

Thickeners are used to make an epoxy mixture that will not run or sag after it is applied. Silica (Cab-O-Sil ®, Aerosil ®), wood flour and plastic minifibers all serve this purpose.

What do you do if you need to make the epoxy thinner, instead of thicker? Isopropyl alcohol or acetone are often used to lower the viscosity of an epoxy mix, but you need to be careful here. Adding a thinner creates a suspension of a volatile substance in the epoxy mixture that eventually evaporates either during or after the curing process. The end result will often be a matrix of voids within the cured epoxy, which reduces both its strength as well as its moisture resistance. There are two options for creating a thinner epoxy. First, try using heat from a blow dryer; this will reduce the epoxy's viscosity, but will also accelerate the curing process. Second, find a different epoxy product that has a lower natural viscosity than what you're currently using.

Since epoxy is the most complex adhesive used in rocketry, there are naturally a number of safety concerns with its use. While cured epoxy is inert, the chemicals in the resin and hardener are not. Epoxy contains a number of compounds that are known to be associated with various health problems; these compounds are easily absorbed through the skin. Keep your direct-contact exposure to uncured epoxy to a minimum, and

Continued on page 4

Continued from page 3

use Nitrile (blue) gloves instead of latex gloves, since they provide much better chemical protection. If you do get epoxy on your skin do not wash it off with a solvent such as acetone, as the thinned epoxy will be more readily absorbed and your body will absorb the acetone as well! Just wipe off as much as you can with a paper towel, then remove the rest with soap and water.

Also beware the dangers when using additives. They are all either very fine powders or miniscule glass strands – none of which have any business in your respiratory system; be sure to wear a good dust mask when handling these materials.

Finally, beware of the strong exothermic nature of curing epoxy; it can generate a considerable amount of heat, even to the point of boiling and causing second-degree burns on skin. The easiest way to avoid problems is to not store the working epoxy in a cup or can, but to use a flat plate instead; this will create more surface area and allow the heat to dissipate into the air, and not stay trapped in the mixture.

Do keep in mind that this is merely a high-level description of epoxy systems and their general use in rocketry. To use epoxy to its full potential, you need to invest time studying the offerings of various manufacturers and talk to other rocketeers that use epoxy. You can start your education with the links in this issue's Websites Worth Visiting section.

Cyanoacrylate

CA is a very popular adhesive because it is fast-acting and quite strong. It can be used to join porous and non-porous materials, as well as objects of differing composition. CA forms a chemical bond, and is available in low viscosity formulations that can infuse porous materials for mechanical bonding as well. CA is the most lightweight adhesive, especially for its strength, so it is very popular for high-performance competition rocket construction.

CA cures reactively through polymerization. In liquid form, it consists of individual monomer molecules. During the cure process, the monomers join together in long strings to form polymers, which also transforms the adhesive's state from liquid to solid. Polymerization is activated (catalyzed) by the presence of hydroxide (OH-) ions formed by the interaction of ambient moisture (humidity) and the part being bonded. So, be sure to keep your bottles of CA capped when not in use; it is also recommended to store CA in a refrigerator for best shelf life.

When cured, CA is an acrylic plastic, and is fairly rigid. Downsides to CA are that it becomes brittle at low temperatures and has low shear strength. Bonds of smooth non-porous materials are most susceptible to shear failure if they are subjected to sharp forces along the line of the bond. This can be advantageous though, if you need to make a temporary bond that can later be broken relatively easily.

CA is available in various viscosities – thin (like water), medium (thin syrup) and thick (heavy syrup). Gel formulations are also available for situations where you do not want any flow while curing. Higher viscosities are better for filling gaps, but it is not considered a structural adhesive; in general, thickening additives tend to reduce the potential end-strength of an adhesive, so always make sure your parts fit together as well as possible and use the thinnest formulation for best results. Cured CA can be loosened with acetone, but beware the effects of this solvent on the parts, especially plastics.

