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How Do Electronic Altimeters Work?

By Norman Dziedzic Jr.

Altimeters are some of the more fun and useful payloads that can be flown in a model rocket. Besides the ability to tell you how high your rocket has flown, many of the larger HPR flights simply cannot be made without an altimeter. The auxiliary functions are necessary to deploy drogue and main recovery devices as well as perform any staging that the flight requires.

Most of the time these devices are treated as "black boxes," but have you ever wondered how they work? This series will attempt to explain how these modern marvels help us enjoy rocketry and make it safe to fly the big stuff. Let's take a look at a block diagram which shows a simplified version of the main parts of an altimeter in Figure 1.

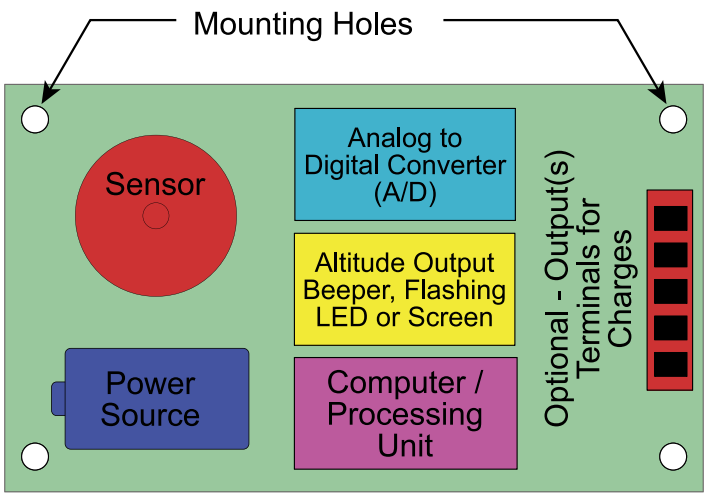

Figure 1: Altimeter Block Diagram

This first article will cover what allows an altimeter to tell you how high the rocket has flown. All altimeters must have some way to sense the altitude, called appropriately the ***Sensor***. There are three main sensor types: pressure sensors (also known as barometric sensors), accelerometers, and GPS sensors. Each of these has their pros and cons when it comes to altitude determination

Of these, the pressure or barometric sensor is the most widely used and best suited for altitude determination. The pressure it measures is the absolute pressure of the atmosphere, which is the air around us. We take the air for granted but it actually has weight when it gets stacked up above us all the way up to the start of space. While temperature, humidity and wind currents are also a factor in determining the pressure at any location, if we think of the air as stacked on top of our rocket, then as the rocket moves up, there is less and less air stacked up above it. With less stacked air, there is a corresponding reduction in air pressure as our rockets move up. In general we say, with an increase in altitude, there is a decrease in pressure.

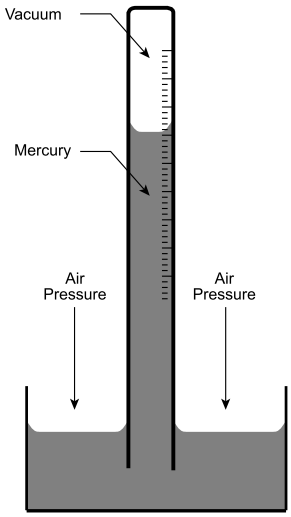

Figure 2: Mercury Barometer

So now that we know what the sensor is going to measure, how does it go about doing so? People have been measuring air pressure for hundreds of years in devices called mercury barometers (Figure 2) but these are not very well suited to model rocketry as they are heavy and rely on a liquid filled tube that would break or be unstable during a rocket flight.

You may also have seen large dial type pressure gages. These use an interesting device called a bourdon tube (Figure 3) that expands when the internal pressure increases and drives the needle through a set of gears but again, they are large, heavy and do not lend themselves to working with electronics.

