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NEWSLETTER

Feature Article:

Where Are The Fins?

Why Doesn't the Ares 1-X Have Fins?

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3355 Fillmore Ridge Heights
Colorado Springs, Colorado 80907-9024 USA
www.ApogeeRockets.com e-mail: orders@apogeerockets.com

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Where Are the Fins?

Why Doesn't the Ares 1-X Rocket Have Fins

Written By Tim Van Milligan

A common question that younger modelers have is why big rockets, like the new Ares 1-X, or the Atlas and Delta rockets, don't have fins to guide them during the flight. That is a great question. I want to answer it here because there seems to be a common misunderstanding about how model rockets are designed to fly straight.

Here is the situation… If you only saw the Ares 1-X rocket, you might conclude that since big rockets don't have fins, then small model rockets don't need them either. Unfortunately, that is going to lead to very dangerous model rocket flights that may seriously injure someone.

The answer to the question of why the Ares 1-X doesn't have fins is simple. The big rockets have a very sophisticated guidance system that steers the rocket and keeps it going straight. The model rockets that we fly, on the other hand, do not have any active guidance on the rocket itself. Once we push the launch button, a rocket without fins is on its own and could go in any direction.

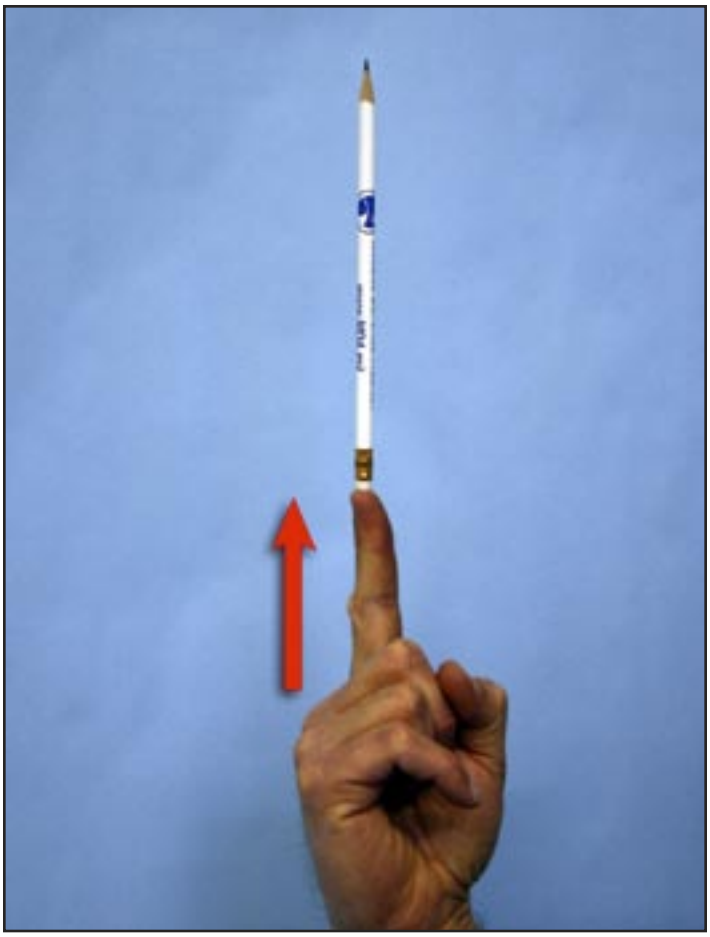

Figure 1: Pushing a pencil in the air is a great demonstration of the complexity of "active guidance."

If you're a teacher, here is a good demonstration you can do.

A rocket without fins is like a pencil that you might balance on the tip of your index finger, with the point of the pencil pointing straight up (Figure 1). Give that a try right now while you're reading this. Now, go walk up a flight of stairs and try to keep that pencil balanced there.

It is pretty hard to do, isn't it? In fact, I bet that it fell off your finger, didn't it? Even keeping it balanced on your finger for a full second is extremely difficult.

As you're trying to walk up the stairs, your finger is pushing the pencil up, just like the thrust of a rocket engine is trying to push a rocket into the air. See the similarity?

In order for your finger to push it straight into the air, you probably had to shift your finger to the left, right, forward and backward to just to keep it pointing skyward. In effect, you were steering the pencil, and your brain is the control system. Since your pencil fell off your finger, what can you conclude? Don't feel too bad. My brain and finger aren't fast enough to keep the pencil balanced and pointed upward either...

This easy demonstration allows you to see how complex it is to keep a rocket without fins going in the right direction.

So how does the Ares 1-X do it, and seemingly so effortlessly?

First of all, the rocket is different from our rockets in one key way. The nozzle on the back end can swivel around. This is called a gimbaled nozzle.

