Using Video To Measure Position, Orientation, and Speed of a Model Rocket

NARAM-53 R&D Project
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Summary

This report describes a procedure to measure the speed, orientation, and flight path deviation of a rocket by analyzing video of a launch. The basic tools needed are a video camera, and some inexpensive software to make the post processing measurements.

While the process can take some time to analyze the video (frame by frame), it can be really helpful for educators to teach real-world applications of basic physics concepts (position, velocity, and acceleration). The process and the results are also useful for designers (like TARC team members), that want to know more about their rockets and how they behave under varying launch conditions.

Originally, this project was to demonstrate that spinning rockets help make rockets fly straighter. And this was actually proved in the project by using the video equipment and post flight analysis. But the second part of the original project was to see how the spinning affected the altitude achieved. Unfortunately, I discovered that the variation in motors had a far greater impact on the altitude than the extra drag created by a spinning rocket.

The procedure for analyzing the flight involves standing a launch rod in front of a video camera so that there was a frame of reference to use to actually measure the deviation from planned flight path (straight up). By strategically placing the video camera and the launch rod, it is possible to get an accurate assessment of the flight path.

This process was used to make accurate visual measurements of the speed of the rocket during ascent by doing a little bit of post-processing of the video and a little bit of trigonometry (if the distances of the camera and the launch rod are known relative to the launch pad).

The Objectives of the Work

When I first started this R&D project, I wanted to see how much spin affected the performance of a rocket. The reason is that induced spin is one way to increase the stability of a rocket, and help it to fly straighter. This would be a great advantage to TARC teams, where insuring the straightness of the flight is a pretty significant factor in achieving consistency from one flight to another. It would also help in altitude events in NAR competition, as a straighter flight has a better opportunity to go higher. This is especially critical in egg-lofting events where the rocket has a pretty high static margin thanks to the massive weight of the egg in the front of the rocket.

But after making a number of flights with the rocket, too many variables were creeping into the project. The big one was wind. I couldn't control this variable, and it is a huge one when trying to get a feel for the trajectory of the rocket. Because the same rocket that will fly well in calm wind conditions, behaves differently in higher winds.

Now that would have been a great experiment – to see how the trajectory changed in different wind conditions. But, it would have required a fairly constant wind to make valid measurements. When I was conducting the flight tests, the wind was quite variable, with random gusts coming in and making wind measurements difficult. I would have needed to launch the rocket at the same time as taking the wind reading. This became a too daunting of a task, especially since I needed help launching the rocket.

Because of that, I needed to refine this project. What I realized though, that going through the original experiment, I had created a process for making trajectory measurements.

The new objective of this R&D report is to create a step-by-step system whereby other modelers, particularly educational organizations (like schools), can actually measure the trajectory (altitude, orientation, speed and acceleration) of their rocket. This is accomplished by providing a fixed frame of reference against which rocket orientation can be measured.

The Approach Taken

In any trajectory experiment, such as measuring the effect of canted fins has on the flight of a rocket, you need to measure the orientation of the rocket at various points throughout the flight. The modern video camera is an ideal tool for this.

The cost of video cameras has dropped considerably in the last few years, and it looks like it will continue to drop, even when factoring in inflation. For this experiment, I used an Aiptek HD video camera with a fixed focus lens. It cost about $125 (at full retail price from Sears) when I purchased it in 2009. A similar camera (actually with better features) can be found for about the same price today.

The other main tool is a personal computer. The key thing is that all modern personal computers play video. By importing the video into the computer, you can play it back and more importantly; you can step through the video frame-by-frame to see what has changed.

The result of combining the video camera with the personal computer is that we now have a way to record the rocket's position, orientation and the time from lift-off at any instance in flight.

The one thing that is lacking is some frame of reference that allows us to get our bearings within the field of view of the camera. A simple, but effective frame of reference that can be used is an object of know size and orientation.

Photo 1: Aiptek HD video camera

I this experiment, I used a launch rod mounted on a tripod that was positioned between the fixed camera and

the rocket's planned trajectory. The launch rod gave a fixed vertical line in the video from which I could measure the deviation and the orientation of the rocket.

So upon playback of the video on the computer, it is now possible to measure the location and the orientation of the rocket at any point in the flight.

Rocket Construction

To begin, I made 6 identical rocket models. The only difference was the fin cant angle. Two were set to each of 0°, 1°, and 3°.

The basic design had several key features. First, I made all the fins a rectangular shape, with no airfoils. They were flat with squared-off edges. This was done to make sure they were all identical. In fact, I sealed the wood smooth with several layers of CyA glue and sanded the surfaces smooth even before I started cutting them to shape. Again, this would make sure that they all had identical surfaces.

I then stack sanded the fins to make sure they all the had identical shapes. I put a line down two sides, as shown in Photo 3. This was done to make sure I knew which edge would be the leading edge and which would be the root. Again, it was to make sure that the fins were as identical as possible.

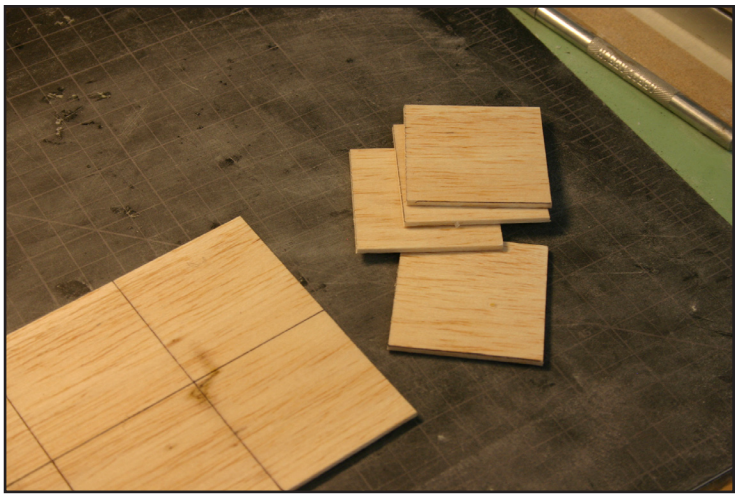


Photo 2: Simple rectangular fins, with squared-off edges.