There are two major varieties of CA available – Regular and Odorless. Regular CA is based on ethyl cyanoacrylate and methyl cyanoacrylate monomers, and has a very sharp odor which many people find very irritating to their upper respiratory systems. Odorless CA

Continued on page 5

Continued from page 4

is a different formulation, based on alkoxy-alkyl cyanoacrylate monomers that do not release these irritating fumes, at least not as readily; it is about twice as expensive as regular CA. The major functional difference between the two varieties is that odorless CA is foam safe, whereas regular CA will dissolve foam.

The greatest risk when using CA is that it bonds skin instantly, especially the thin varieties, so be very careful to not spill it. It can wick through clothing and bond your clothes to your skin just as quickly.

Regular CA vapors can cause intense cold-like symptoms – sneezing, stuffy nose and a long-lasting dry cough – as well as asthma. I personally am very sensitive to CA fumes, and have experienced mild irritations from even odorless CA, so do be careful with all CA's. Note that CA is not toxic; it does not contain cyanide in its monomer or polymer states.

Plastic Cement

Plastic cements are not adhesives; they do not work the same way as wood glues, epoxies and CA. Instead, they are solvents. Chemicals such as toluene, acetone or methyl-ethyl-ketone (MEK) partially dissolve the plastic, reducing its viscosity. This allows the plastic molecules of two individual pieces to mix together. Then, as the solvent dissipates through evaporation, the plastic re-hardens as a single unit. So in effect, the plastic parts are welded together. When joining plastic parts with porous non-plastics such as wood or paper, the softening process of the solvent allows the plastic molecules to flow into the porous material, so that it forms a mechanical bond when it hardens.

Different plastics require different solvents. For example, polystyrene is easily dissolved by toluene, which is the active ingredient in Testor's Plastic Model Cement. Note that the plastic in a number of recent Estes kits seem to be resistant to toluene, and this cement does not adequately bond this plastic (kits such as the Blue Ninja, Liquidator, Wacky Wiggler); look for a cement with acetone or MEK if you find that a toluene based cement doesn't work well.

Special note: Testor's Plastic Model Cement comes in two formulations – one with solvent (red tube) and a non-toxic child-safe version without solvent (blue tube). Do not use the non-toxic formula for rockets; it uses a chemical bonding method and does not provide rocket-grade adhesion. In general, if a cement is non-toxic, it will likely not work well for rockets.

Some plastics, such as polycarbonate (Lexan®) are especially difficult to bond. You will need to do some experimentation with various cements using different solvents to find a good match. You can easily test the effectiveness of a particular cement with a specific plastic; here are two tests that you can do. First, apply a small test drop of cement to an inconspicuous spot on a part (or a spare piece, if you have one). After a few moments but while the cement is still wet, take a toothpick and stir the spot. The spot should turn into a gooey plastic blob; this indicates that the cement is readily softening the plastic. Second, pick two inconspicuous spots that can be easily joined then cut apart later. Use the test cement and make a small bond between the two parts. When dry, the bond should be very strong, and should not snap cleanly apart.

There are some newer products that show promise for strong plastic bonding capability. Devcon's Plastic Welder line are epoxy-like products that claim to bond polycarbonate. Loctite's All Plastics claims to bond the waxy plastics such as polyethylene and polypropylene. If you need to work with these specialty plastics, consider giving these types of products a try.

Since plastic cements all use petroleum based volatile compounds, they must be used with adequate ventilation. They are soft tissue irritants, and can cause neurological damage with prolonged exposure.

Continued on page 6

Continued from page 5

Other adhesives worth mentioning

Polyurethane Glue: This is a relatively new one-part adhesive; the most prevalent brand is Gorilla Glue ®, though there are many other brands available from the likes of Elmers and Titebond. Polyurethane glues have a dark brown color and thick syrup consistency. They have excellent adhesion to many materials, and are very strong when fully cured. Mineral spirits or acetone are needed for cleanup before full cure.