A gimbal system like this isn't so hard to visualize. Just imagine a small fishing boat with an outboard motor on the back end, like shown in Figure 2. The spinning propeller

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Newsletter Staff

Writer: Tim Van Milligan
Layout / Cover Artist: Tim Van Milligan
Proofreader: Michelle Mason

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Figure 2: An outboard motor on a boat uses gimbal system control to steer the boat.

creates a thrust force that pushes the boat forward in the water. The motor can be turned side-to-side to direct the thrust force. Once it is turned, the boat turns too.

Where the boat moves through water, the rocket moves through air. But the principle of how it is steered is exactly the same. Orient (or turn) the nozzle to the right, and the rocket will also turn to the right. Turn it to the left, and the rocket goes to the left.

The one big difference is that the boat can only swivel left or right. This is the "yaw axis" of the boat. A rocket nozzle can also pivot up/down (along the pitch axis). Basically, it can point the rocket in any direction you might want it to go in space.

The thrust will control the "up" movement of the rocket, but it is the swiveling of the nozzle that controls the rocket's movement to the upwind/downwind, cross-wind, and the orientation of the rocket with respect to the pitch and yaw axis. That is five out of the six degrees of freedom of the rocket as shown in Figure 4 (see Newsletter 186 at www.ApogeeRockets.com/Education/Downloads/Newsletter186.pdf for more information about what 6 Degrees-of-Freedom means).

Figure 3: The Ares 1-X rocket's nozzle can point in any direction to control the rocket's trajectory

The movable nozzle of the Ares 1 is officially called the *Thrust Vector Control system*, or TVC system for short. It shares the same two hydraulic actuators as used on the Space Shuttle. These hydraulic rams literally push on the nozzle to move it side-to-side. Since it is the same hardware as the Space Shuttle, I anticipate that the deflection of the nozzle on the Ares is similar. The NASA web site does not state the gimbal angle, so I had to dig this information out from other sources.

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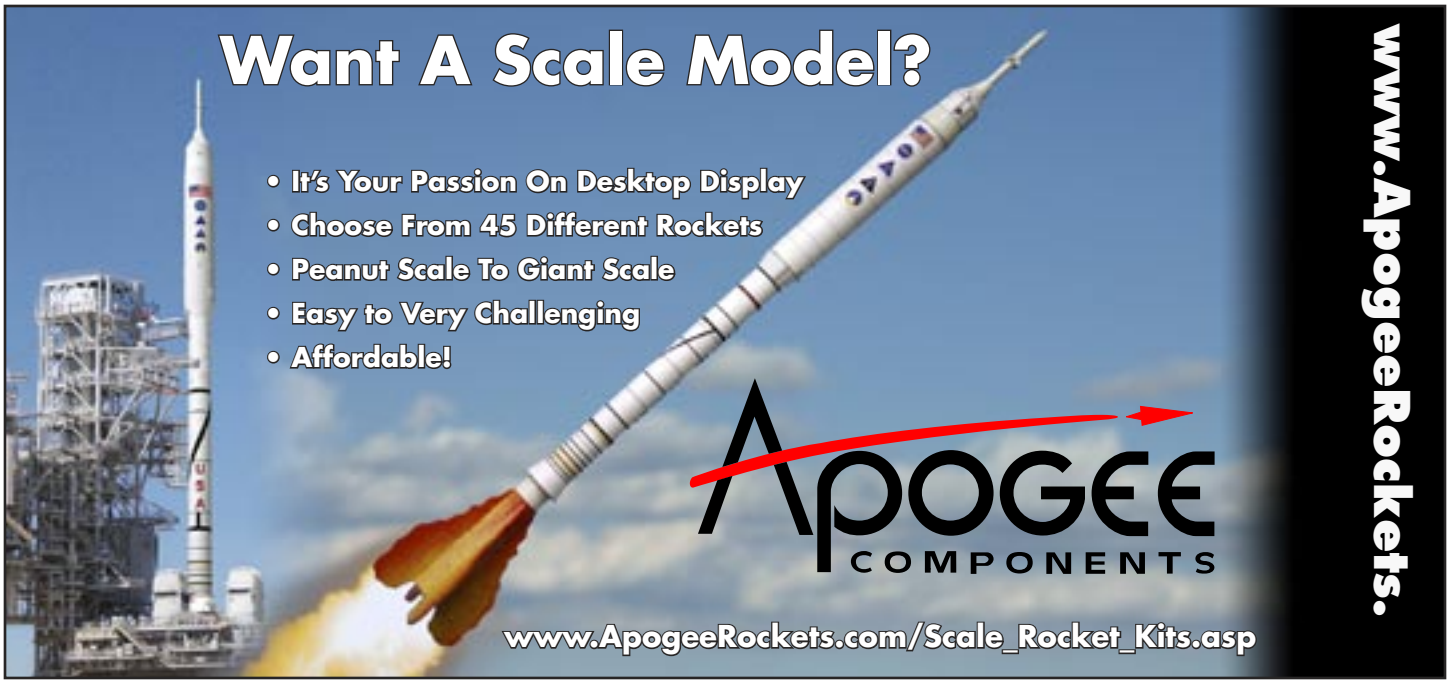

