ISSUE 193 - SEPT 25, 2007

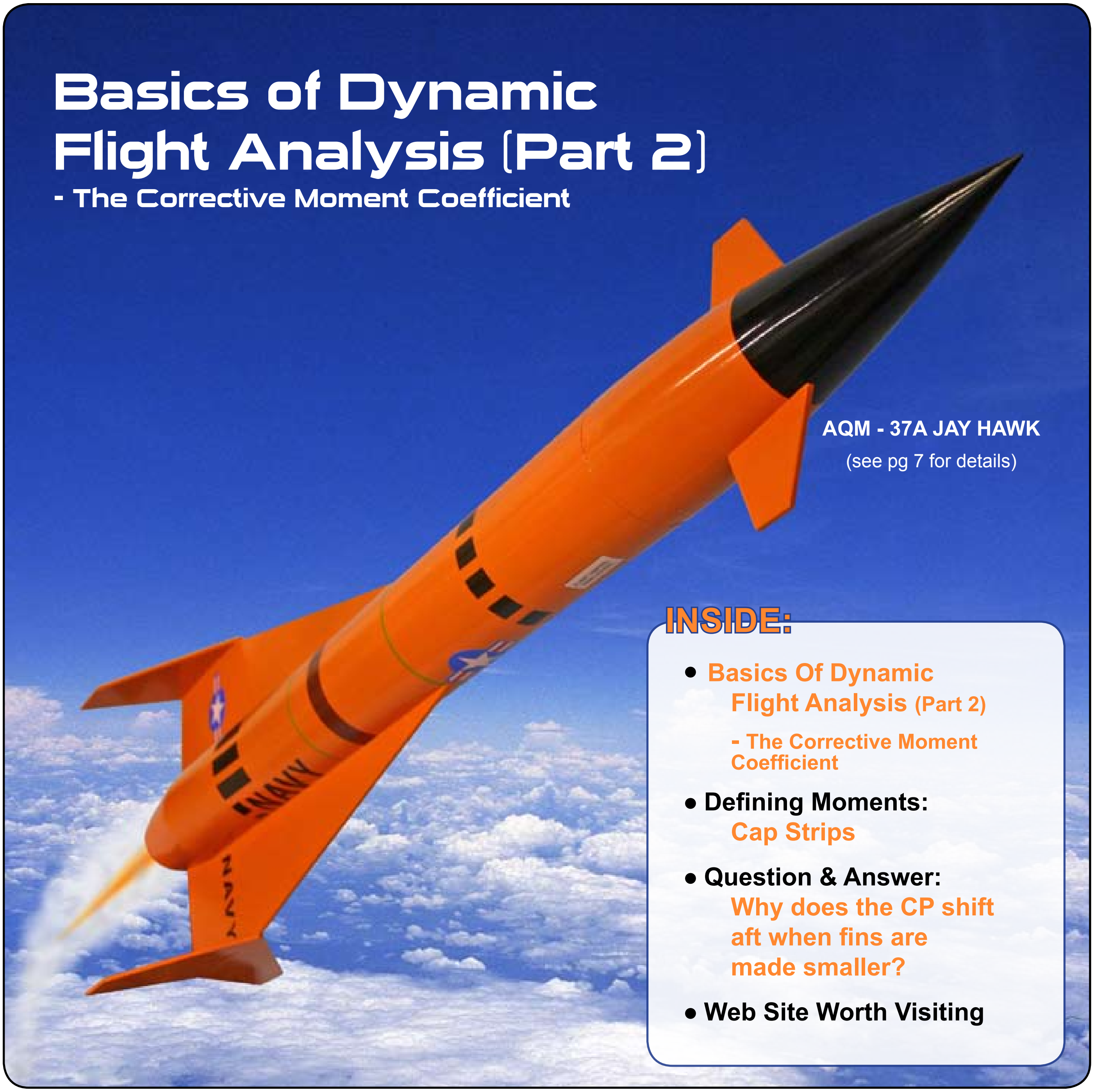
APOGEE

PEAK OF FLIGHT

NEWSLETTER

Basics of Dynamic Flight Analysis (Part 2)