To make sure the cant angle was as perfect as possible, I made three different body tube wraps as shown in the image. The tubes were marked in the conventional way using a pencil.

The 0° fins were then applied using a metal fin alignment guide to make sure they were as perfectly aligned with 0°. I wanted to prevent any spinning of these rockets when they were launched.

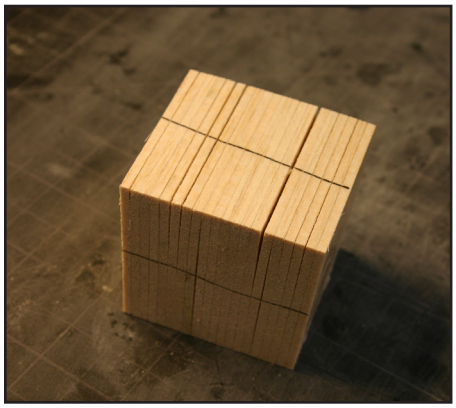
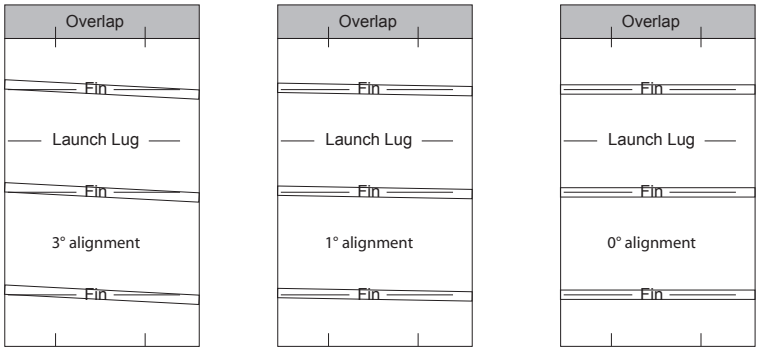


Photo 3: The leading edge and the root edge were marked to make sure all fins were oriented identically on the rockets.

It was a bit more difficult putting on the 1° and the 3° canted fins since I didn't have a fin jig for these. But I applied them as best as humanly possible to make them as consistent as I could. See Photo 5.

The other key feature is that the rockets had a payload bay to hold the altimeter. The payload tube actually had two chambers. The forward chamber would hold the altimeter. I used a separate bay for the AltimeterTwo, even though it could go into the body tube of the rocket. The reason is that I have found that the placement of the parachute in the rocket can sometimes block off the pressure sensor on the altimeter, giving a false reading of altitude. By putting it in its own chamber, it would not have this problem. It worked great, as I didn't have any false altitude readings for the duration of the flights.



Drawing 1: Paper wraps were made to accurately position the canted fins on the rocket tube.

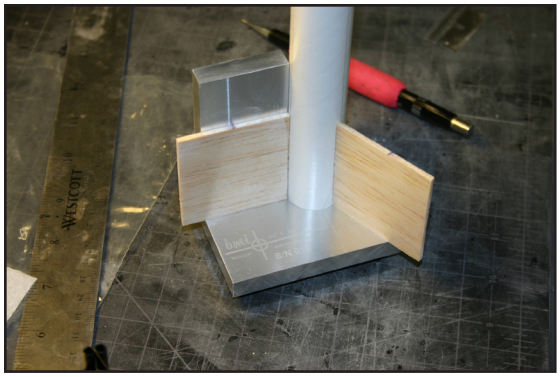


Photo 4: A fin jig was used to make sure the 0° fins were aligned straight on the rocket tube.

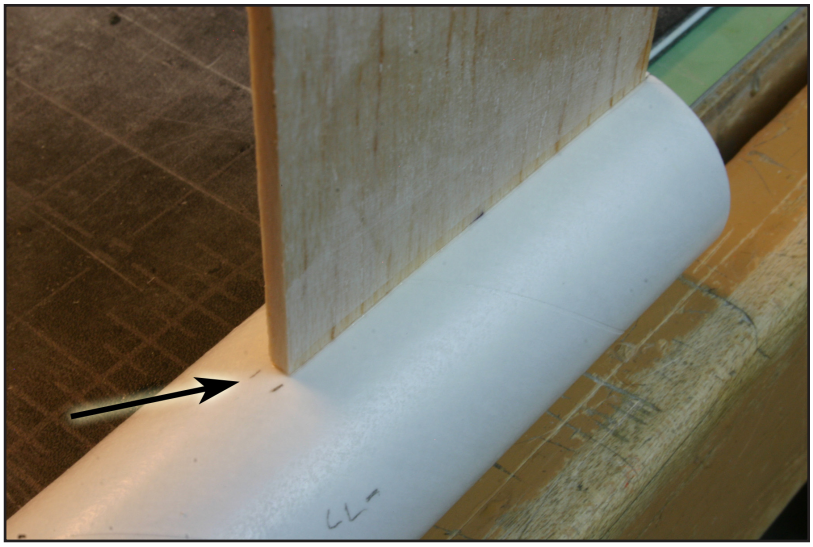


Photo 5: Aligning the canted fins along the tube.