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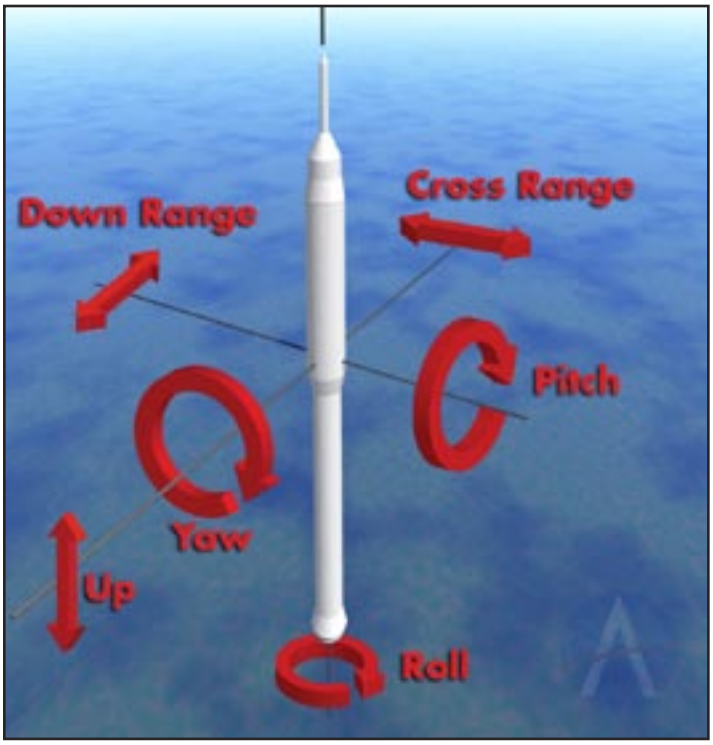

Figure 4: The thrust force controls the up/down motion, and the direction the nozzle points controls the motion either up/down range, cross range, pitch and yaw.

Model rocketeer Matt Steele, who worked on the Space Shuttle, helped me to find this information. The criteria for the Space Shuttle's TVC system is this:

> *"The SRB TVC subsystem shall have a gimbal angle capability of 5° in both the actuator extend and retract directions. The Flight Control System software shall limit the gimbal angle to 2° or less in both directions for all times less than SRB ignition command plus 2.5 seconds. For all times greater than SRB ignition command plus 2.5 seconds, the FCS shall limit the gimbal angle to 4.5° in both directions."*

What this means is that for the first 2.5 seconds of flight, they don't want the nozzle to move very much (less than 2°). Why not? Because you don't want the rocket steering itself into the gantry. Makes sense, doesn't it?

Once the rocket clears the tower, then the nozzle can tilt all the way to 4.5° if it needs to.

But why not go all the way to 5°?

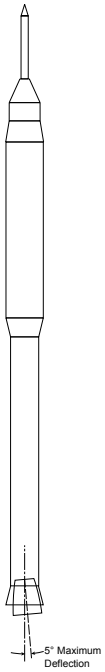

Figure 5: The nozzle can rotate up to 5° to steer the rocket.

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Why Doesn't The Ares 1-X Have Fins?

Matt says that you have to leave some room for error in the system, in case the actuators push a little too fast and accidentally overshoot. I would be willing to bet that there is some sort of hard-stop, or a block of steel that prevents it from ever going past 5°. If the nozzle ever had to go that far, there is something seriously wrong in the trajectory, and the rotation of the rocket in an attempt to correct it would be so fast that it could probably knock the astronauts unconscious.

With the first launch of the Ares now behind us, how did the Thrust Vector Control system do on the flight?

I asked a friend at NASA, and he shared some of the actual flight data for the rocket. Figure 6 is a chart that shows how far the nozzle was rotated at any point during the entire flight. The top chart shows the chamber pressure inside the solid rocket motor. This gives you some indication of where lift-off was, and when burn-out occurred.