The major differentiating characteristic of polyurethane glues compared to wood glues is that they expand when curing, and so require clamping to hold parts in place. Polyurethane monomers contain isocyanate molecules that react with moisture in the air to form carbon dioxide gas, which is why they generate foam when curing. This expanding foam aspect of polyurethane glues makes them difficult to use for rocket construction. If you are able to clamp your parts, and the added mess of the expanding foam can be dealt with, then give this glue a try.

Polyester Resin: There is another two-part resin available based on polyester chemistry instead of epoxides; Bondo® is a prevalent version of this adhesive. The main differentiating characteristic between epoxide and polyester resin systems is the mix ratios. Epoxides use a liquid hardener in a ratio of 5:1 or less; polyester hardeners are usually in cream form, dispensed from a tube, and have usage ratios around 10:1. Polyester resins typically have shorter working times than epoxides. They also emit a very strong and potentially toxic odor when curing and must be used outdoors with good ventilation.

Polyester based resins are not recommended for rocketry use mainly because they are less convenient and less versatile than epoxides. Their shorter working times, higher mix ratios and strong odors all add up to make these products more difficult to use than marine epoxies for rocket construction.

Rubber Cement: Rubber cement is a latex based surface adhesion glue that cures by drying. It is primarily used in arts and crafts. It is removable in most applications. It is not a strong enough adhesive to be used for structural rocket construction.

One potential application though is for attaching nonstructural components such as tube wraps, where a water-based glue would cause shrinkage and warping. There are better adhesives to consider for this though, such as CA or spray adhesives.

Hot Melt Glue: Hot melt glues are thermoplastic adhesives. They are solids at room temperature, but melt when heated to over 250 or 350 degrees for the low and high temperature varieties, respectively. They are primarily used in arts and crafts. They have good surface adhesion, but do not create strong mechanical bonds like mainstream hobby-grade adhesives. Hot glue is applied with a pistol shaped electric glue gun, which heats sticks of glue and dispenses the molten glue through a fine tip nozzle.

One potential use for hot glue is on specialty plastics that do not respond well to hobby-grade adhesives. If hot glue does happen to have decent surface adhesion to your problem plastic, be sure to incorporate other forms of mechanical reinforcement to augment the hot glue bond.

The greatest concern with hot glue is that it is, well, hot. Very hot. Great care must be taken to avoid burns. It also cools and sets very quickly; its working time is in the range of seconds. It is not easy to work with after it cools; you must either cut or scrape excess glue, as it is not sandable.

Spray Adhesives: Spray adhesives are unique in their delivery method – by aerosol can. They typically cure by drying. There are many formulations available,

Continued on page 7

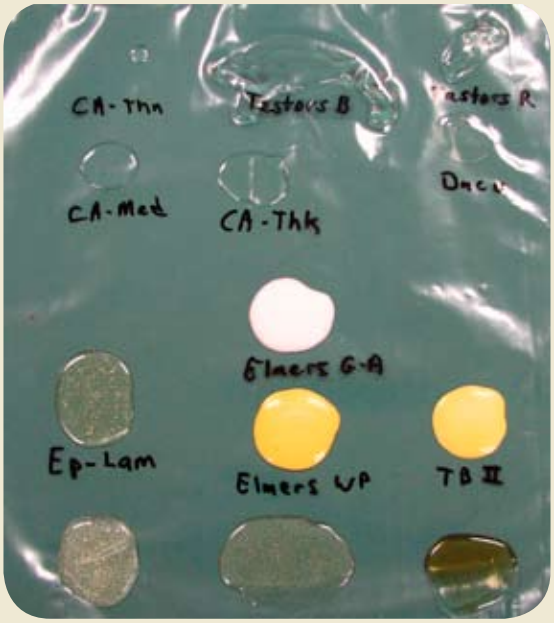
Continued from page 6

from low-tack temporary glues to permanent types. Since they are dispensed from a spray can, they can be quite messy; be sure to protect against overspray.

Spray adhesives do not lend themselves to structural rocket construction both due to the adhesive formulations as well as the dispensing method. However, they can be of use for non-structural components such as body wraps, or for temporarily attaching a printed template to a sheet of stock material.