- The Corrective Moment Coefficient



AQM - 37A JAY HAWK

(see pg 7 for details)

INSIDE:

Apogee COMPONENTS

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

ISSUE 193 - SEPT 25, 2007
PEAK OF FLIGHT
APOGEE

Basics of Dynamic Flight Analysis (Part 2)
- The Corrective Moment Coefficient

By Tim Van Milligan

In Part 1 of this article we discussed the Longitudinal Moment of Inertia and the role it played in determining the trajectory of a rocket. If you missed it, see Newsletter 192. http://www.ApogeeRockets.com/education/downloads/newsletter192.pdf

The next parameter of the rocket that is important to our discussion of dynamic flight analysis is called the "*Corrective Moment Coefficient*."

The first word, "Corrective," gives away what this term does. It is used to determine the corrective force that the rocket creates in response to a disturbance in flight. The larger the value, the more force the rocket creates and the quicker it will react to a disturbance.

Let's put this into perspective with what you already know about rockets, and I'll show you that probably have a good understanding of the concepts used in computing the Corrective Moment Coefficient.

For starters, ask any experienced rocketeer what part on the rocket has the most effect on the trajectory, and they'll likely tell you it is the "fins." Based on this, you probably won't be surprised to find that the fins are a big factor in how large the Corrective Moment Coefficient will be.

Dig a little deeper with your questioning, and ask them how the fins can be made to produce more force. Pause here to think about it.

I bet you that you and your rocket friends will be able to come up with answers like: fin size and shape, airfoil contour that is sanded into the fin, and the speed at which the fin moves through the air. This all makes sense, doesn't it?

Guess what? You're dead right. And now you'll see that it is the Corrective Moment Coefficient that takes all these variables into consideration.

The formula to calculate the Corrective Moment Coefficient is:

$$C_1 = \rho/2\ V^2\ A_r\ C_{Na}\ [Z - W]$$

C_1 = Corrective Moment Coefficient
ρ = Density of Air
V = Velocity of the Rocket.
A_r = Reference Area (usually the maximum frontal area of the rocket tube)
C_{Na} = Normal Force Coefficient
$[Z - W]$ = Distance the CG is in front of the CP

The first thing that we need to point out when looking at the formula for the Corrective Moment Coefficient is that it will be constantly changing throughout the flight of the rocket. Compare this against the Longitudinal Moment of Inertia that we discussed in Part 1 of this article. Except for when the engine was burning and losing weight, the Longitudinal Moment of Inertia was a static value. It stayed the same throughout most of the flight.

Why is the Corrective Moment Coefficient a dynamic (*constantly changing*) number? Let's look at the individual components that are used to calculate it from the formula above.

Density of Air – As the rocket ascends, the density of air is constantly decreasing. Note that when in outer

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
Writers: Tim Van Milligan
Layout / Cover Artist: Dave Curtis
Proofreader: Michelle Mason

Continued from page 2

space, the density becomes zero, so the Corrective Moment Coefficient also becomes zero. That means in outer space, fins can't be used to control the rocket's flight path; they won't work at all to produce a restoring force.

Velocity of the Rocket – The rocket's speed is constantly changing during the flight; it starts fast at liftoff and gradually slows down to its lowest value at apogee. The velocity of the rocket has the biggest effect on the Corrective Moment Coefficient because the term is squared. In other words, if you double the velocity of the rocket, the Corrective Moment Coefficient goes up by a factor of four.

Normal Force Coefficient – This number will depend on the size of the fins and airfoil used on the rocket. More than that though, it also depends on the angle-of-attack that the rocket is flying at. The higher the angle-of-attack, the more lift force the fins produce and the greater the value for the Normal Force Coefficient.

Distance the CG is in front of the CP – This number changes throughout the flight too. First off, the CG of a rocket shifts forward while the engine is burning. Why? Because the back end of the rocket gets lighter as the propellant is burned, so the balance point must move forward. The CP location of the rocket also shifts around during the flight depending on the angle-of-attack of the rocket.