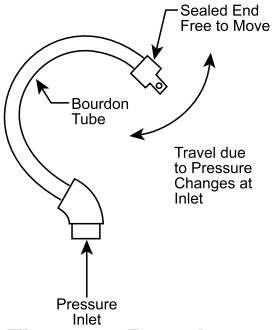

Figure 3: Bourdon Tube.

Modern electronics has answered the call and come up with a device called a pressure transducer or integrated pressure sensor (IPS). It works by actually measuring the strain in a very thin film of metal that has a static reference pressure on one side and the changing ambient pressure on the other.

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An example that may help you think of this would be a balloon. Before we inflate it, the inside and outside of the balloon are exposed to the same pressure. The surface of the balloon is not strained or stretched at all and the material sits there in its original loose state. As we increase the pressure inside the balloon by inflating it, the surface expands and stretches. The stretch of the balloon increases as the pressure inside increases and it decreases as the pressure inside decreases. All the while, the pressure outside of the balloon, the ambient air pressure, remains constant. It is this difference in pressures which makes the balloon expand. If fact, if you blew up a balloon, then put it in a chamber and increased the chamber pressure to match the pressure inside pressure, the balloon would deflate to its original state.

Inside of a pressure transducer, instead of a balloon there is a diaphragm or die of very thin metal (Figure 5). While the metal does not stretch anywhere near as much as the balloon, the way it reacts to pressure differences is very repeatable and so for the same pressure difference, it will always stretch the same amount. Now on one side of this diaphragm there is a chamber that is evacuated to an almost perfect vacuum. This vacuum provides a fixed reference pressure of 0 $psi_{(absolute)}$. Having a fixed pressure on one side of the diaphragm means that any strain or changes in the diaphragm result from changes in the ambient pressure.

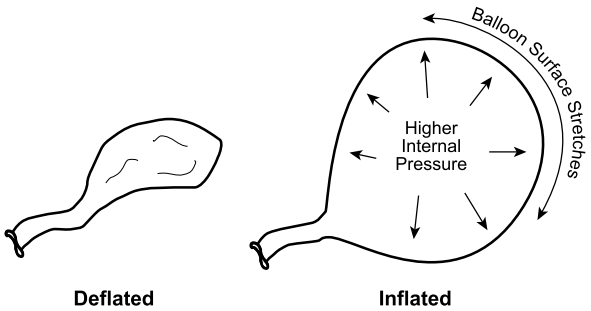

Figure 4: Balloon Stretch

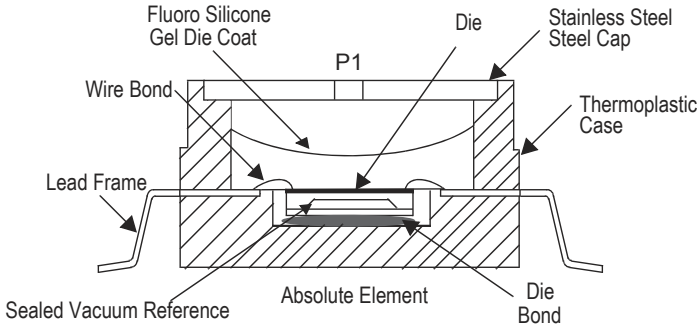

Figure 5: IPS Internal Components

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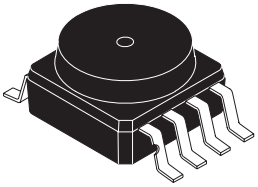

Figure 6: Outside of an Integrated Pressure Sensor (IPS)

You might be thinking, "so that's nice, but I want to see flashing lights or hear beeps that tell me how high my rocket went. I need an electrical signal to tell the smarts of my altimeter how high my rocket went. Enter the strain gauge.