You can see from the bottom two charts that about 30 seconds prior to lift-off, the hydraulic pump is turned on, and then the two actuators that controlled the tilt-angle of

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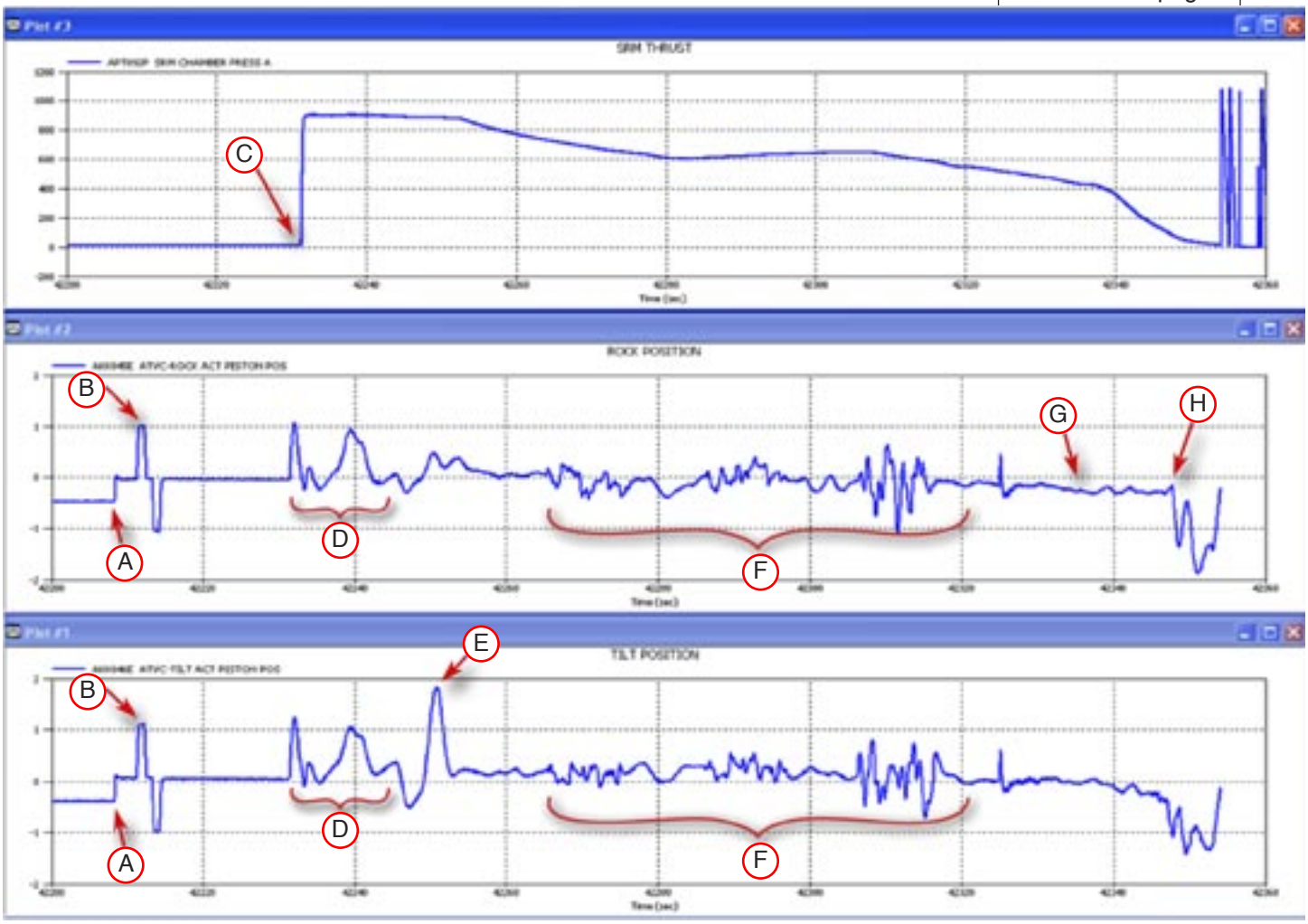

Figure 6: Actual flight data from the Ares 1-X launch. Top: Chamber pressure inside the solid motor. Middle and bottom: The nozzle deflection in degrees on the "rock" and "tilt" actuators. They are called "rock" and "tilt" instead of "pitch" and "yaw" because they are from shuttle and are oriented 45° from the actual pitch and yaw axes. Callouts: A) Hydraulic actuators turned on. B) Actuators slewed to test the control system. C) Ignition of the motor. D) The motions during the first 10 seconds are a tower clear manuever, followed by a pitch&roll to align the vehicle onto the planned trajectory. E) Peak deflection of the actuator. F) While it is hard to see, during this portion, there are the 3 programmed test input manuevers lasting 10 seconds each, followed by a step function (just before it smooths out) for data gathering purposes. G) Calmest portion of the flight. H) Actuators deflect more because thrust level is dropping off at the end of the burn.

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Why Doesn't The Ares 1-X Have Fins?

the nozzle are intentionally tested by slewing the nozzle in both directions by exactly 1 degree. This is actually a very critical test. If the nozzle does not respond correctly, the computer onboard the rocket will sense the failure, and the countdown will be aborted before the motor is ignited. Why? Because once the solid motor starts firing, there is no way to stop it until it burns out of all its propellant. So it is mission critical that the steering system be glitch-free and fully operational before the thrust from the motor kicks in.