The aft chamber was seal with glue, after I had added any necessary ballast weight to make sure they all weighed the same. The rockets all weighed 29.6 grams (empty, no motor, no altimeter).

To make it easier to tell the rockets apart, I marked them with numbers. In addition, Rockets #1 and #2 had molded blue plastic nose cones, and used fins with 0° cant angles. Rockets #3 and $4 had 1° fin cant angles, and sported a bright red nose cone. Finally, rockets #5 and #6 had the 3° fin cant angles, and had dull red molded plastic nose cones.

Finally, to make it easier to tell rotation of the rockets in flight, I colored one fin on each rocket with a black permanent marker. The image shows a typical rocket that was used in this experiment.

For recovery, I used a streamer made from Tyvek®. I just wanted to make sure that the rocket landed fairly close, as I didn't want to lose any models in the middle of the trials.

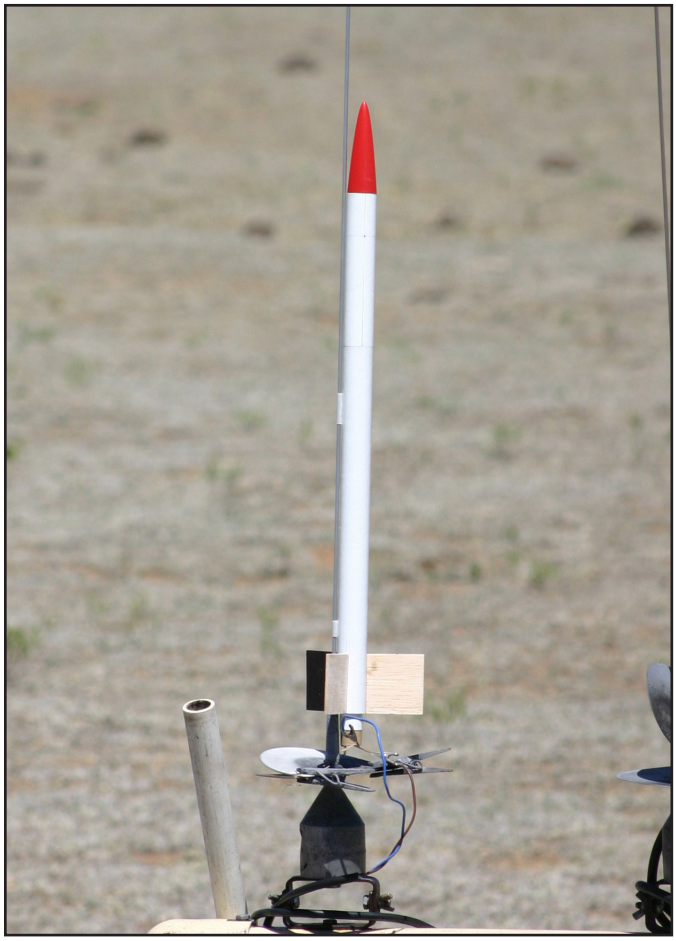


Photo 6: One of the completed rockets on pad.

Flight Testing

For the original experiment, where I wanted to measure the altitude difference of the spinning versus non-spinning rockets, I used the AltimeterTwo (www.ApogeeRockets.com/AltimeterTwo.asp) to make the data measurements. This device measures 10 different parameters of the flight using both a pressure sensor and a accelerometer. These are:

1: Peak altitude

2: Top speed

3: Burn time (seconds)

4: Peak acceleration (g's)

5: Average acceleration (g's)

6: Coast to apogee time (seconds)

7: Apogee to ejection time (seconds)

8: Ejection altitude

9: Descent Speed

10: Flight duration (seconds)

Photo 7: The AltimeterTwo weighs only 7.7 grams and fits into a 18mm diameter tube.

Drawing 2 on the next page shows a pictorial representation of each of these data parameters.

At the beginning, I was most interested in Top speed, Apogee altitude, and I was hoping to see how the peak acceleration changed between the non-spinning and the spinning rockets.

For the flight tests, I used Estes B6-6 motors. The reason for the long delay was to make sure that the rocket did go past apogee before deployment of the streamer. That way, I was certain to capture the peak altitude on the altimeter, even if the rocket didn't have a perfect trajectory.

Video Set-up

To document the flights, I set up a video camera that was mounted on a tripod. I used the Aiptek HD video camera, but I used the regular video mode instead of the HD mode. The reason being that in regular mode, the camera records 60 frames per second of video, compared to only 30 frames per second in HD. This means that I could capture more frames of the fast-moving rocket before the rocket left the field of view of the lens.

The series of images (Photos 8 - Photos 37) shows a typical flight of a rocket taking off. At first it looks like nothing is happening. You have to look closely in the first few images to see the smoke just starting to come out of the rocket.

It is hard to see the rocket initially, because I placed a 3/16" diameter by 5-foot long launch rod (mounted vertically on a tripod) between the camera and the rocket. I positioned the launch rod so that it would be aligned with the vertical orientation of the rocket as it sat on the pad. In effect, the launch rod would tell me the intended flight path of the rocket – which I wanted to be perfectly vertical.

By comparing the position of the rocket to the launch rod in the video, I could tell how much the rocket veered from vertical. This gives me the first part: the position and the orientation of the rocket

I got the idea from the real space program! The range safety officer at Cape Canaveral uses a vertical line on a TV monitor to tell if the rocket is staying on the intended course. If the rocket deviates from this line, then he is authorized to blow it up using the self-destruct charges mounted on the rocket. But for this project, the vertical line would tell me how straight the rocket flew.