A strain gauge is a very thin wire embedded in a piece of foil that gets bonded to the diaphragm so that any stretch in the diaphragm also stretches the wire. Stretching the wire changes its electrical resistance and it is this change that lets us move from the physical movement of the diaphragm to an electrical signal. Because this movement is so small, the wire in the strain gauge is routed back and forth many times so multiple segments are stretched at once. This is a nice way of making the effective wire length longer and producing a larger change in resistance than could be generated from a single small wire. A special circuit called a Wheatstone bridge is used for measuring the change in resistance. Explaining the Wheatstone bridge is beyond the scope of this article but the end result is that the Wheatstone bridge circuit will output a change in voltage proportional to the resistance change in the strain gauge. Unfortunately, because the stretch due to strain is so small, these signals are also very small. They are in the range of thousandths of a volt or milivolts (mV).

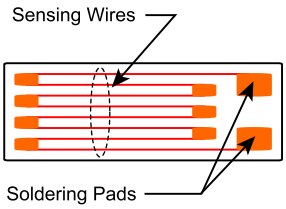

Figure 7: Foil Strain Gauge

The next step is to take this signal and amplify it so that it can be read by the analog to digital converter. Amplifier circuits built into the IPS boost the milivolt signal to a range of 2 or 5 volts. In doing so, the design of the circuit has to take care not to add noise to the signal so that what comes out doesn't turn into an unreadable jumble of static. There is a trade off here in that the more you amplify the signal, the better the resolution; but, with more amplification the circuit is more likely to produce a noisy output. In the design of an altimeter, the entire system has to be investigated to find the best combination of circuits and components

Another important step in the conversion of strain to voltage is called linearization. While the signal from the strain gauge is very repeatable, it will not be linear. If we looked at a plot of the pressure vs. the raw strain gauge output it would not be a straight line but some sort of curve.

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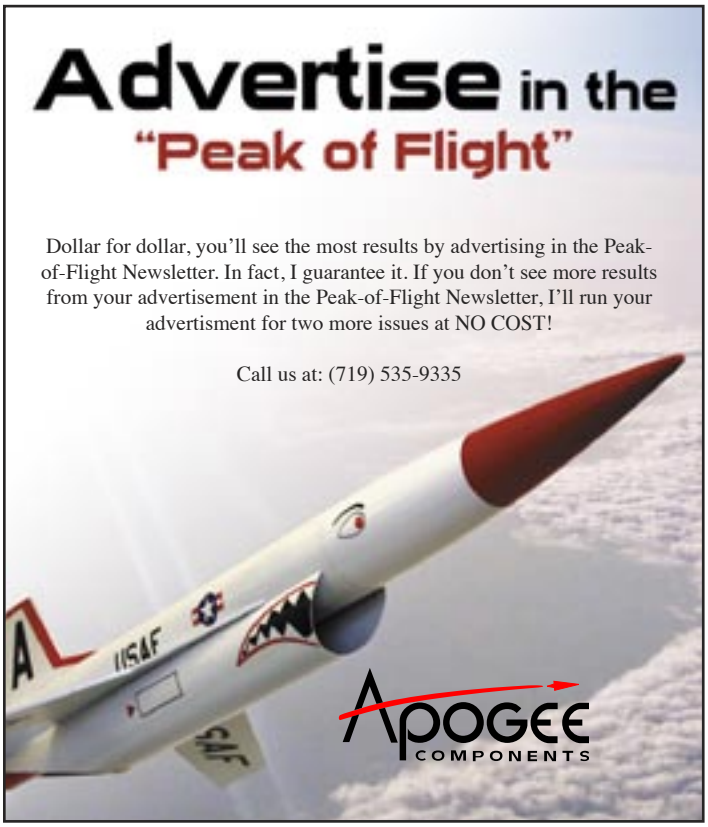

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The job of the computer or processing unit would be much easier if every change in voltage corresponded to the same change in pressure.

Lastly, a good sensor will have a feature called *temperature compensation.* This is important because the resistance of the strain gauge changes as the temperature changes. Without a way to adjust for temperature, a cold or warm front could make your altimeter believe it is moving up or down and could play havoc with ejection sequences programmed into the altimeter. A common way to provide temperature compensation is to have a 2nd sensing element (i.e. strain gauge) in the circuit that is not under strain and is wired in so that its signal is opposite from the main strain sensing element. The two elements will have the same reaction to temperature and since their outputs are opposite, the temperature effects will cancel each other in the output signal.

