PEAK OF FLIGHT
NEWSLETTER

APOGEE
COMPONENTS

What is the Difference Between the Barrowman Equations and the RockSim Method?

Cover Photo: Cosmodrome "Nike-Apache."
To get one, visit:

www.apogeerockets.com/Cosmodrome_Nike_Apache.asp

What is the Difference Between Barrowman's Equations and The RockSim Stability Method?

By Tim Van Milligan

Christoper Dale writes: *"Thanks for the info on choosing the right motor, and yes I'll send pics of the V2. I know you've probably been asked this a hundred times (and I've found pretty much conflicting info on the web), but what explains the large discrepancies in CP/CG between Barrowman and rocksim? My V2 comes in at 1.80 calibers RockSim and 1.01 Barrowman -- enough to make me question how I should manage my nose cone mass."*

This is a common question, and as I always tell people, the RockSim method is really the Barrowman Method. People don't believe me… Why? Because if they are the same, then they should yield the same results. But they don't.
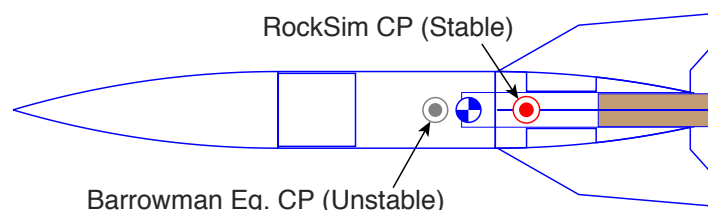

Figure 1: On the V2 rocket, the RockSim Method indicate that the rocket is stable, while the Barrowman Equations say it is unstable.

So let me explain why the RockSim method gives different values than the classic Barrowman equations.

But first, what exactly is the Barrowman Method?

Simply, the Barrowman Method (or Barrowman Equations; the terms mean the same thing) is a set of formulas that are used to estimate where exactly the Center-of-Pressure (CP) of a rocket is. As you know, the CP is an important concept in rocketry. It is the physical location on the rocket where all the aerodynamic forces (such as lift and drag) are said to be balance.

Once the CP is estimated it is relatively easy to determine if the rocket is stable. If the CP is behind the Center-of-Gravity (CG), the rocket is stable. On the other hand, it the CP is forward (towards the nose) of the CG, the rocket is unstable.

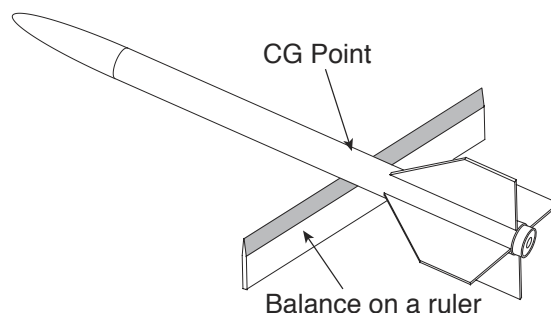Finding the Center-of-Gravity of a rocket is relatively

Figure 2: Finding the CG of a rocket is accomplished by finding its balance point.

easy to do. You simply balance it on a ruler and find the balance location. But how do you find the location on the rocket where the aerodynamic forces balance? That is a very hard question to answer. It was the Barrowman Equations that gave us a reasonable answer.

Let's take a little trip back to the 1960's and learn some history. Up to this point in time, your average rocketeer really didn't have a clue where the CP was. There were basically three methods he could use to find out if his rocket was stable without actually flying it.

The first method is to actually use a wind tunnel to measure the forces on the rocket and see where they balance. This, incidentally, is the most accurate thing to do, even to this day. But everyone that has a wind tunnel at your disposal, please hold up your hand high so I can count you. I see no hands raised, except those jokers in the back of the room who are students in universities that have wind
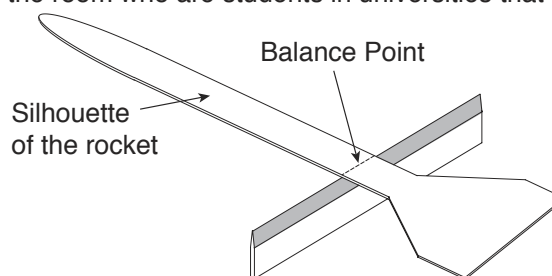

Figure 3: The cardboard cut-out method of finding the CP puts the location way too far forward

RockSim versus the Barrowman Equations

tunnels. So basically, this option is not very practical.