What Effect Does the Corrective Moment Coefficient Have On The Flight?

The Corrective Moment Coefficient is used to determine how quickly and with how much force the rocket reacts to a disturbance in flight. A high Corrective Moment Coefficient value means that the rocket will produces forces (primarily Lift) to counter the disturbing force, such as a gust of wind when the rocket leaves the launch pad.

Let's verify this by studying the results produced by the RockSim software.

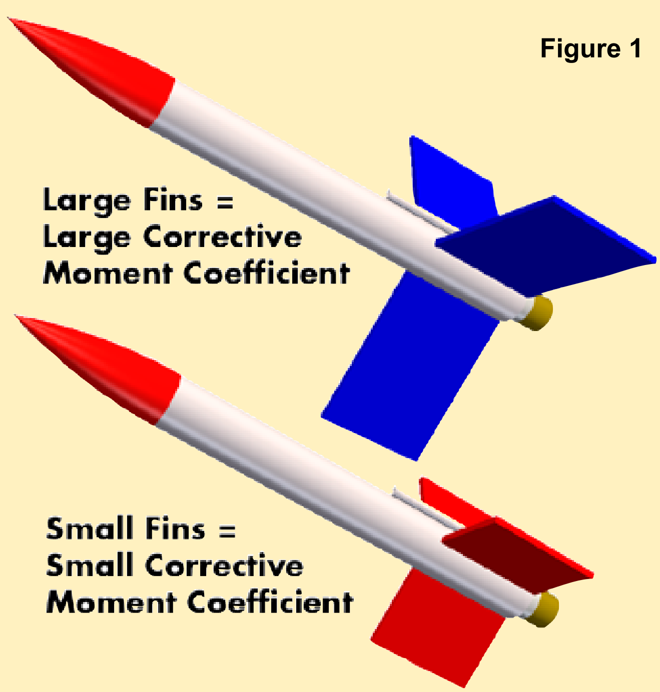
But before we do that, let's ask the question: "what might a rocket look like if we had a rocket with a low Corrective Moment Coefficient value versus one with a high value?"

That's a trick question really… Remember from our discussion of the terms used to calculate C1, the speed of the rocket has a big effect on the overall value. If you double the speed of the rocket, you can increase the Corrective Moment Coefficient by a factor of four. That means that switching to a higher thrust motor will change the way the rocket behaves because the motor is what controls the speed of the rocket.

But lets say that for sake of discussion that we want to have the same lift-off speed to compare rockets. In that case we can control the Corrective Moment Coefficient by the size of our fins and the distance the CG is ahead of the CP.

Figure 1 shows the difference between two rockets.

Figure 1



Continued on page 4

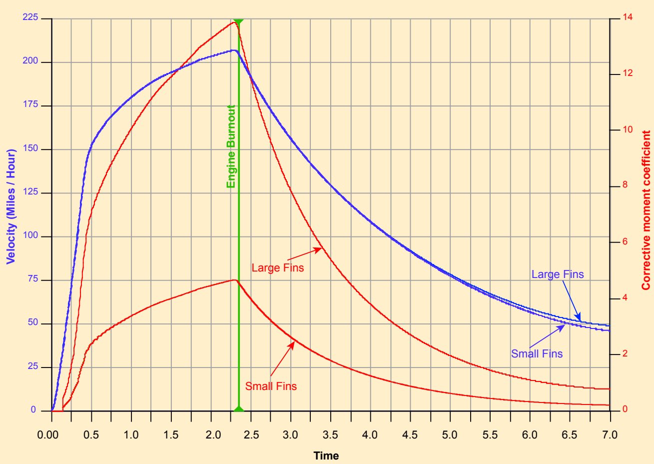
Continued from page 3

As you can see in Figure 1, I made two rockets, the only difference being the size of the fins. I used rectangular shaped fins for simplicity. The dimensions of the fins are identical except for the span. I doubled the area of the fins by simply doubling the span of the fins.