In the end, a typical integrated pressure sensor will give an output like the one shown in Figure 8. This graph tells us almost everything we need to know about the sensor. Across the bottom we read the absolute pressure and see that the sensor works in the range of 15 to 115 kPa. Outside of this pressure range, the voltage output line is horizontal and not changing.

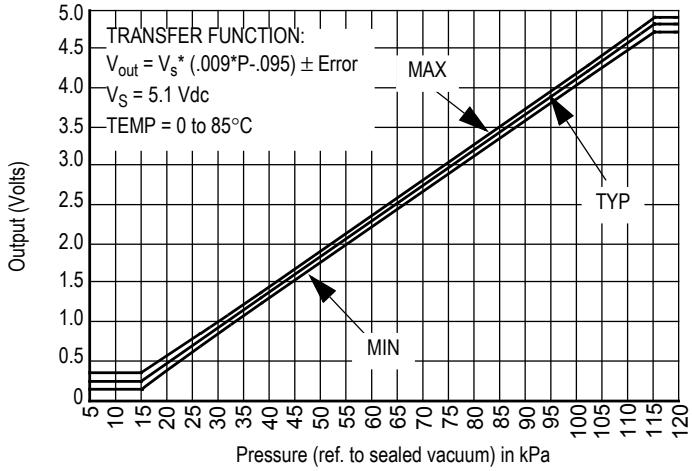

Figure 8: Sensor Output vs. Absolute Pressure

Within the pressure range (15 to 115 kPa) the graph is a nice straight line so the signal has been linearized and the note TEMP=0 to 85 C tells us that the sensor is temperature compensated so long as it is used between these two temperatures.

The fact that there are three lines on the graph is an acknowledgement that nothing is perfect and that even with all the linearization, temperature compensation and careful selection of amplification circuits, there can be some error

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in the sensor output. The important thing here is that this error is defined.

For this particular sensor, the maximum error is listed in the data sheet as +/- 1.5% of the full scale output. This a very generic way to express error that component manufacturers have adopted but in this example, there is a 100 kPa range (115 – 15) so +/-1.5% of that is +/- 1.5kPa of possible error. Knowing the possible error from the sensor, the altimeter designer can decide if this is acceptable for their system and how the sensor error will affect the overall error of the altimeter. It will come as no surprise that sensors with smaller error are more expensive because they have to use more precise components and more complicated circuits.

A couple of sensor characteristics not on the graph which are also important are the required current and the response time. If the current needed to power the sensor is too high, the altimeter would require a large battery or not be able to run for a long time. If the response time is too slow, the sensor would be late in sensing apogee and could miss the peak altitude all together.

Lastly, hidden on this graph is the fact that the output signal from the sensor is dependent on the input voltage. This is seen in the transfer function where $V_{out} = V_s$ times some other coefficients. V_s is the supply voltage and so any changes in this voltage will result in a corresponding change in the output. When the output of a device is dependent on its supply voltage, the device is called *ratiometric*. This fact will lead us to the next installment of this series where we will cover power sources and analog to digital converters.

While all pressure sensors may not use these exact components and techniques, they will all need to convert some physical movement into an electrical signal. They will all need to handle linearization, amplification and temperature compensation. Hopefully learning a little more about the sensor in your altimeter gives you a better appreciation for the engineering that goes into its design.

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About The Author:

Norm Diedzic Jr. is an avid rocket flyer and a member of NIRA (Northern Illinois Rocketry Association; NAR Section 117). He has written several technical articles for their LAC winning newsletter, *The Leading Edge*, as well as a treatese on hemispherical parachute construction that appears in the book *Model Rocket Design and Construction*.