The second method is to use the cardboard cut-out technique to estimate where the CP of the rocket is. To be honest, I don't have any idea who came up with the cardboard cut-out method. It assumes that the rocket is flying sideways as it is moving upward into the sky. That is a really peculiar situation. Think about a rocket going sideways, when the force of the motor is perpendicular the direction of travel. I have a hard time wrapping my mind around that concept.

But if the rocket was going sideways, then it is easy to determine where the forces are acting on the rocket. It is the center of lateral area. That means if you draw a silhouette of the rocket, cut that out, and balance "it" on a knife edge, you will find the center of lateral area.

Is this method any good? It depends. If you have nothing better, it is good. But how useful is it in real-world conditions? In reality, the cardboard cut-out method places the CP too far forward on the rocket. So a rocketeer may think his rocket is unstable, when it actually could be stable and safe to fly. In that sense, it is considered an "overly conservative" method because it will be over stable in real life. It won't allow you to fly a rocket that is unstable, and hence you're always going to get a rocket that flies straight.

By the way, is an overly stable rocket good or bad? To find out the answer, see Peak-of-Flight Newsletter 05 (www.ApogeeRockets.com/education/downloads/Newsletter05.pdf).

When using the cardboard cut-out method to make sure the CG is in front of the CP, you'll have to add a lot of nose weight to the rocket. This is a disadvantage in two ways. First, now you have a really heavy rocket, which means you'll need a bigger motor to get it into the air. Second, if the rocket were to go unstable, because it is heavier, it has more potential energy associated with it, and therefore could cause more damage when it crashes. Making a rocket heavier is not a good way to make it "safer." Making a rocket lighter is my priority when it comes to making it safer.

To me, the cardboard cut-out method is the technique of last resort to estimate the CP location on the rocket. By the way, if you want to learn more about the cardboard cut-out method, see Peak-of-Flight Newsletter 18 (www.ApogeeRockets.com/education/downloads/Newsletter18.pdf).

The third way that modelers used in the 1960's to determining if their designs were safe to fly was to use the string/swing test. Basically, you would tie a string around the rocket, and tape it down at the CG position of the

RockSim versus the Barrowman Equations

rocket. Then you'd swing it around your head as fast as you could. If the rocket pointed itself into the direction of travel, you'd assume that it was stable and safe to launch with a rocket motor.

The string/swing test has its disadvantages too. First of all, you actually have to build the model in order to test it for stability. That gets tedious and expensive if you want to test several different variations of the rocket. And if you have a really big rocket, it is very awkward to try to swing it around your back yard without crashing it into something and breaking the model.

Second, the string test often fails. Sometimes the rocket would fly fins forward instead of nose first. There are a couple of reasons the string test fails to indicate that real rockets are stable when the string/swing test shows them to be unstable. I wrote about this previously in Newsletter 53 (www.ApogeeRockets.com/education/downloads/Newsletter53.pdf).

The point I want to make is that back in the early 1960's, rocketeers didn't have a good way of accurately estimating the CP location of a rocket. They were really flying blind.

But in 1966, suddenly everything changed. Rocketry would forever be altered. What happened was that a rocketeer named James Barrowman, while working at NASA as an aerospace engineer, developed a series of equations that enabled us to estimate the CP of rockets. He published this in an R&D report for NARAM-8.

It was a very detailed report with lots of calculus in it, which meant it still wasn't easy for a modeler to calculate where the CP of the rocket was.

It was also very labor intensive to do the calculations.

Jim Barrowman (right) is still active in model rocketry. Pictured with Tim Van Milligan (left) and Marc Lavigne at NARAM-50 in August 2008.

Why was that? Because you have to remember, the year was 1966. I'll ask you again to raise your hand if you had a personal computer back in 1966. I don't see any hands up in the air as I look around to the people reading this.

So Jim went one step further, and this was the brilliant part. He recognized that in general, most stable rockets have similar shapes. Furthermore, if he could limit the rocket to those shapes, then the equations to calculate the CP of the rocket got relatively easy to chug through using simple multiplication and addition. He went on to publish those simplified equations in the now famous reports that were put out by Centuri called TIR-30 and TIR-33 (both of these are available at JIMZ Rocket Plans. The web site to download them is: www.spacemodeling.org/JimZ/pubs.htm).