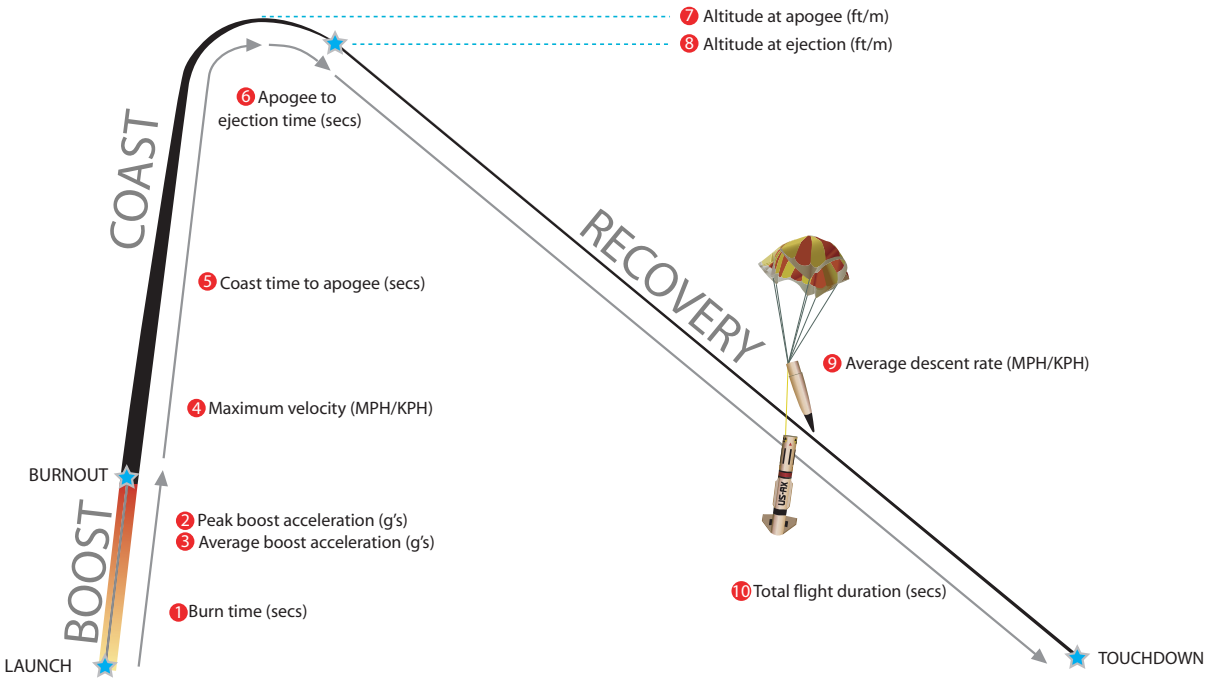
Once everything was set up, I launched each rocket and recorded the AltimeterTwo data, along with wind speed

ALTIMETERTWO Data Log Sheet

		Flight #1	Flight #2	Flight #3	Flight #4
Rocket Name					
Motor Used					
Apogee Altitude					
Top Speed					
Burn Time	burn				
Peak Acceleration	PAcc				
Avg Acceleration	AAcc				
Coast to Apogee Time	C2AP				
Apogee To Eject Time	AP2E				
Ejection Altitude	EALt				
Descent Speed	dESc				
Flight Duration	durA				

www.ApogeeRockets.com

ALTIMETERTWO From jolly logic
Flight Analysis Data



Drawing 2: An image that shows the data captured by the AltimeterTwo.

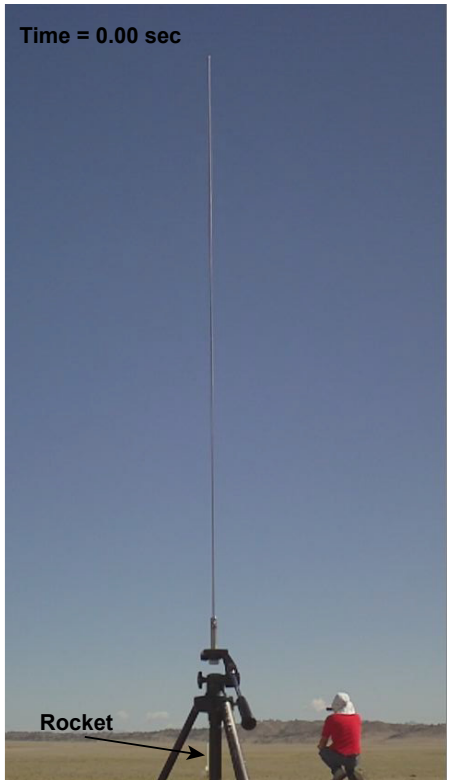
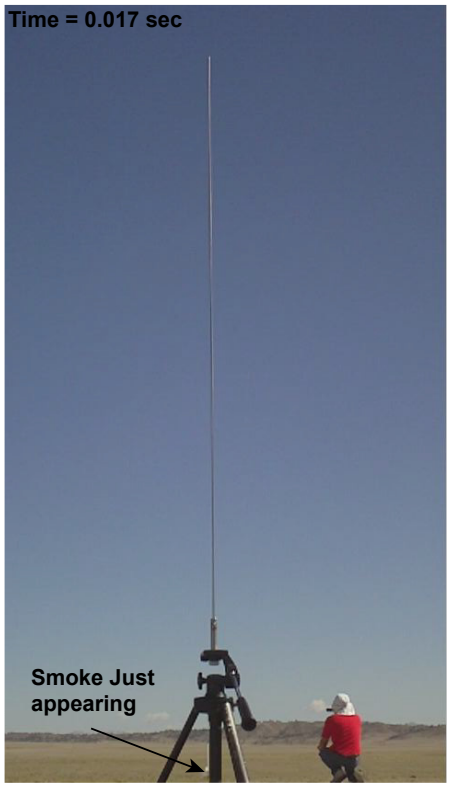