You may also recognize Norm as the inventor of a method of restraining small rocket motors in minimum diameter models, called the Dziedzic cut-out method (see *Model Rocket Design and Construction,* 3rd Edition, page 100)

He has an M.S. in Mechanical Engineering from University of Illinois at Chicago, and is currently the Engineering Manager at CMA/Flodyne/Hydradyne, an industrial distribution company serving Northern Illinois and Wisconsin and specializing in hydraulic and electrical motion control.

Reader Questions And Construction Tips

By Tim Van Milligan

The Strength Of Ejection Charges

Shawn M. wrote and ask these questions: *"I purchased a Nike-X model from Apogee (www.ApogeeRockets.com/Q-Modeling_NikeX.asp) last year sometime. I recently got around to launching it with the Aerotech E30-4T composite motors (www.ApogeeRockets.com/aerotech_motors.asp). The rocket looks good on the pad and the composite motor is impressive! On one flight the ejection charge deployed the parachute and also ejected the motor. It seemed like a bad idea to have the hard plastic casing ejected and falling to the ground over the launch area, so on the next launch I taped around the retaining clip and the motor. This worked to keep the motor secure in the rocket. Unfortunately the ejection charge deployed with so much force that the screw eye securing the Kevlar cord to the nose cone was pulled out. The cord also detached from the rocket body where it was tied around the balsa frame for the main fins and engine mount. So I had the rocket tube, nose cone, and parachute all come down separately!!*

Question 1: Are the ejection charges on the composite motors stronger then the regular Estes motors?

Question 2: The main rocket body and nose cone are still in good shape. I need some ideas about how to re-at-

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Reader Questions and Construction Tips

tach a new parachute cord to the rocket body and how to beef up the attachment points so that everything stays together in the future. Any suggestions?? I really like this rocket and want to try to repair it and get it back on the launch pad!!"

To answer question one, I don't think there is much difference in the strength of the ejection charges between black powder motors. I haven't weighed out the amount of black powder in each, which is probably the only way to know for sure. But the similar size of the 24mm D and the 24mm E would seem to indicate that they both contain somewhat the same amount.

Currently, all rocket motors use loose black powder for the ejection charges. The way it works is by burning this black powder which creates a lot of hot gas inside the rocket. The gases are composed of molecules that move fast. The hotter the gases, the faster they move around. This movement of gas particles creates a high internal pressure inside the rocket. It is so high that the rocket can't contain it. The gases have to go somewhere, so they try to pop open the rocket like a balloon. Fortunately, since the nose cone is designed to slide off before the tube fractures, we get a nice controlled ejection of the parachute.

If both types of motors contain about the same amount, then why would one seem more powerful than the other? There could be three reasons that I think might be happening. First, it may just be an optical illusion.

There are a few things that control how fast a nose cone comes off, with the biggest one being how tight the nose cone is on the rocket. If it is really tight, it can come out of the tube like a canon shell. I suspect this is the case with the Nike-X kit. The reason is that the nose cones on the kit are urethane, and have a bit of variability on their shoulder diameter.

When the nose cone comes out so hard, it puts a lot more stress on the shock cord and the attachment points and could cause them to fail. It is a delicate balance, and depends on the diameter of the rocket. Too much friction on the fit of the nose cone shoulder, and it either comes out like an artillery shell or the engine gets kicked out the back end. Too loose, and it may come off prematurely while the rocket is still traveling upward (see newsletter 68 at www.ApogeeRockets.com/Education/Downloads/Newsletter68.pdf). You have to pay attention to how much friction is on the nose cone.

Another reason they may seem more powerful is that most times a rocket with a composite motor flies a lot

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higher than a black-powder propelled rocket. Since the atmospheric pressure decreases with altitude, the pressure difference between the inside of the rocket and the outside air is going to be much greater. The nose should come out faster as the rocket goes higher.

Finally, the difference may be because the ejection charge in the composite motor is not tamped down like it is an Estes motor, so the flame may propagate through the powder faster and create higher pressure quicker.