RockSim versus the Barrowman Equations

Suddenly, what was hard to do became much easier. Note: If you've ever run through the Barrowman Equations by hand using a pencil and paper, you know that they are still not trivial. But it is do-able.

The famous TIR 33 report

How did he make them simpler to perform? Great question. He made a lot of assumptions and restrictions on the shape of the rocket.

For starters, he assumed that the rocket would be generally long and cylindrical in shape. He also assumed that simple geometric shapes would be used for the nose cone, transitions, and fins. For fins, he restricted the number to 3, 4, or 6 fins that were placed symmetrically around the perimeter of the rocket. Plus, he assumed that the rocket would be flying at very low angles of attack, and that the tube would not produce any lift or drag forces. In addition, he constrained the location of the fins; they could not be attached to nose cones and transition sections.
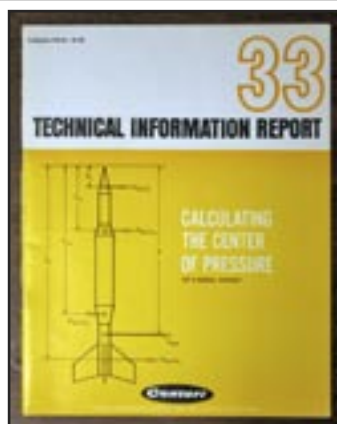
So from 1966 to the mid 1980's, modelers now put their pencils to a piece of paper and chugged through the equations to find the CP of their rockets. It should be noted that it would take about an hour to run through all the equations. If you changed your design, you'd have to start all over again. So modifying a design once you got it stable was a time-consuming process.

The next break-through in rocket design occurred when personal computers became inexpensive enough for people to afford to get their own. This was in the early 1980's. I don't know who did it first, but someone took the simplified Barrowman Equations and created a little program to chug through them. What this program did was to drastically reduce the time to find the CP location of the rocket. It was now just a few seconds instead of close to an hour. Modifying the design was simplified too. It was now possible to optimize the design by shifting the location of components around to reduce the weight of the rocket and still have it be stable enough to launch.

There was only one small problem with the programs. They were more like word processor programs, and did not contain any graphics. In essence, they simply asked you questions about your rocket, and at the end of the process, it would spit out the CP location from the tip of the nose cone. For example, the first few lines of the code would say

RockSim versus the Barrowman Equations

some thing like:

1. What is the length of the nose cone? <type your answer and hit the enter key>
2. What is the diameter of the nose cone? <type your answer and hit the enter key>
3. What is the shape of the nose cone? <type your answer and hit the enter key>

You can see something similar at: http://www.webcalc.net/calc/0225.php

A Center of Pressure Calculation program for the Mac by Tom Beach.

As you can tell, it wasn't nearly as sophisticated as the programs of today, like RockSim.

The first rocketry programs that contained graphics came out in the late 1980's, and were only for the Macintosh computers. The first one that I saw was a "hypercard stack" program written by Tom Beach (the current Editor of *Sport Rocketry* magazine). I still have it

on an old Mac computer that I bought in 1989. It was pretty static, but at least you got to see a picture of your rocket to confirm that you were putting the numbers in the right boxes on the screen.

In the early-1990's Microsoft finally did away with the DOS operating system and came out with the "Windows Operating System". This finally allowed the non-Mac users to start catching up to Mac users by getting programs that were more graphics intensive. Along the way, rocketeers were quick to exploit this, and a program called VCP was created. The "V" in VCP stood for "visual."

I've told this next part of the story several times before, so if it bores you, please skim forward.

In late 1994, Microsoft came out with a very sophisticated operating system called Windows95. It was much more complicated than the previous versions of Windows, and in the Microsoft tradition, the old programs the people had would not run with the new operating system. Everyone wanted this new type of computer, but the rocketry software was not available for it.

A rocketeer and programmer, Paul Fossey, came to me around this time period and asked if I would help him with a new rocketry program that would run on the Windows95

RockSim versus the Barrowman Equations

operating system. Paul had gotten a hold of the first edition of my book *Model Rocket Design and Construction* (www.ApogeeRockets.com/design_book.asp) and wanted my input on the program he wanted to create. I literally didn't think much of the project. I was a Mac user, and I was working with Tony Wayne on a rocketry program for the Mac that I could personally use. But to be polite to Paul, I told him I'd offer my technical expertise in any capacity that he needed. I had a hunch that he'd give up on the program after a few weeks. And for several months, I never heard from him again.