At this point, we can run RockSim simulations comparing the effects of these two rocket designs. In order to isolate the effect of the corrective moment coefficient, I used a mass override for the entire design (to keep the Longitudinal Moment of Inertia equal). I also used a fixed drag coefficient instead of letting RockSim calculate it during the flight. It is obvious that the rocket with bigger fins will have more drag than the smaller one. But I don't want the drag coefficient to be different and skewing the results of the simulations.

For the flight simulations, I used a C4-7 motor with the rocket launched straight up. The disturbing force is a constant-velocity 20mph wind.

Chart 1 shows us the difference between the Corrective Moment Coefficients of the two designs.

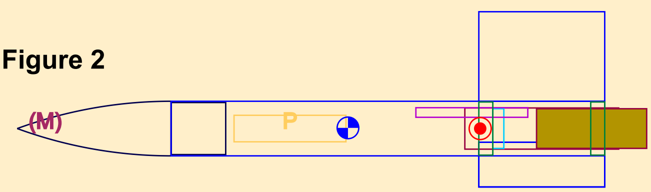


On the left side of the chart, we see the velocity of the two rockets with the blue lines. For the most part, the velocity is very similar except after about 5 seconds into the flight. This makes sense because both rockets use the same motor, have the same mass and drag coefficient.

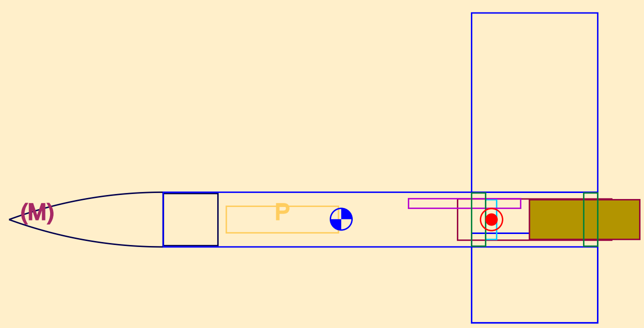
On the right side of the graph, we see the corrective moment coefficient values. While the actual values don't mean much, we can make some observations by comparing the rocket with the large fins versus the small fins. First note that the rocket with the large fins does generate bigger values for the corrective moment coefficient. We would expect this because fin size is one of the factors used to calculate the Normal Coefficient of the Rocket.

Additionally, a bigger normal coefficient for the fins means that it will shift the CP of the rocket rearward. If you look at the 2D drawing of the two rockets, you'll notice that the CP of the rocket with the bigger fins is indeed further aft (See Figure 2). Also take note that the CG is identical in both rockets, thanks to the use of the mass override for the entire rocket.

Figure 2



Length: 10.7500 In. , Diameter: 0.9760 In. , Span diameter: 4.1760 In.
Mass 55.227 g , Selected stage mass 55.227 g (User specified)
CG: 5.9217 In., **CP: 8.2744 In.,** Margin: 2.41
Engines: [C4-7,]



Length: 10.7500 In. , Diameter: 0.9760 In. , Span diameter: 7.3760 In.
Mass 55.227 g , Selected stage mass 55.227 g (User specified)
CG: 5.9217 In., **CP: 8.6058 In.,** Margin: 2.75 Overstable
Engines: [C4-7,]

Continued on page 5

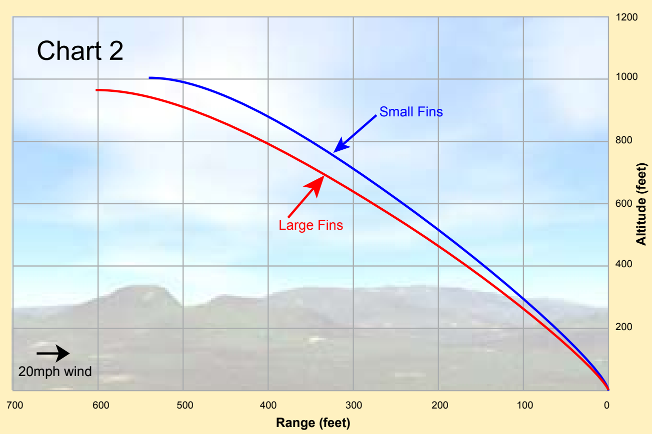
Continued from page 4

Reviewing our formula for the Corrective Moment Coefficient, you'll recognize that the greater the distance between the CG and CP, the higher the number will be. And this is one of the reasons why the larger fins contribute to a bigger value for the Corrective Moment Coefficient.