As the motor was ignited, there appears to be a spike in the position of the nozzle in both the pitch and the yaw direction. This is probably because the entire rocket is shaking a little bit because it was jarred by the spike in pressure inside the motor. The nozzles reacted instantly to this.

The farthest deflection of the nozzle during the flight was nearly 2°, and occurred about 20 seconds after ignition. My own personal guess was that might be the added stress on the rocket when it was going through Max Q. "Max Q" stands for maximum dynamic pressure. This is the point in the flight when the aerodynamic forces acting on the rocket are at their peak. It is the most stressful part of the entire flight, except for maybe the moment of ignition.

I asked Marc Lavigne what happened at this time during the flight. He said it was probably the rocket reacting to a wind shear. He mentioned that the rocket went supersonic at T+39, and Max Q was T+55.

You might be asking who is Marc Lavigne. You'll be proud to know that he's another rocket modeler, who happens to be the guy you heard in the background giving the official description of the launch on NASA TV. Marc, "aka: Moose", is a dear friend, and if you were at the NARAM-50 reunion in 2008, you probably met him there. He is pictured in Newsletter 238 (www.ApogeeRockets.com/education/downloads/Newsletter238.pdf). It is so cool that the guys in control in the real space program are also model rocketeers and are just like you and I. If you're a parent or a teacher, you'll be happy to know that the *model rocketry* that your students are doing today is a great stepping stone to help them get a good job in the future. That's why you're glad you came to Apogee Components for your rocketry knowledge and supplies, isn't it?

There are a couple of other things that you can pick up from the flight data charts that are of interest. Toward the end of the flight (about 30 seconds prior to engine burnout), is the quietest portion of the flight, where the nozzle movement is the smallest. That makes sense, doesn't it? At that point in the flight, the rocket is so high that it is above most of the atmosphere. There arent hardly any aerodynamic forces on the rocket trying to push it off its intended path.

During thrust *tail-off*, which begins about 10 seconds before burnout (the point where the chamber pressure

Figure 7: The Ares 1-X immediately performed a pitch manuever on lift-off in order to avoid strking the shuttle gantry. The heat from the exhaust toasted the tower so intensely, that the elevators were rendered inoperable.

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inside the motor drops to zero), the nozzle activity picks up again very strongly. This happens because the thrust has dropped to a very low level, so the steering has to be stronger. Think of it this way… When you are driving your car at high speeds, you don't need to turn the steering wheel very far to move over in the lane on the road. But if you are going slow, you have to turn the wheel much further to make a correction.

Even if the charts don't seem to make sense to you at this point, what I really want you to notice is that throughout the entire flight, the nozzle is constantly moving. This isn't random noise in the charts. Everything you see is intentional by the two actuators that tilt the nozzle. It is a constant adjustment of the nozzle to keep the rocket going in the intended direction. It is exactly like the movements you had to make with your hand when you tried to balance the pencil on the tip of your finger.

The Rocket is Highly Unstable!

Did you watch the actual launch or the video yourself? Did you see that as soon as the rocket separated the top section went unstable? Wasn't that cool?

But it shouldn't have come to a big surprise to us modelers. We know that a rocket traveling in the air without fins or a gimbaled nozzle is going to go unstable, and that is exactly what happened.

Gravity Stabilized Rockets?

Figure 8: The upper part of the Ares 1-X immediately went unstable as it separated from the booster motor.

A long time ago, when I worked on the Delta II rocket, a friend of mine wanted to build a scale model of that rocket. He thought that since it was so tail heavy that the rocket would be gravity stabilized. Sort of like a pendulum that always seeks to swing its weight down to the bottom.

Was he right?

Of course not. That is a disaster waiting to happen. It is still just like balancing a pencil on your finger. The weight near the bottom isn't going to help. In fact, it makes the problem worse!

If you want to do a simple experiment, use a longer

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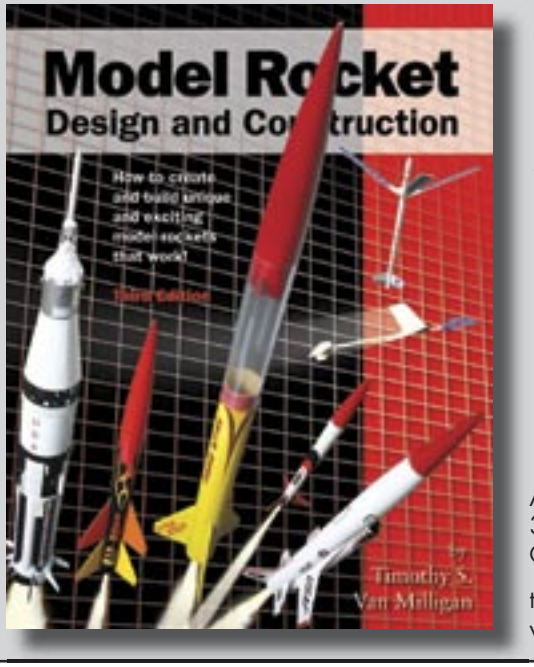

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By Timothy S. Van Milligan

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wooden dowel and try to balance that on your finger. Tape some weight near the bottom. Now flip the dowel over so the weight is near the top. You'll find that it is actually easier to balance the dowel on your finger if the weight is near the top end.