What does that mean? Basically, the fire spreads through the loose powder faster when it isn't packed down because there are more directions for the fire travel as it goes from particle to particle of powder.

This makes sense, right? Because you're a rocket scientist, you know that the more surface area exposed in the propellant, the faster it burns. After all, that is how a manufacturer controls how long a rocket motor burns. An end-burner takes longer to burn than a core burner because it has less surface area exposed to the flame front. The same is true in the ejection charge.

In the ejection charge, the smaller the particles and the looser they are packed down, the quicker the flame will travel through the space. That liberates the molecules faster, which results in a big spike in internal pressure making the nose cone come off faster.

The second question is how to repair the damage.

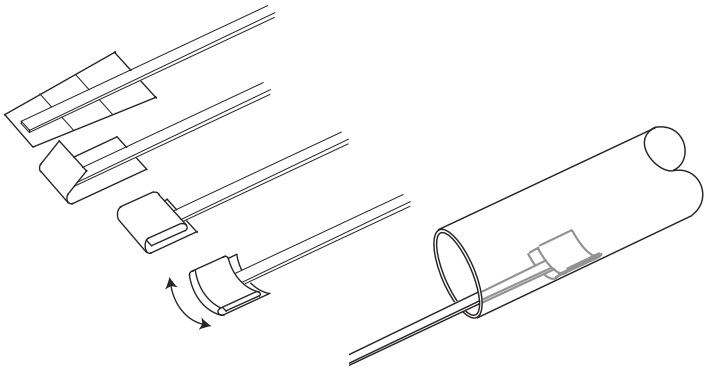

Figure 1: The typical Estes style shock cord mount attachment method.

In my opinion, you're going to have to do an Estes style shock cord mount on both sides of the cord (cone and body). That is the only thing that I can think that will work to salvage the rocket.

The reason is that you can't easily get down inside the tube to reattach to the engine mount. If it was a small rocket you could make a removable engine mount like shown in Peak-of-Flight Newsletter 231 (www.ApogeeRockets.com/Education/Downloads/Newsletter231.pdf). But for a big rocket like this, I think you'll need something a bit stronger.

Nose cones are harder to fix. The Nike-X has a hollow base and a bulkhead that is glued into it. One method would be to try to remove the old bulkhead and replace it with a new one. But that is going to be a chore. I would

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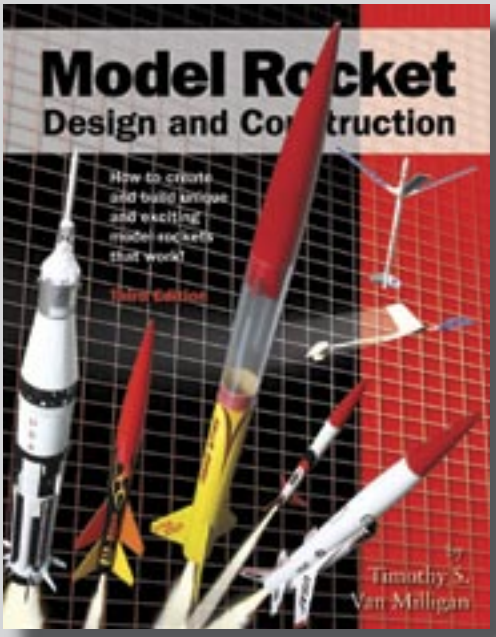

Model Rocket Design and Construction

By Timothy S. Van Milligan

New 3rd Edition Now Shipping!

This new 328 page guidebook for serious rocket designers contains the most up-to-date information on creating unique and exciting models that really work. With 566 illustrations and 175 photos, it is the ultimate resource if you want to make rockets that will push the edge of the performance envelope. Because of the number of pictures, it is also a great gift to give to beginners to start them on their rocketry future.