Photo 8



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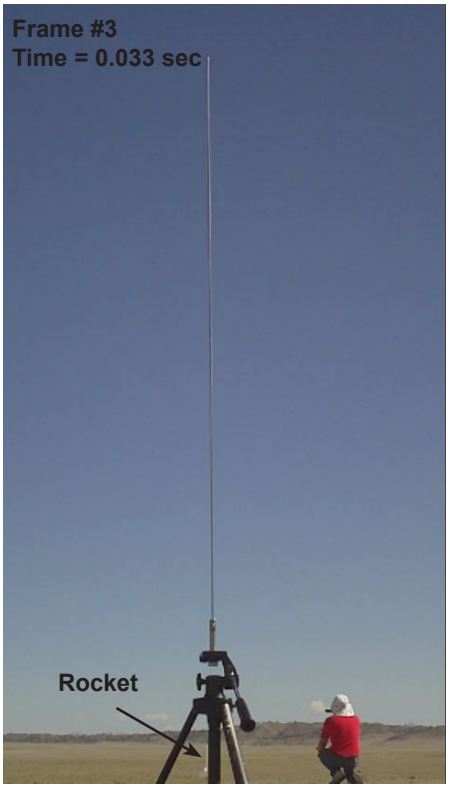

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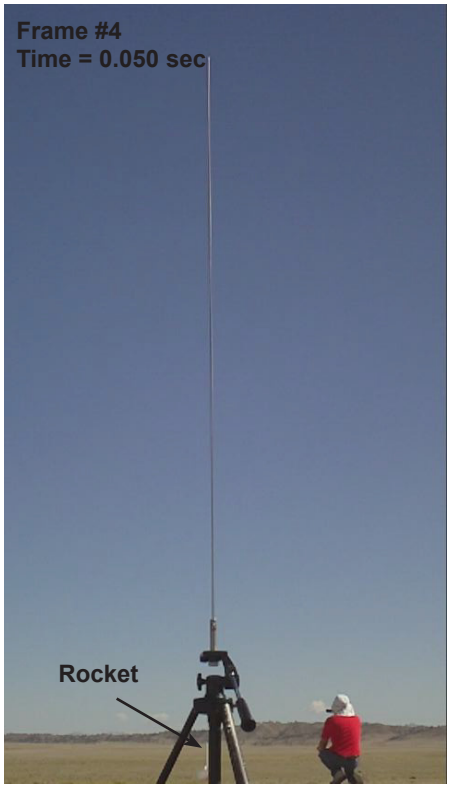

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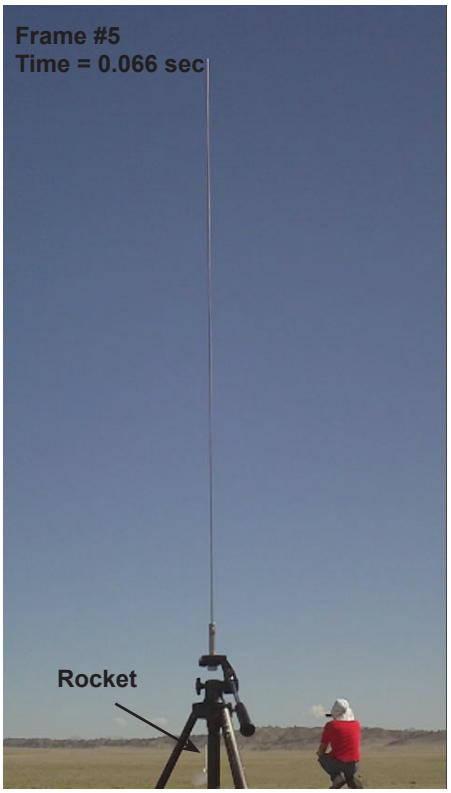

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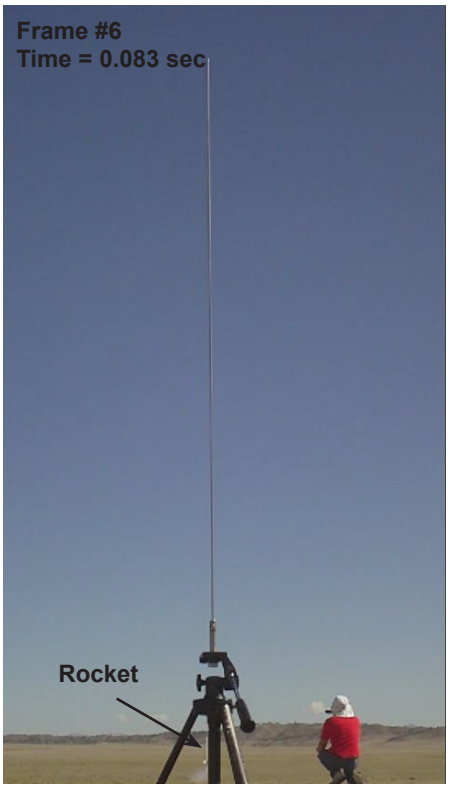