But suddenly, he emailed me again and said he had made progress on the program he called RockSim. He then sent me a bunch of print outs of the various screens of the program. When I saw them, I can say that I did one thing right. I recognized the genius of what he had done. It was like being slapped upside the head, and my jaw was on the floor.

What he had done was brilliant. He had married the calculation of the CP (what I call designing a rocket) with the simulation. Up to this point, not only were there no Windows95 programs for rocketry, there were two types of rocketry programs. There were programs like VCP that calculated the CP of the rocket, and then there were programs that figured out how high the rocket would fly (the popular one at the time was called W.R.A.S.P. for "Windows Rocket Altitude Simulation Program"). So with this one new program from Paul, a modeler would have three of their wishes satisfied.
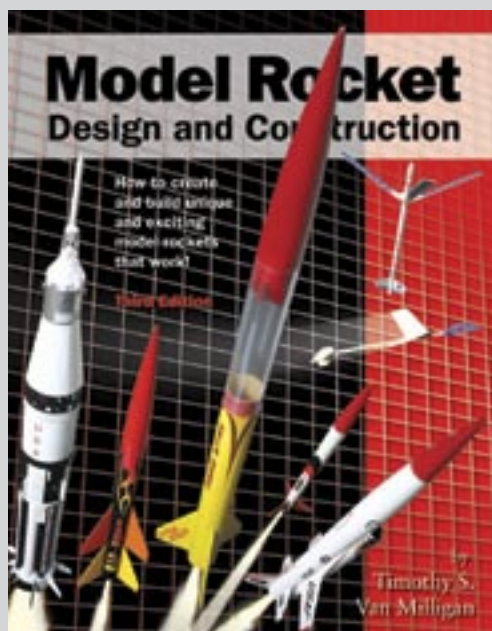
But it was more than that. It was dynamic in a graphical sense. If you have RockSim, you know what I mean. Instead of typing a number in, such as keying in the length of the nose cone and hitting the enter key, a user could simply move a slider bar to change the length of the nose cone. The image of the nose cone displayed would change shape instantly in response to the slider bar movement. At the same time, the CP location was also updated, as was the weight of the rocket.

It was big, and RockSim v1 was born.

Getting back to our original discussion, RockSim v1 used those simple Barrowman Equations that all the other programs used. But when users of RockSim saw how cool it was to design rockets using it, they quickly started shouting for more design options. They wanted to put fins on a transition section, like you would see on a V2 rocket. They also wanted more choices of fin shapes than simple trapezoidal shapes and ellipses.

Solving the fin shape problem was not trivial. If you want a non-uniform shape, you have to get creative. In 1998, Paul came up with a really unique method of finding the CP of free-form shapes. In fact, we copyrighted it! If you are interested in reading how we do it, you can purchase Technical Publication #17, which describes the process. It can be ordered from our web site at: www.apogeerockets.com/technical_publications.asp

RockSim versus the Barrowman Equations

If you look at the method, you see that it references the Barrowman Equations pretty heavily. What RockSim does is to find the equivalent fin size that would plug into the Barrowman equations.

Where RockSim and Barrowman really diverge is when the fins are attached to a boattail (a transition where the small end is toward the bottom of the rocket), like on a V2 rocket. This is almost always the situation that causes people to email me and ask me the difference between the two methods. That is why I am writing this article, and have directed you to here to read it.

First of all, the Barrowman method does NOT allow for this configuration. That begs the question: "So how do you come up with a number for the Barrowman Method?" What we do is take the worst case situation, and make that the Barrowman Method for this special case. It is sorta like the cardboard cut-out method; which is also a "worst case" situation. To make a worst-case situation workable, you usually have to add extra nose weight. And in the case of a V2 rocket, the Barrowman Method will always put the CP far enough forward that the rocket will be unstable (see Figure 1 on page 2).