Do your own testing

Here's a simple experiment that you can do yourself to learn about the basic properties of various adhesives. Take a piece of polyethylene sheet (re-sealable storage bags are made out of this material), since it is impervious to nearly all glues; lay out one-inch square samples of all of the glues that you like to use. After they have cured, remove them from the sheet and compare them to each other.



- How did the samples change during curing – did they shrink, expand or change color?
- How easily did they separate from the sheet?
- How stiff or bendable are they?
- Are they elastic – can you stretch them?
- How brittle are they – do they break easily?
- Heat the sample – how do its properties change?
- Chill the sample – how do its properties change?

These characteristics of the adhesives will not change when they're used in an actual bonding application. This knowledge will help you as you consider different adhesives for specific situations.

Analyze your requirements

Every time that you glue two or more pieces of anything together, you should ask yourself these questions:

- What are your weight requirements – Does the rocket need to be as lightweight as possible, or is the weight penalty of a heavier, bulkier adhesive acceptable?
- Does the bond need to be rock-hard, or is a bit of flex acceptable or even desirable?
- From which direction(s) will the strongest forces be applied to the joint? Is it long and thin, such as a fin-to-body joint, where strong shear strength is needed?
- Does the glue need to add any structural reinforcement to the joint, or simply hold the pieces together?
- How much heat resistance is needed? Will the glue be subjected to the motor's heat?

Knowing the answers to these questions, you can apply your in-depth knowledge of all of the adhesives at your disposal and be best prepared to answer the ultimate question: What is the best glue to use for this particular joint?

About The Author

Dave Virga holds a Bachelor's degree in Computer Science, and is an Information Technology Specialist for the Department of Defense. A typical Born Again Rocketeer, he enjoyed building and flying rockets through high school, then set the hobby aside for college, career and family. He re-discovered rocketry in the late '90s, and has become a voracious student, teacher and practitioner of rocket science. In past lives, he has been a naval submarine officer, computer systems engineer, ski instructor and Scout leader. A trombonist since elementary school, he will also on occasion sit in with his wife's early music ensemble when a bit of sackbut is needed. He lives in Black Forest, Colorado with his wife, son, dogs and parakeets.

DEFINING MOMENTS

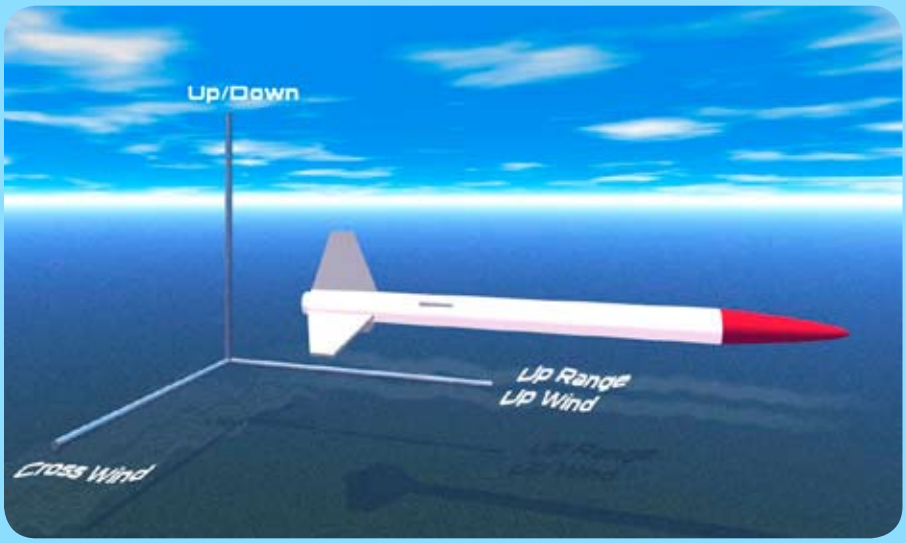
What Does 6-Degrees of Freedom mean?