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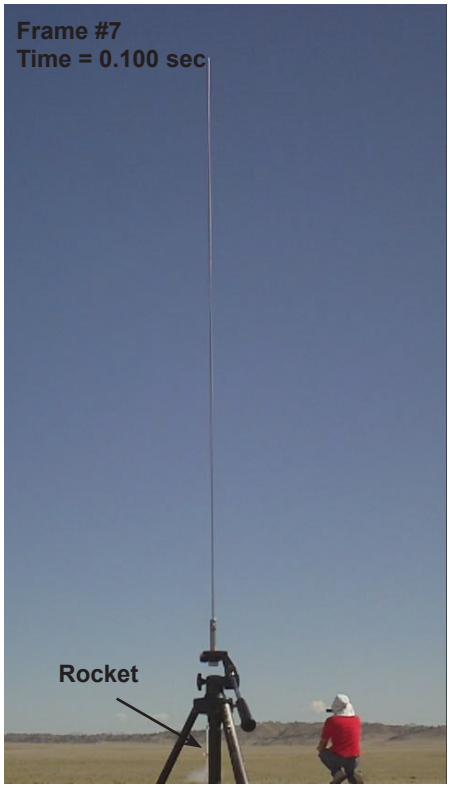

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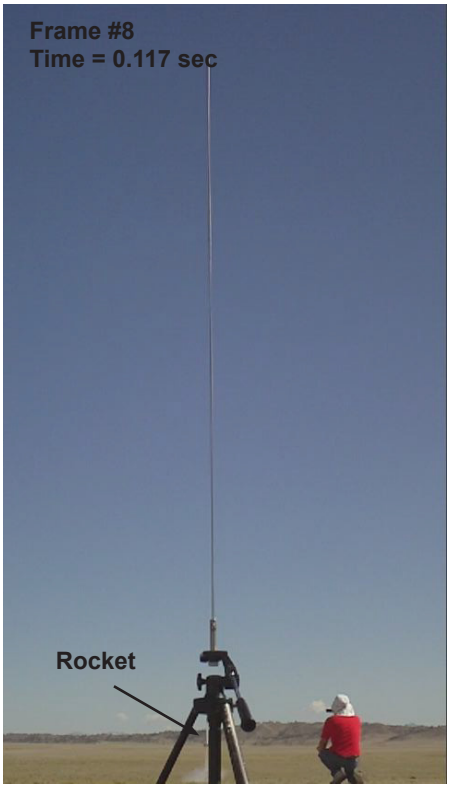

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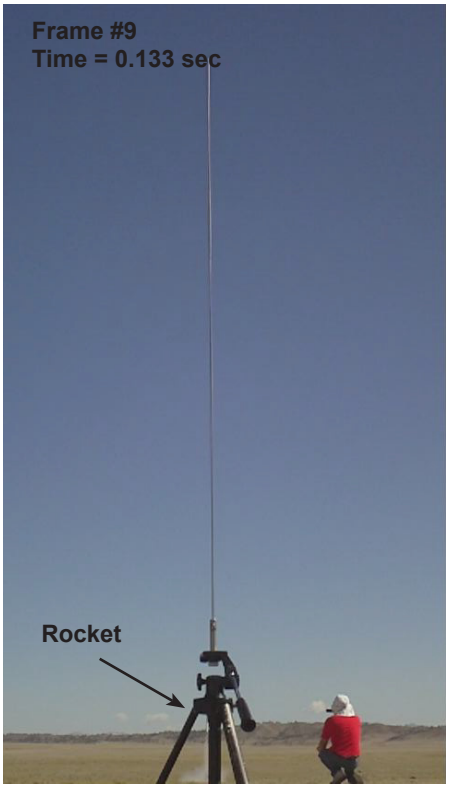

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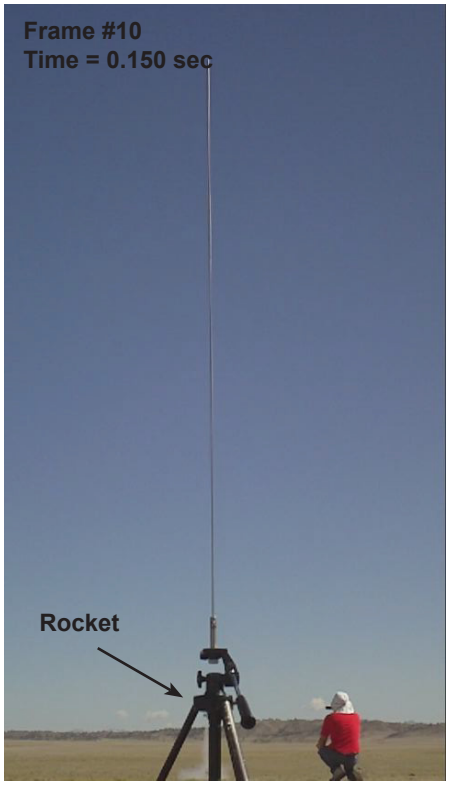

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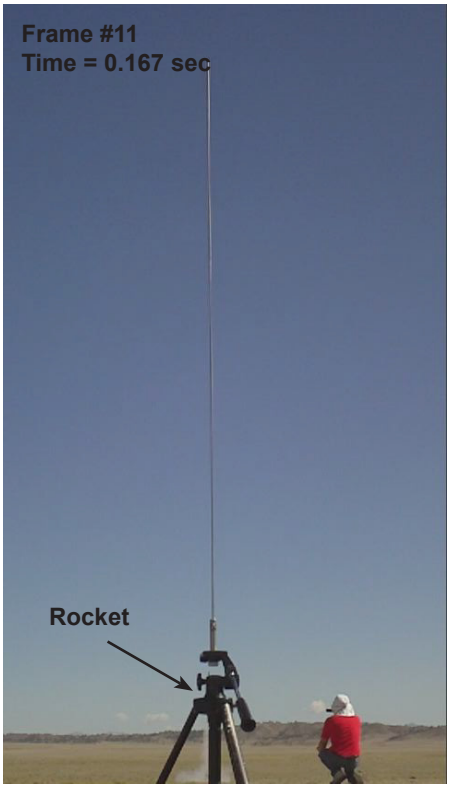