Incidentally, according to the Barrowman Equations, the worst case in such a configuration would be if the fins
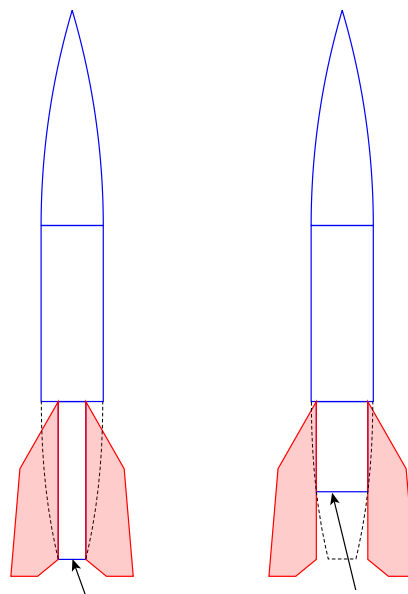

Figure 4: Where the fins are attached to a boattail is a big difference between the Barrowman Method and the RockSim Method. In the Barrowman method (left side), the fins are attached to a diameter that is the same as the base diameter of the tail. In the RockSim Method (right side), the fins are attached to a fictional diameter that is larger than the base diameter.

RockSim versus the Barrowman Equations

were attached to the smallest diameter of the transition. In other words, they would be close to the rocket and would not stick out into the airstream. Therefore they wouldn't be very effective (see Figure 4).

In the RockSim method, we use the mid-point of the root chord as the reference location. When you do this, the fins stick out into the air more (as seen by the equations), and are more effective. This moves the CP back, which is more stabilizing.

In defense of this assumption of fins attached to boat-tails, I'd like to point out that the RockSim method is a half-breed method. It isn't a worst-case method like the Barrowman Method, and it isn't a best-case method either. The best case would be to assume the fins are attached to the large part of the transition. So the RockSim method is right in the middle.

Does it work? I can say

that in practice, the theory seems to work fine in the case of the V2 rocket. I've never seen any V2 go unstable in the 10 years since we made this assumption. If you don't like the assumption, you can always use the CP location provided by the worst-case Barrowman Method; in which case you'll have to add nose weight to the rocket to make is stable.

More Advances

When we made these advances in how a rocket could be configured, we got a lot of user feedback. They loved it that RockSim could allow them to make designs that were not possible before. What's more, these customers would then ask for other restrictions to be lifted. For example, once we allowed the shape of the fins to be modified, they asked if we could allow a different number of fins other than 3, 4, or 6 fins. This is how progress is driven, through customer feedback.

To get around the restriction of having a rocket with 3, 4, or 6 fins, we had to go back to the original paper from Jim Barrowman. You see, when people think of the Barrowman Equations today, they actually reach for the simplified version (such as TIR-33 that you may have downloaded). Recall from what I mentioned earlier, he simplified the equations to those that were easily solvable using simple

Continued from page 9

RockSim versus the Barrowman Equations

multiplication and addition (because computers weren't around yet).

Once you go back to the original report, you'll find the starting point he used for the calculations for the CP of an individual fin. Once you have that, it is just a matter of doing a little 3D geometry to find the effect that a single fin has on the overall location of the CP. It isn't trivial, but it is solvable by a computer.

What I like to tell people is that the RockSim Method is the Barrowman Method. The difference is that we went back to the original equations and tried to remove as many assumptions as possible. The result is that you can design a wide variety of configurations and the rockets will be stable. It is good enough to trust.

Is it perfect? I know it isn't perfect. But where it is inaccurate, it is usually off on the conservative side. In other words, RockSim will probably estimate the CP further aft than where it would be found if you actually did wind tunnel testing. That is a good thing, since we don't want people to fly an unstable model.

Are the Barrowman Equations Accurate?

For the most part the Barrowman Equations are great. Modelers have been using them for nearly 45 years, and they have proven themselves to be reliable.

But this past weekend, we found that there is a special case of rocket shape that causes the Barrowman Equations to blow up. We didn't realize this until we ran an actual simulation using RockSim.

The situation is when you have a very tiny nose, compared to a big bottom section where the fins are attached. The classic example is the Saturn 1B design with the escape tower on the tip of the nose cone.

In this configuration, the Barrowman Equations predict that the fins are REALLY effective (more than they should be). So what happens is that as soon as the rocket leaves the launch rod, it reorients itself into the wind so fast, that the overall altitude that the rocket reaches is really low.

I've had several people report this to me in the last few months, and we didn't figure out that it was the Barrowman Equations that were breaking down. It was RockSim's simulator that pointed us to the cause.