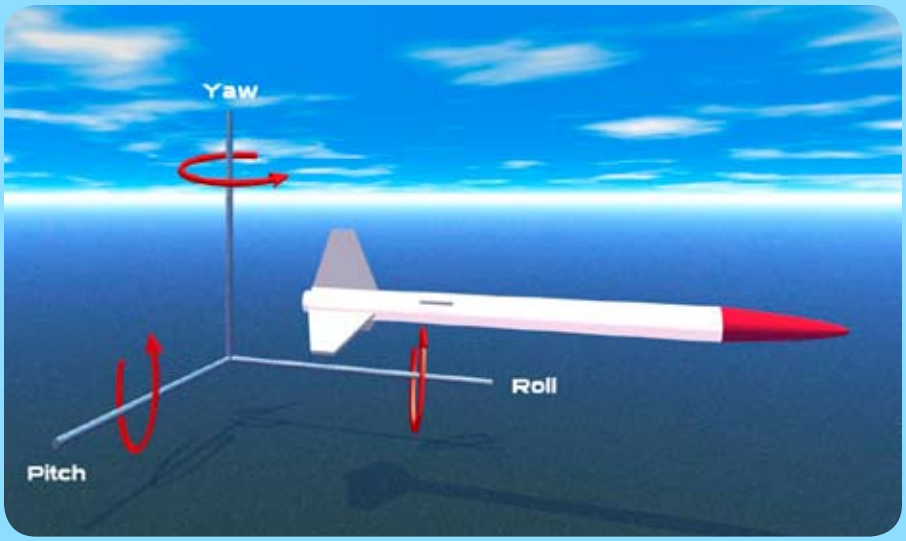
Basically, 6-Degrees of Freedom (also called "6-DOF") means that the rocket can move six different ways.

To make it easier to visualize, lets create a 3-dimensional coordinate system. If you look at this page, you can say that it has a height and a width; that would be two dimensional. The third dimension would be the depth into or out of the paper.

It the rocket world, that would be like saying the rocket can go (1) up into the air, (2) either upwind or downwind, and (3) cross wind. That defines the "translational" coordinate system. We say "translational" because the rocket translates, or can move in any direction in that coordinate system.

But the rocket can do more than that, it can also spin or rotate in three directions. It can move so that the nose cone goes up or down (pitch), as well as left or right (yaw). Finally, it can roll around the long axis. This is the rotational coordinate system (pitch, yaw, and roll).





Add all these ways the rocket can move, and you get six! What does this mean to us rocketeers? **Great question**.

As rocketeers, we always want to know where our rocket is, and what it might do next. Why? So that we can insure safety and make sure we've got our rockets configured correctly to accomplish the mission we would like to achieve.

For example, say we want to send a rocket 1km into the air to take a picture of our flying field. Sounds simple enough, doesn't it? But say there is a 10 KPH wind blowing out of the west, and that the field is also surrounded by trees. Obviously, we'd like to recover the rocket back so we can reuse our expensive camera payload.

As tricky as it seems, you could probably use RockSim to predict how the rocket is going to weather-cock into the wind. With that information and the correct choice of rocket motor, we can angle the launch rod into the wind and hit our target altitude of 1 Km. Plus, with the right choice of parachute, we can get the rocket back without it drifting into the trees.

RockSim is perfect for this situation, and I'd recommend it to everyone. But let me throw in one more constraint...

You drive out to the field that morning, and you find out that the range is set up in such a way that there are spectators directly west of the launch pads. Because of this, the range safety officer will not allow you to tilt the launch rod to the west. Why? Because if the chute were to fail, the rocket would come down in the spectator area. For safety reasons, you are required to point the rocket to the north or south, which is cross wind.