Another thing that Chart 1 shows is that as the velocity increases, the Corrective Moment Coefficient will also increase. Since the velocity term is squared in our formula, you'll notice that the curves for both rockets increase dramatically as the rocket goes faster.

At this point, we have verified that what RockSim is computing is reasonable. Everything we expect to see happening in the formula is indeed being displayed in this first graph.

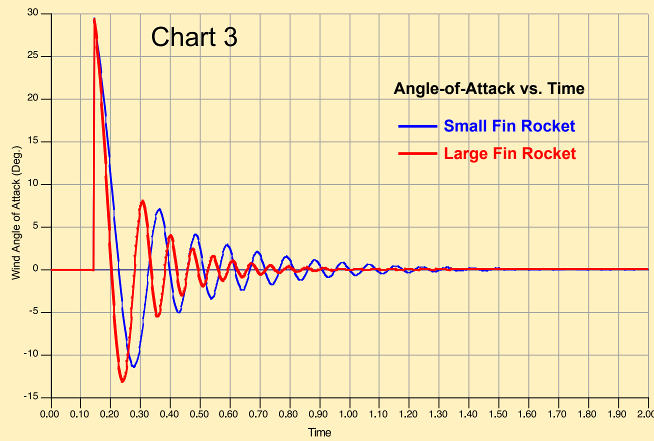
But we still haven't seen what effect the different Corrective Moment Coefficient has on the flight. For that, let's look at the trajectories of the flight. This is shown in Chart 2, which is a comparison of Altitude versus Range.



As the graph shows, the rocket with the large fins weathercocks more into the wind. That means it travels further horizontally and doesn't fly as high as the rocket with the smaller fins.

Does this make sense based on personal experiences with actual models? Yes. We know that rockets with bigger fins are going to weathercock more. So what Chart 2 shows should be logical to all modelers.

How do the rockets compare right at the instant when they are hit with a gust of wind? For that we will look at the Angle-of-Attack of the two rockets. This is shown in Chart 3. As you study this chart, remember we're looking at the instant the rocket leaves the launch rod and is hit by the 20 mph wind.



What you should notice in Chart 3 is that both rockets hit the same AOA as the rocket leaves the launch rod. The rocket with the large fins responds quicker to the sudden change in AOA, and zeros out its angle-of-attack quicker. At about 1.0 seconds, its AOA has flat-lined. For the rocket with the smaller fins, it doesn't zero out until about 1.5 seconds into its flight.

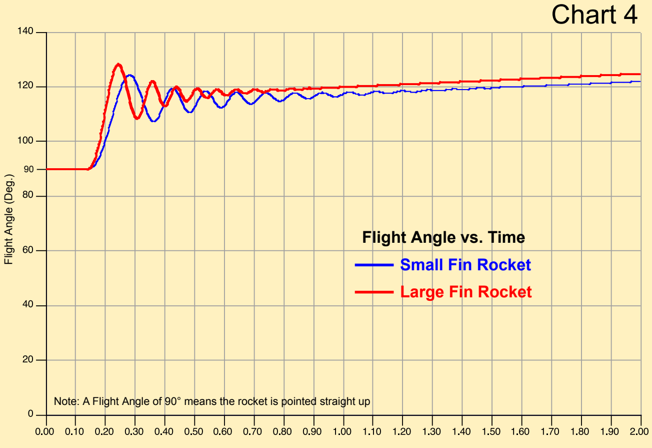
You may think that the half-second difference doesn't seem like a lot, but what happed in that short time changed the trajectory of the rocket just enough that the rocket weathercocked more into the wind that you saw in Chart 2.