This should be no surprise to you as a rocketeer. You know that the further forward the CG is, the more stable the rocket is going to be.

Gravity stabilization, as my friend thought, does not exist. Now you know how to refute this concept if someone proposes that type of rocket to you.

Can We Make Our Own Gimbaled Engines?

This is a really cool concept. And with modern servos and electric gyroscopes, it is totally possible!

In fact, I saw one such model rocket fly at LDRS in 2008. I can't remember the name of the person that built it, but afterward he showed me the system (Figure 9). The rocket didn't look anything like what you'd expect. It more resembled a flying stool. But it did work!

Figure 9: An example of what a gimballed model rocket looks like.

While it is technically feasible, there is one huge problem to using a gimbaled motor in a model rocket. The duration of the thrust from our rocket motors is too short. A typical model rocket motor burns out in less than two seconds, while the ascent trajectory could be 30 or 40 seconds. After the motor burns out, there is no way to control the path of the rocket. It will always go unstable as soon as the motor burns out.

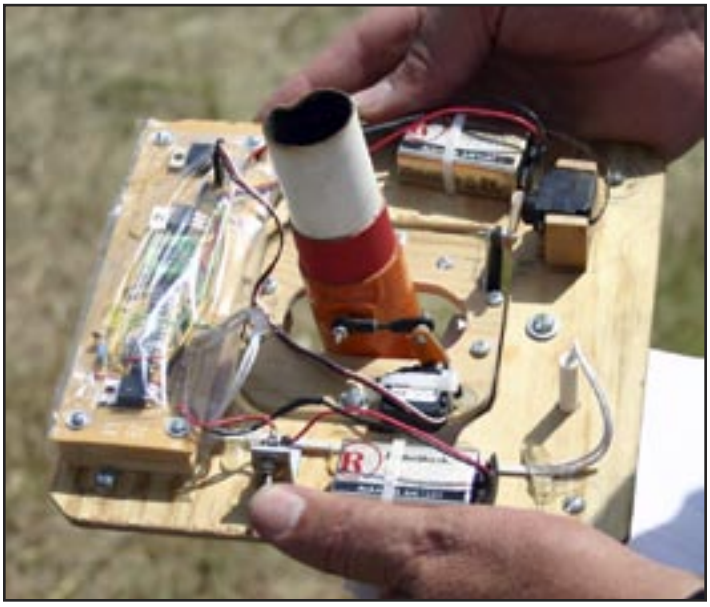

Figure 10: Close-up of the gimballed model rocket (without the landing legs attached).

If you want active guidance and control on a model rocket, the more logical choice is to use movable fins instead of a gimbaled motor. That way, as long as the rocket is moving through the air, you'll have forces acting on the fins that can be used to control where it goes and how it is oriented. Incidentally, this was first accomplished on a model rocket more than 20 years ago in 1988 by George Gassaway (http://homepage.mac.com/georgegassaway/GRP/AOL/GCGassaway/Sunguidance.htm).

Why We Need Fins On Our Rockets?

Without some means of providing the restoring forces on our model rockets, they will go unstable. The only fea-

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Why Doesn't The Ares 1-X Have Fins?

sible means of gaining control on our rockets is through the use of fins. It is the air flowing over the fins that creates the forces necessary to stabilize the rocket.

It should be noted that some of the early NASA and Air Force rockets had fins on them too. Why was that?

The reason is that back in the early days of rocketry, the guidance systems weren't as precise as they are today. In other words, they were much more crude in that they reacted slower, and controlling the exact angle of the thrust was not as accurate. Additionally, the instruments that sensed the orientation and position of the rocket were less accurate too. In that case, using some fins to dampen out the oscillations of the rocket would be a good thing. And that is why they had them. If the Mercury Redstone had as good control system as the Ares 1-X rocket, it wouldn't have needed fins either.

What about roll control on the Ares?

In this article, it was mentioned that the main nozzle and the thrust coming out of it account for five of the six possible directions of motion. The one that it can't control is the spinning of the rocket around the long axis (called roll).

If the Ares 1-X rocket had two nozzles on the bottom, like the Titan rocket, they could be used for roll control. In

Figure 11: Note the size of Ares' roll thruster motors.

that case, all you would do is cant the two nozzles in opposite directions, which would induce a roll in the rocket.