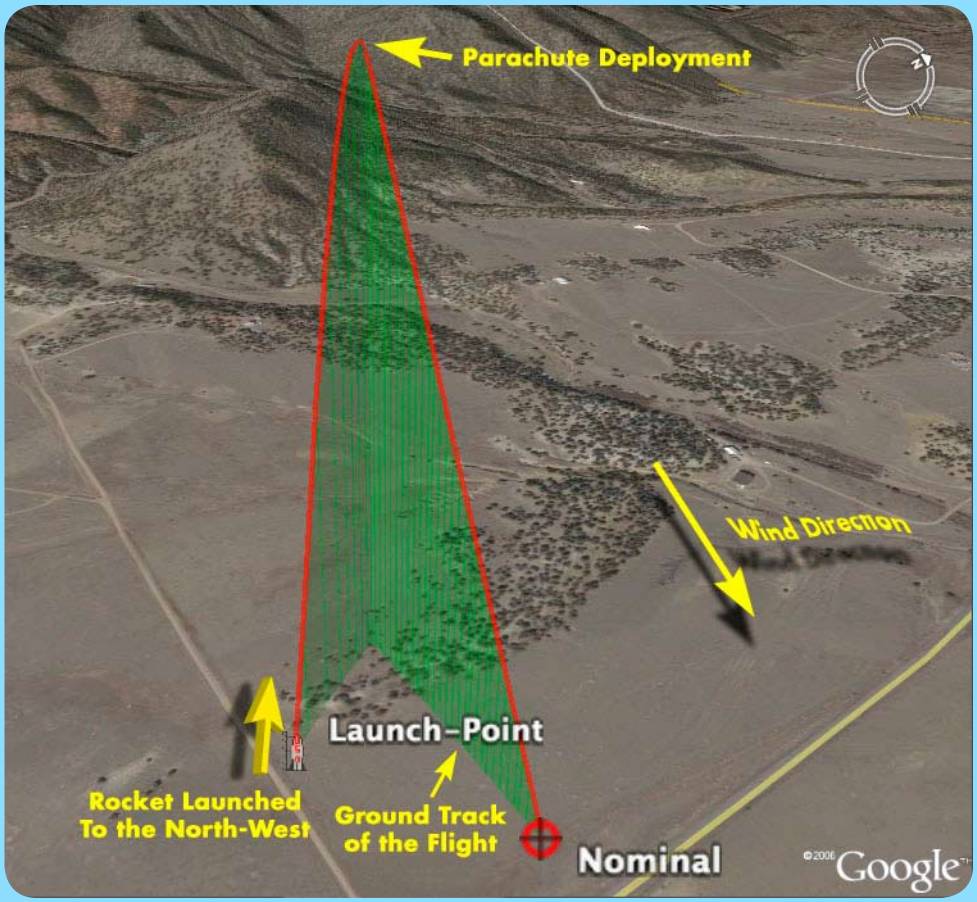
In this case, RockSim is not going to give you a good-enough representation of the flight. It cannot calculate the trajectory in the cross-wind direction. You see, RockSim is a 3-Degree of Freedom simulation software. It can estimate the rocket's location and orientation in only three ways: (1) Up/down, (2) upwind/downwind, and (3) rotation about the pitch axis. But it wasn't designed to handle crosswind translation, or yaw and roll rotation.

To predict the situation above, we need a full 6-DOF simulation program because the rocket is going to move in the cross-wind direction. But if RockSim can't handle this, what can?

The answer is Apogee Components' new program called "RS-PRO!"

RS-PRO is a full 6-DOF simulation program that was designed to pick up where RockSim leaves off. Not only can it handle these types of complex simulations, it can be used to simulate rockets that travel up to 632 km (392.7 miles) in altitude, and speeds up to Mach 10. It is also abled to simulate rockets that have an initial velocity and initial altitude, such as those launched from airplanes. It is totally awesome!

If you'd like to learn more about RS-PRO, please visit the Apogee Components web site at: http://www.ApogeeRockets.com/RS-PRO.asp



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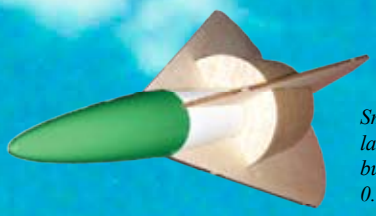
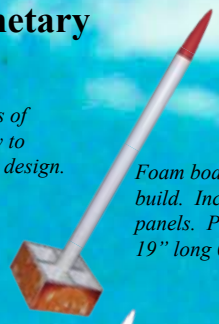


Interplanetary Shuttle

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.