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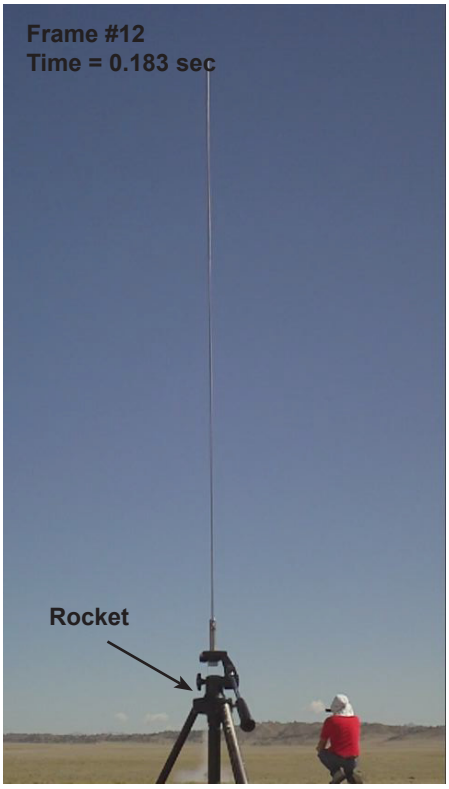

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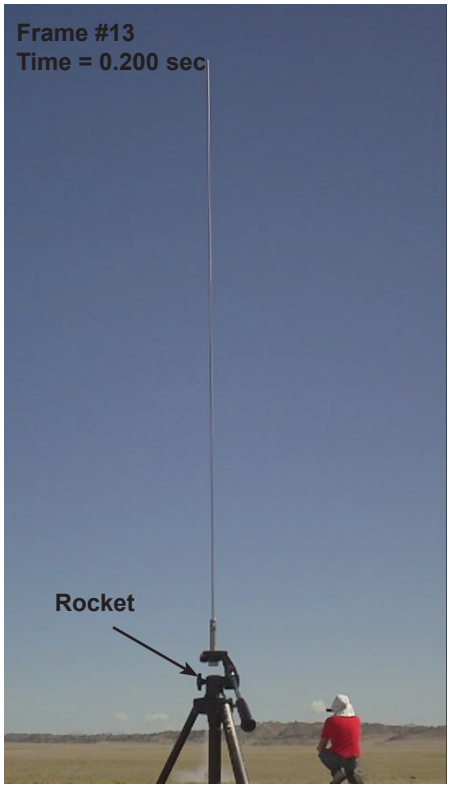

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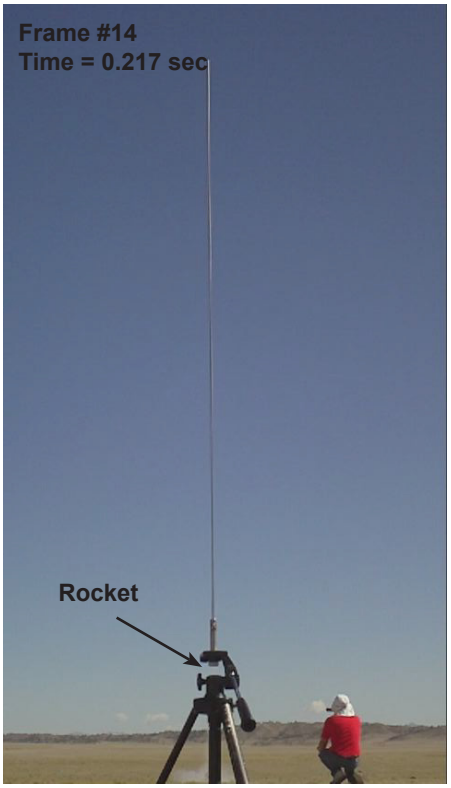

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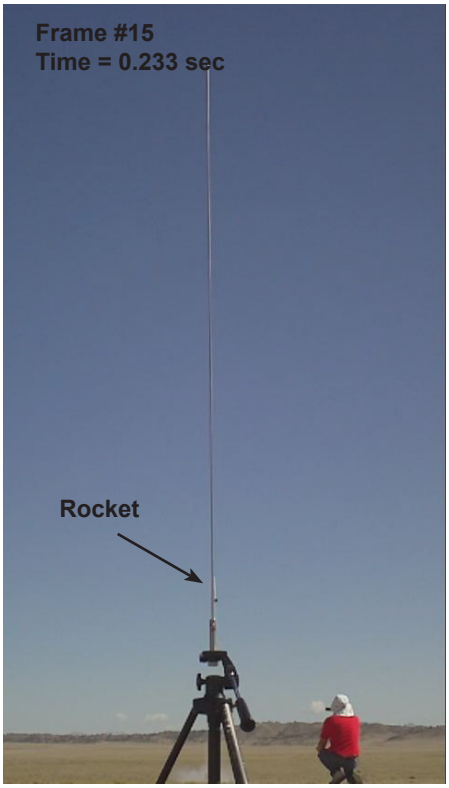