But there is only one nozzle on the Ares 1-X. So to control roll, the engineers had to install four smaller motors on the side of the vehicle.

The Roll Control System (RCS) is located in the lowest segment, upper section of the rocket. It consists of two modules, each containing two thrusters capable of generating up to 2,250 pounds of force. The Roll Control System modules are positioned on opposite sides of the outer skin

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of the rocket, and fire tangential to the skin and at right angles to the roll axis to provide a controlling roll torque.

They aren't exactly small, as the photo in Figure 11 shows. And they are powerful. Just look at how thick the metal stiffeners are on the place where the rocket motors are attached. If the metal was thin, they would rip the rocket in half, like you could to an old aluminum pop-can.

By positioning them on the fattest part of the rocket, they are much more effective in creating the torque necessary to roll the rocket. They are called thrusters, which seems to indicate that they operate for just brief periods of time. And that is exactly right. They pulse on and off only when necessary.

It is interesting to note that the thrusters came from decommissioned Peacekeeper missiles and didn't cost NASA anything. The Air Force agreed to transfer the engines as well as the propellant and pressurization tanks, "for just the cost of shipping."

You might be thinking, since the rocket doesn't have any fins, and seems to be very uniform in shape, why would it need to have roll control. That is a good observation on your part. As uniform as the rocket is, it isn't perfect. There are enough things jutting out into the airflow that a little bit of induced roll might just happen. NASA anticipated that the roll control might have to start and stop up to twenty times during the Ares 1-X launch. In actuality, it only came on three times. If you watch the launch video where the camera is looking down toward the back end of the rocket, you an see a couple of brief times where this yellowish-grey smoke is seen in the bottom left-hand corner

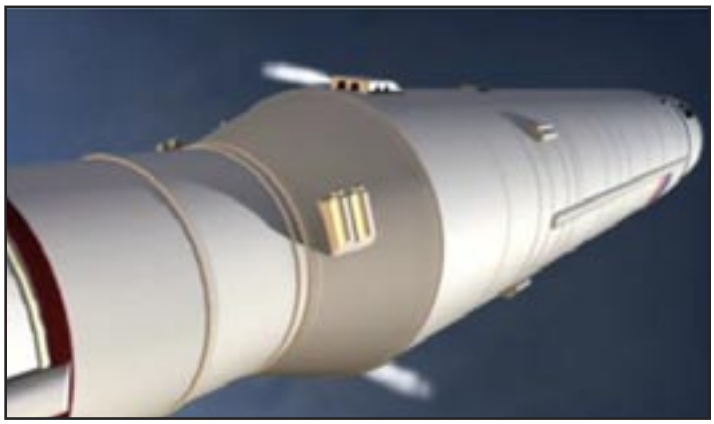

Figure 12: In this artist rendering from NASA, the roll motors on the side of the Ares 1-X are shown firing. The motors on the transition (called* Frustrum*) are use to cause the booster motor to tumble after it has burned out. On this first flight, these forward tumble motors were dummies, only present to simulate the aerodynamic forces on the vehicle.

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of the video frame. This is the roll control motor pulsing on. It only lasts about a frame or two, so don't blink, or you'll miss it.

Other Rocket Motors On the Ares 1-X

When I first saw a picture of the Ares 1-X rocket, I saw some rocket motors on the frustrum cone that transitions the fat part of the rocket to the smaller diameter of the solid rocket motor (see Figure 12). I originally thought that these were the roll control motors. I was wrong. They're not.

The motors on the side of frustrum are actually the "Booster Tumble Motors" (BTM). There are four of them, and they all point the same direction. They ignite after the upper section separates from the solid rocket motor. The separation plane is just above the frustrum cone, so the BTM are actually attached to the solid rocket motor. For this first flight, these were actually inert dummy motors. They didn't actually operate, and were only present to make sure that the aerodynami loads were accurate.

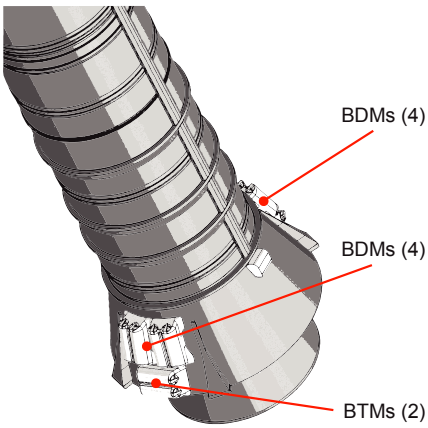

Figure 13. The motors on the base of the solid rocket motor are to decelerate and cause the stage to tumble.