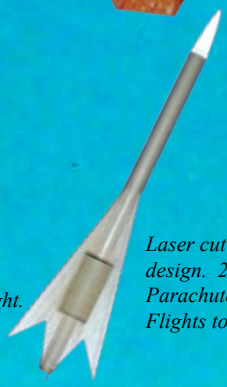
Space Speedster

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

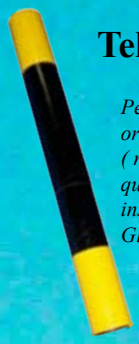
Laser cut 4 fin with distinctive design. 21" long 0.976" dia Parachute recovery. Flights to 750'/ 250m

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



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TIP OF THE FIN

BY DAVE VIRGA

Use thin CA as a surface sealer and hardener

There are many ways to seal wood fins. A lot of people like to use Elmers Light Wood Filler, for example. If you're not careful, you might warp the fins due to its water content. Another popular method is to use Midwest's Balsa FillerCoat. This product works well, but it takes many coats to achieve a smooth finish, plus it's getting harder to find.

My favorite method is to use thin formula cyanoacrylate. Thin CA soaks into porous materials and dries quickly to form a durable acrylic coating; it also sands easily with 400 grit sandpaper. Two coats on balsa fins, with a light sanding after each, are usually sufficient to completely smooth most fins.

Thin CA also works very well to toughen up body tube openings and motor mount tubes. A single coating and light sanding is all that's needed here.

One application method is to use your finger wrapped in a sandwich bag made of polyethylene (HDPE), as CA doesn't stick to this material. **(Figure 1)** Another method for coating the fins is to use a cotton swab. **(Figure 2)** Note that CA has an exothermic (heat generating) reaction to cotton, so you may see a few wisps of vapor, but there's no danger. With either method, just wipe an even coating of CA on the fin surfaces and body tube interiors. Keep the cotton swab moving to prevent it from sticking, and re-wet it frequently.

The downside to using CA is that it's an upper respiratory irritant, and both the application and sanding of the CA for this purpose generate a lot of airborne irritants. So be sure to work in a very well ventilated area – outdoors is strongly recommended – when both applying the CA and sanding it.