Let's look at the flight angle to expand on this idea. This is seen in Chart 4. (page 6)

Continued on page 6

Continued from page 5

Chart 4



In Chart 4, you'll see that for the large-finned rocket, at 1.0 seconds it was at a flight angle of 120°. If a flight angle of 90° means the rocket is pointed straight up, the 120° flight angle tells us that rocket has pointed itself to 30° from vertical (120° - 90° = 30°). Compare this for the small finned rocket. It doesn't get to that 120° flight angle until approximately 1.50 seconds into the flight.

All Chart 4 does is to confirm that the rocket with the bigger fins is starts to arc into the wind quicker.

Conclusion

What we learned from this exercise is that the Corrective Moment Coefficient controls how fast the rocket will respond to a disturbance in flight. The larger the Corrective Moment Coefficient, the quicker the rocket responds.

Furthermore, as rocket designers, we can control how big the Corrective Moment Coefficient is going to be by adjusting the following parameters:

1. The speed at which the rocket flies is the biggest factor, because in the formula, the velocity term is squared. We control speed by the thrust level the rocket motor produces.
2. Fin size and shape controls the Normal Coefficient of the rocket.
3. How far the CP is away from the Center-of-Gravity, the position of the fins on the rocket controls the location of the CP. The Center-of-Gravity is controlled by the placement of parts in the design. i.e., by the length of the rocket and how much extra nose weight has been added. The greater the distance between the CG and CP (called the static stability margin), the larger the Corrective Moment Coefficient.

From #3 in the list, it should be mentioned that if the CP is in front of the CG, the Corrective Moment Coefficient will become a negative value. If this happens, we'll end up with an *Anti-Corrective Moment Coefficient*. That sounds bad, doesn't it? And it is very very bad. It means the rocket will not correct at all; leading to a rocket that cartwheels dangerously across the sky. Don't ever let the CP get ahead of the CG.

The next point I want to make is that because the Corrective Moment Coefficient value is constantly shifting, we are again left at the conclusion that there isn't an optimum value that we should shoot for when we are designing a rocket.

And the final conclusion is that from what we've seen from the trajectory plots, a rocket with a high Corrective Moment Coefficient going to weathercock excessively if the flight speed is low.*

*Footnote: Even though high flight speeds increase the Corrective Moment Coefficient, high speeds always reduces weathercocking because the angle-of-attack is reduced when the rocket is hit by a gust of wind.

It is a delicate balancing act when designing a rocket. Too small of a Corrective Moment Coefficient and the rocket will not zero out disturbances quickly enough (you can play with this as an exercise in RockSim); too large of a coefficient and weathercocking could become severe. In that case, your rocket won't go as high.

Continued on page 7

Continued from page 6

But is there a case when a high Corrective Moment Coefficient is desirable? Yes, when you want a rocket that doesn't oscillate around wildly in flight. An example might be a rocket carrying a video camera. To get nice pictures, you want it to zero out any oscillations quickly. I was looking at the Estes Astrovision rocket and noticing how huge the fins are (http://www.ApogeeRockets.com/Estes_Astrovision_Video_Rocket.asp). But this is actually good because the rocket isn't going to be jittery in flight, which increases the chances of getting good video back.

There's a bit more to Corrective Moment Coefficient, but we need to come back to that later, after looking at some of the other parameters that control the dynamic stability aspects of the rocket. Until then, keep digging into your RockSim simulations and you'll learn all kinds of things about your rocket.