But as the name describes, they are there to create a sideways push on the front part of the solid rocket motor, and cause it to start tumbling. This then exposes the side of the solid motor to the airstream, increasing the drag and slowing it down.

There are also eight rocket motors on the bottom skirt of the solid rocket motor as shown in Figure 13. These are called *Booster Deceleration Motors* (BDM).

The Booster Deceleration Motors actually fire forward, opposite to the direction of travel. They are designed to slow the speed of the solid rocket booster so it doesn't ram into the upper stage after separation. It is kinda cool that someone had to sit down and think of all the things that could go wrong in the flight, and come up with a way to prevent them from happening.

And finally, there are also two additional Booster Tumble Motors on the bottom too. Like the ones on the frustrum cone, they are there to ensure that the booster tumbles as it falls back to earth.These motors were actual live motors and did fire on this flight to get the whole rocket for tumbling.

Other Ares Rocket Motor Trivia

Did you know how slow the Ares 1 takes off? The acceleration of the rocket is only 2.48 gees. That is slower than the Space Shuttle's 3g lift-off acceleration and the 4 gees that the Saturn V had.

I hesitate to mention that piece of information, because I know what people are going to ask me next... "how can I get that slow realistic lift-off on my models?"

The answer is that you need a minimum lift-off speed of 30 miles per hour (based on historical data of safe launches). The best way to get slower speeds and having it fly straight is to use a longer launcher (either a longer rod or a rail launch pad). I know that is not what you wanted to hear, but you have to be safe, right?

Model Rocket Stability Reference Information

Fins are a good thing. If you would like to know more about stability, see the book *Model Rocket Design and Construction* (www.apogeerockets.com/design_book.asp)

There are also many articles about rocket stability on the Apogee Components web site at: www.apogeerockets.com/Peak-of-Flight_index.asp#stability. Pay particular attention to the articles on dynamic stability, beginning in Newsletter 196.

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.

New Book Available: *"Rocket Science"*

By Dave Ketchledge

After writing *The Next Shuttle,* it was my intention to do another follow on book called *"Rocket Science"* if there was even a moderate success with the first book.

Rocket Science, in 910, pages spans the areas of hobby rocketry and professional aerospace engineering for key reasons.

First it is essential to give young men and women who are just starting in rocketry a technical resource that represents some 50 years of experience.

For those in aerospace engineering, *Rocket Science* is a detailed reference that demonstrates how low cost vehicle test methods through radio control and high power rocketry have yielded positive results. Leading senior members of NAR and TRA have flow RC boost gliders of the Bell X-1, North American X-15 and Space Shuttle, along with several lifting bodies like the NASA HL-10 and X-38.

During the 1960's, Dale Reed at Edwards AFB flew experimental vehicles including the M2F1, X-33 and Space Wedge. All were accomplished at a fraction of the cost of full size prototypes and yielded significant design issues in each craft. The M2F1 showed that at certain roll and pitch angles the vehicle would shed the leading edge lift vortex, a trait that repeated itself years later in manned vehicles.

Thus it's a proven fact that R/C and high power rocketry have made a positive impact in aerospace development.

Rocket Science as a book also reflects the work at SpaceX, XCOR Aerospace and Scaled Composites, with a specific chapter on the ongoing efforts and future potential of each design.

The world of 2009 is a flux of change both in government and commercial spaceflight. One expects the Orion will fly in 2015, that we can reach the Moon again by 2020 and potentially Mars a decade later. We also include a copy of the Augustine Report on NASA's return to the Moon..

To accomplish this, a new generation of space capable students and professionals is needed in technology and engineering. *Rocket Science* lays out a foundation for the reader, and is a reference. Like my first book, key NASA reports are included in Propulsion, Aerodynamics and vehicle development.

Rocket Science gives you the technical tools, resources and engineering insight that has been developed over decades. Besides the book itself, the NASA documentation and software make *Rocket Science* one of the best resources in rocketry. Visit http://www.rocketengineer.bravehost.com to purchase the book. As always our pricing is very low at only $ 35. *Rocket Science* has appeared on "The Space Show" and at NARAM - 51. Those individuals who have viewed the book come away impressed by the depth and detail. *Rocket Science* will be one of your best assets in rocketry today and into the future.

I fondly remember a poster from Apogee Components, which is operated by Tim Van Milligan. The poster shows a Space Shuttle lifting off and a boy holding a model rocket (get your own at: www.ApogeeRockets.com/education/downloads/Newsletter77.pdf). The caption reads:

"The first step into space is a model rocket."

Rocket Science is the road map to achieve that, all in one text. It is in essence a legacy to the future you will be a part of making it a good one.

Finally, Harry Stine, the father of model rocketry asked each of the senior members to pay forward, because each new member we have is worth our attention, guidance and assistance to be a success. *Rocket Science* will make the path to your aerospace future brighter.