The solution, by the way, is to take the escape tower off the rocket, and use the Apollo capsule as the nose of the rocket. That is the way I had it set up in the sample files in RockSim version 8. But because v9 allowed me to put other pods on the Saturn 1B design, I went back and put the escape tower on it too. So if you have a v9 design file of the Saturn 1B, it won't give you good altitudes until you modify the design. Like I said, this is a strange situation, and it is going to take some more research to figure out how to prevent it from happening in future versions of the software. All I can say is that Rocksim is a great tool that allowed us to find this situation. Otherwise, we might not have seen it at all.

Conclusion

In the past 10 years, the RockSim method (which only

Apogee 1/70th Scale Saturn 1B
Length: 37.5421 In. , Diameter: 3.8300 In. , Span diameter: 7.0300 In.
Mass 522.751 g , Selected stage mass 522.751 g
CG: 20.8335 In., CP: 28.0654 In., Margin: 1.89
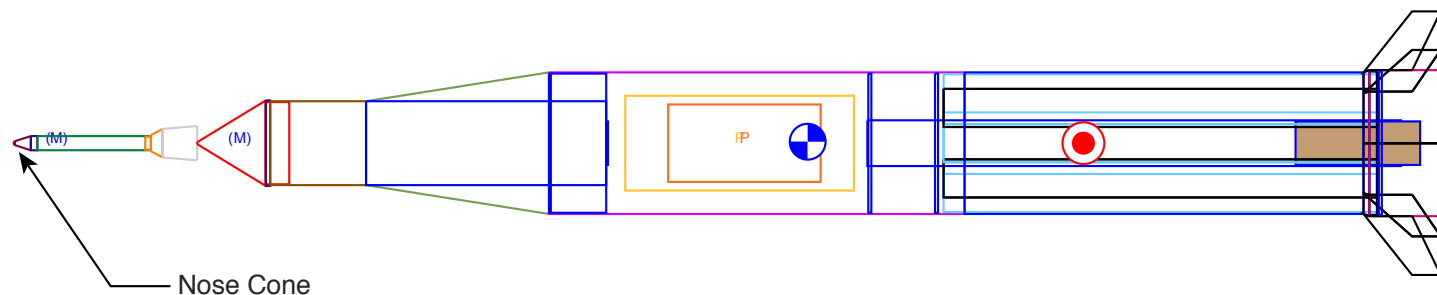Engines: [F20W-4,]

Nose Cone

Figure 5: The tiny rounded nose on the escape tower of the Saturn 1B design file will trick the Barrowman Equations into thinking that the fins are really efficient because of how far they stick out in the airstream. This creates a high Normal Force Coefficient for the fins. When the rocket hits a cross wind, the rocket corrects so fast by weathercocking into the wind, that it doesn't fly very high. The solution is to remove the escape tower from the rocket design.

RockSim versus the Barrowman Equations

differs slightly from Jim Barrowman's original method) has proven itself to me to be reliable. When people ask me which method I use, I don't even hesitate to say that I trust the RockSim method with my designs. When I use it, the rockets all seem to fly straight and stable, which is one of my definitions of a safe flight.

I know it takes trust on the part of other modelers to say they trust it too. I can't force them to trust it. So if they don't, my recommendation is to build a small sub-scale version of their rocket and fly it in a place where it wouldn't cause any harm if it should go unstable. This scale version is a good approach to take. In fact, it was the method modelers had to use in the 1960's before they had access to the Barrowman Equations.

References:

Other articles on the subject of CP location and topics relating to stability, including the original Barrowman R&D report (with all its glorious calculus) can be found on the Apogee Components web site at: www.apogeerockets.com/education/rocket_stability.asp

For articles on rocket stability that have appeared in this Peak-of-Flight Newsletter, see: www.apogeerockets.com/Peak-of-Flight_index.asp#stability

About The Author:

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. Before he started writing articles and books about rocketry, he worked on the Delta II rocket that launched satellites into orbit. He has a B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University in Daytona Beach, Florida, and has worked toward a M.S. in Space Technology from the Florida Institute of Technology in Melbourne, Florida. Currently, he is the owner of Apogee Components (http://www.apogeerockets.com) and the curator of the rocketry education web site: http://www.apogeerockets.com/education/. He is also the author of the books: *"Model Rocket Design and Construction," "69 Simple Science Fair Projects with Model Rockets: Aeronautics"* and publisher of a FREE e-zine newsletter about model rockets. You can subscribe to the e-zine at the Apogee Components web site or by sending an e-mail to: ezine@apogeerockets.com with "SUBSCRIBE" as the subject line of the message.