About The Author:

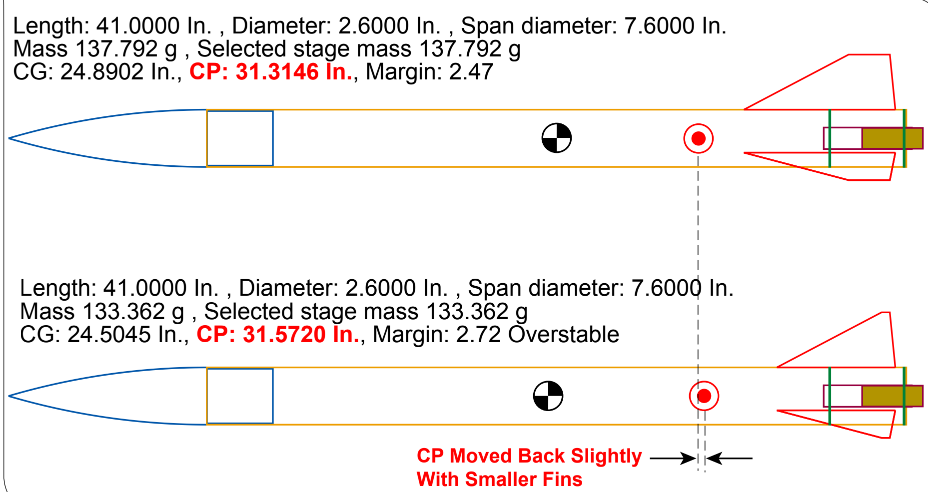
Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. Before he started writing articles and books about rocketry, he worked on the Delta II rocket that launched satellites into orbit. He has a B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical 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.

The carts and graphs used in this article were created using flight simulation data generated by the RockSim software. The only thing I did was to merge the pictures of the graphs in Adobe Illustrator software so the data between the two rockets was overlayed. This makes it easier to make a direct comparison between the two designs.

Question & Answer

This question comes from a fellow RockSim user:

I have made two near-identical RockSim designs, and the stability calculation results are very surprising. According to RockSim the short fins produce a better (more rearward) CP than the rocket with longer fins. The only difference between the designs should be the fin root and tip cord lengths.



What you are seeing is real. The CP does move back when you shorten the fins the way you are doing.

Why?

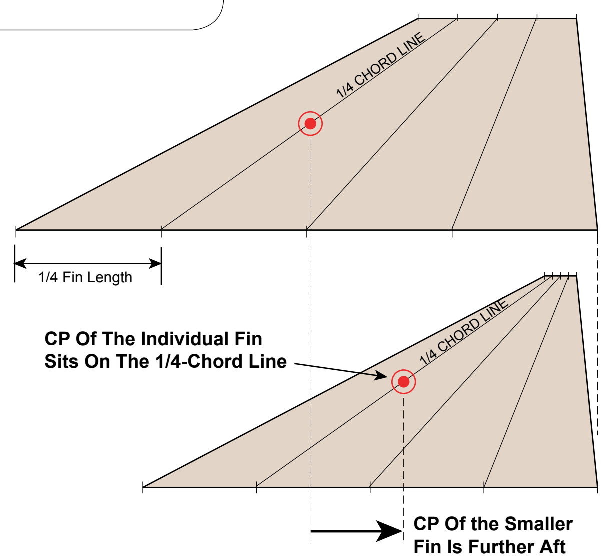
By definition, the CP position for an individual fin is located on the 1/4-chord line of the fin. What is a 1/4-chord line you ask? Take the length of root edge of the fin and divide it into four equal lengths. Then take the tip of the fin and also divided it into four equal lengths. Draw a line from the first tick-mark on the root edge to the first one on the tip edge. This line is called the 1/4-Chord line as shown in Figure 2. The CP of the fin sits near the middle of this line.

If you move the location of the 1/4-chord line, you move the CP location of the individual fins too.

In these two designs, the fins are referenced from the base of the tube. When you shorten the fins, you're actually shifting the whole fin rearward on the tube to keep the back edge in the same place. Hence the position of the 1/4-Chord line of the fin moves aft. That moves the overall CP position backwards because the fins provide a large stabilizing force for the rocket. This does make the rocket more "statically" stable.

HOWEVER...

Since you're decreasing the area, the amount of force the fins produce is smaller too. This is reflected in a smaller value for the Normal Force Coefficient. You can see the value for the Normal Force Coefficient in the simulation graphs or in the "details" of the 2D Flight Profile. For the design



Continued on page 9

Continued from page 8

shown in Figure 1, here is a table showing the smaller Normal Force Coefficient for the smaller fins.