For more information, and to order this hefty book, visit the Apogee web site at: www.ApogeeRockets.com/design_book.asp

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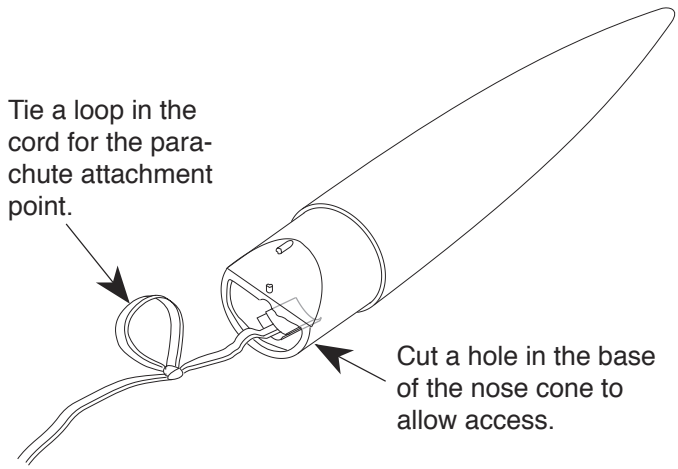


Figure 2: On a hollow plastic nose cone, you can also use the Estes style shock cord mount to reattach the nose to the rocket.

chisel out a bigger hole and simply glue a Estes style shock cord mount on the inside of the nose.

Reader Rocket Tips

William Blair writes: *"Here are a few tips I've come up with in my never ending quest for cheap or free hobby materials.*

Tip 1: To apply glue into tight spots, inject or draw glue into a coffee stirring straw like the ones supplied by fast food chains. Put your finger over the end opposite the glue and position the end holding the glue into the tight spot. Uncover the end you were blocking and then, depending upon the viscosity of the glue, either allow gravity to flow the glue onto the desired spot or apply some positive pressure at the end of the straw you were blocking with your finger. I've actually used this method _only_ with wood glue which I've _injected_ into the straws with the bottle applicator tip. Works GREAT. Note that I _did not_ say "suck" on the straw or "blow" on the straw since I don't want someone getting epoxy or CA in their mouth.

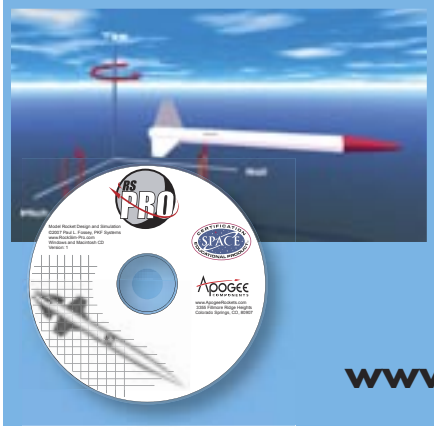
To get viscous glues to flow from the straw without blowing into it, I guess you could do so by not removing your finger from the stirring straw's end and squeezing it along its length moving towards the glue end. Haven't tried that since, like I said previously, I've only used the straw application method with wood glue (Titebond III) which flows out of the straw on its own.

Tip 2: For large epoxy mixing jobs, use empty snack pudding cups. For smaller jobs, use nested paper ketchup cups like the ones supplied by fast food chains."

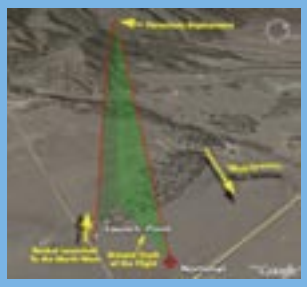
Great tips William. I'll pass them along to the readers of the Peak-of-Flight newsletter. Maybe it will inspire them to send in their construction tips too.

Sim Your Rockets With The Confidence of 6-Degrees-of-Freedom

RS-PRO is a 6-degree-of-freedom rocket simulator to find the behavior of high-performance rockets. It picks up where RockSim leaves off:



- Speeds up to Mach 10
- Altitudes up to 392.7 miles
- Reads RockSim design files
- Create landing zone patterns in Google Earth
- See a 3D trajectory path
- Developed for university researchers and aerospace professionals.



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