Figure 1

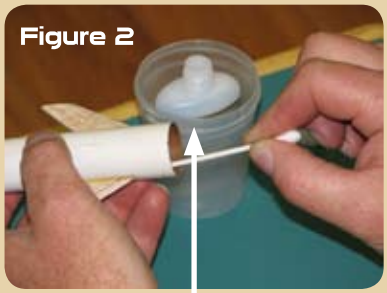
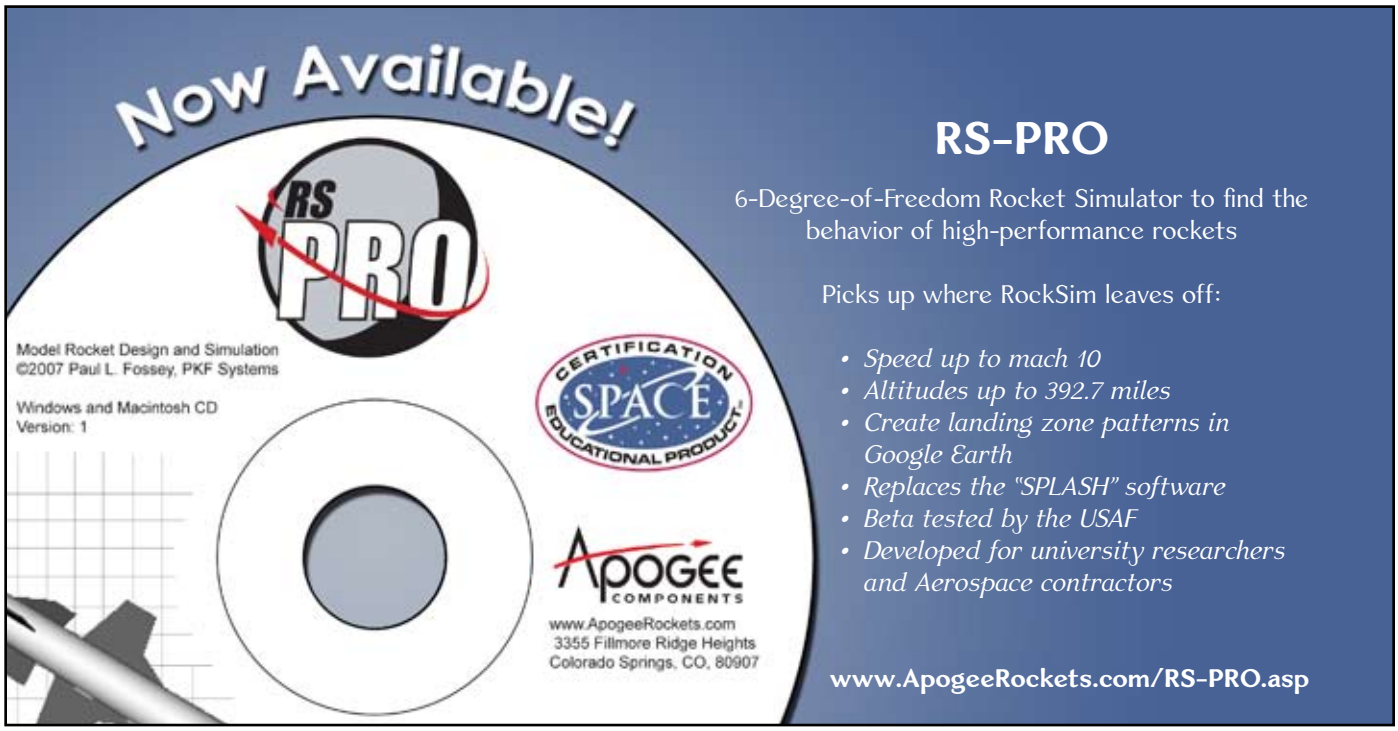


Figure 2

Put your CA into a small cup to prevent it from tipping over.



Web Sites Worth Visiting

A lot of online research went into the Ultimate Rocketry Glue Guide! Here is a collection of web sites that I used:

http://en.Wikipedia.Org/wiki/Main_Page I had only casually perused Wikipedia prior to this article. I was very pleasantly surprised at the wealth and breadth of good info that I found here, not just in the text of the topics, but in the reference links as well. Try searching on these topics, delving into the linked material of each as deeply as you dare:

Adhesive	**Adhesion**	**Aliphatic**
Emulsion	**Wood glue**	**Epoxy**
Cyanoacrylate	**Plastic**	**Thermoplastic**
Resin		

The Boeing Employees Model Rocket Club has good documents on CA and epoxy in their Rocket Build Seminar area: www.bemrc.org/main.html

Here are a few of the more popular epoxy manufacturers used in the rocketry community: AeroPoxy (www.ptm-w.com); Fibre Glast (www.FibreGlast.com); MAS Epoxies (www.MASepoxies.com); System Three (www.SystemThree.com); West Systems (www.West-System.com). They tend to be oriented to boat building or aviation, and so work well for rocketry. Bulk purchases from industrial suppliers like these also reduce the overall costs if you are working on larger projects. Epoxy manufacturers all have excellent documentation on how to use their products; look for it and read!

You can read about Bondo's polyester based resins at www.bondo.com.

Go to the Elmers (www.Elmers.com) and Titebond (www.Titebond.com) websites and read the product descriptions for their various wood glue and polyurethane products; be sure to read the Material Safety Data Sheets (MSDS) for more detailed information.

Bob Smith Industries (www.bsiadhesives.com), Devcon (www.Devcon.com), Loctite (www.Loctite.com/int_henkel/Loctite_us/index.cfm), E-Z Bond (www.e-zbond.com) and Handibond (www.handibond.com) produce a variety of epoxy, CA, plastic cement and specialty adhesive products; check them all out!