Rocket	CP Location	CNa
Big Fins	31.3146 inch	12.4468
Small Fins	31.5720 inch	11.3039

When the rocket gets disrupted in flight, the fins will produce lift, but at a smaller amount than if they were bigger. Typically this means that it will take longer to dampen out any oscillations that are produced by the disruption (See the article on Corrective Moment Coefficient in this issue).

In this particular case, the smaller value for the Normal Force Coefficient will be compensated to some degree by the fact that the CP is further away from the CG, so the moment arm that the force acts on is greater.

Is this better or worse? That is a good question. You can find out by looking at the 2D Flight Profile in RockSim to see what the trajectory is going to look like. From that, you can make a determination if the flight is going to be safe.

This is really a great question, because it illustrates why *dynamic stability* is just as important as *static stability*. And it proves that using RockSim is critical to the success of a rocket's flight. Without RockSim, you'd have no clue if your rocket will fly straight or not. ALWAYS LOOK AT THE 2D FLIGHT PROFILE! It will tell you a lot of information about the flight that you can't get by looking at the summary screen.

If you don't have RockSim, you're making guesses about the stability of your rocket designs. That's dangerous and borderline irresponsible. Only RockSim gives you this information. Get it today!

Web Site Worth Visiting

http://www.rocketshoppe.com/

I think every modeler in the hobby for more than 10 years has a bit of nostalgia in them. Why? There is something about reliving the days of early youth when the future seemed to hold so much promise. Building rockets from those times brings back those optimistic feelings.

With that in mind, the web site you might want to check out is http://www.rocketshoppe.com/. It will certainly bring you back to those old days of rocketry when Estes and Centuri where building rocket kits that used fewer pre-molded plastic components. Many of the models could be assembled with common materials like balsa wood and paper. For someone trying to relive the old days of rocketry, this simplicity will really help you out. Hint: When you need tubes and rings to build all these old designs, remember to visit the Apogee web store. I'd sure appreciate the business.

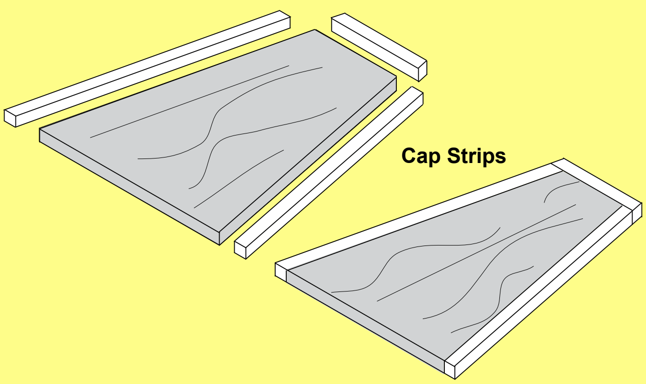
But the web site holds more than just old rocket designs. It also serves as a host for many new designs created by your fellow rocketeers. Just click on the BARCLONE link to get to them. Most of the designs were created using our RockSim software, so if you want to build them, you'll want to download the free trial version of RockSim from the Apogee web site at: http://www.ApogeeRockets.com/rocksim_demo.asp

You're going to find a lot of really neat things on this web site. I like the portable rocket display rack, and the Teflon® wadding pom-pom balls.

If you need a diversion from your other rocketry stuff, then give this website a try. I found it worth visiting and placing in my bookmarks.

DEFINING MOMENTS

Cap Strips



Cap Strips - The use of cap strips is a way to reinforce balsa wood fins by attaching hard sticks of wood around the perimeter of soft balsa wood. Once the strips are attached, they make the balsa fins stiffer (so they can't split), and more resilient to being dinged when the fin lands on a hard object like a rock.

An example of a kit that uses cap strips is the Mad Cow Rocketry MIM-23B Hawk. This can be found at: http://www.apogeerockets.com/MIM-23B_Hawk.asp

For more information on reinforcing fins, see the book *Model Rocket Design and Construction* at: http://www.apogeerockets.com/design_book.asp