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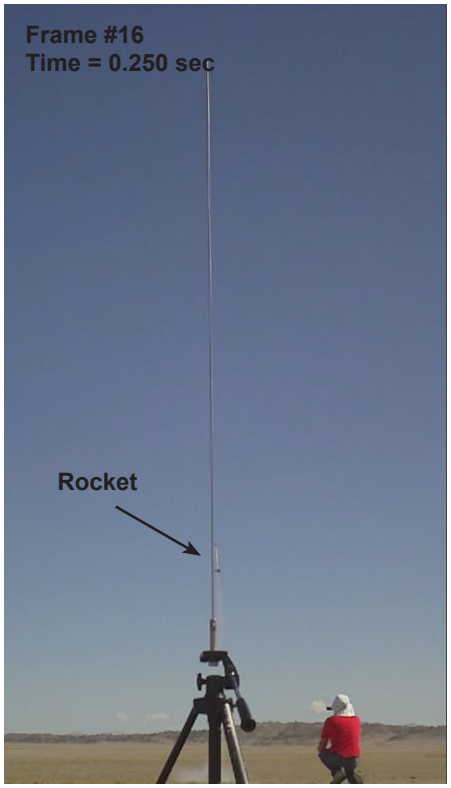

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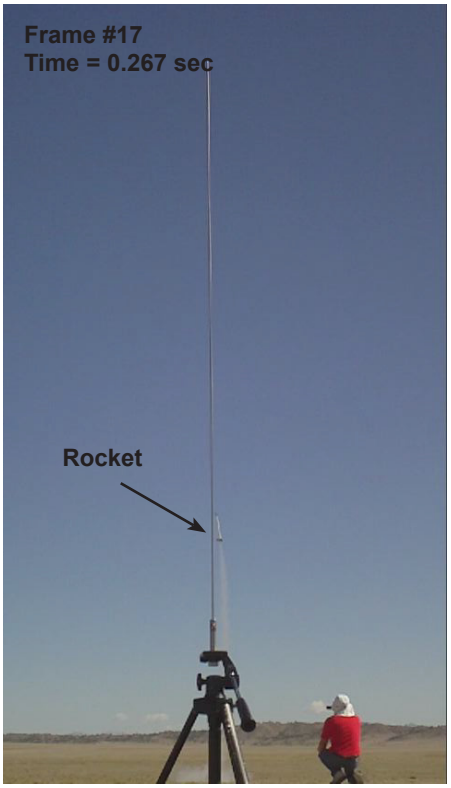

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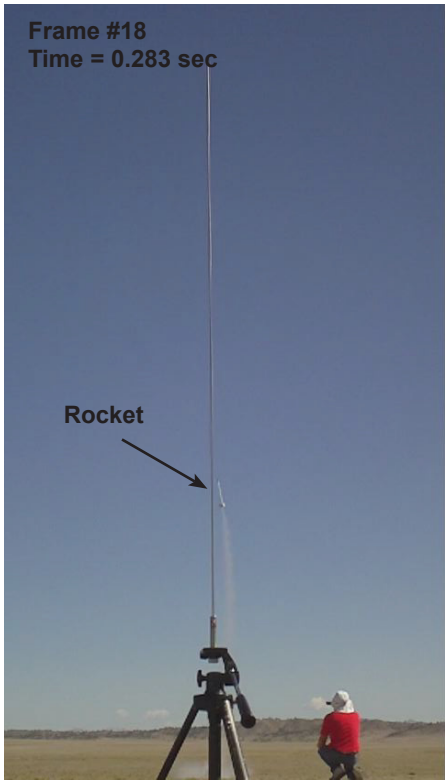

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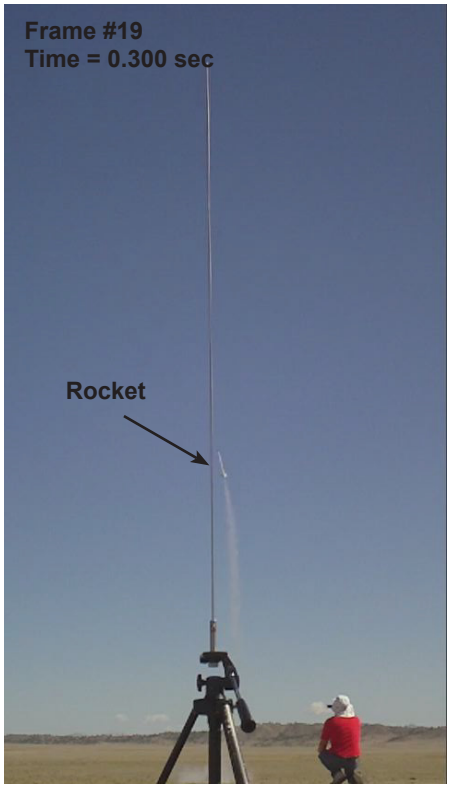

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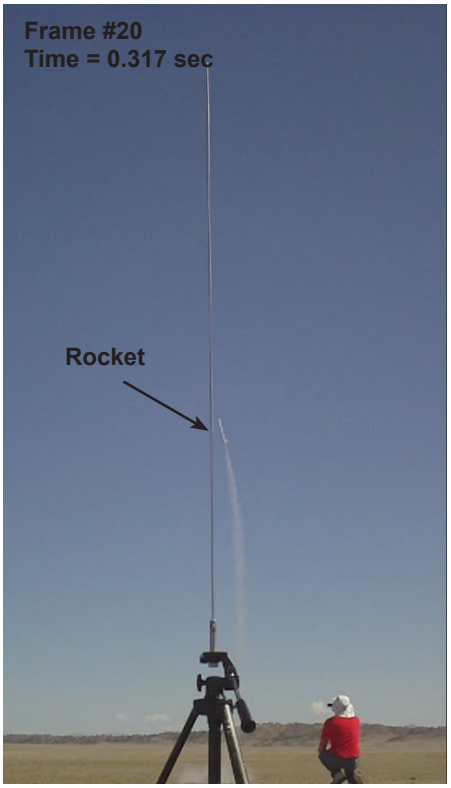

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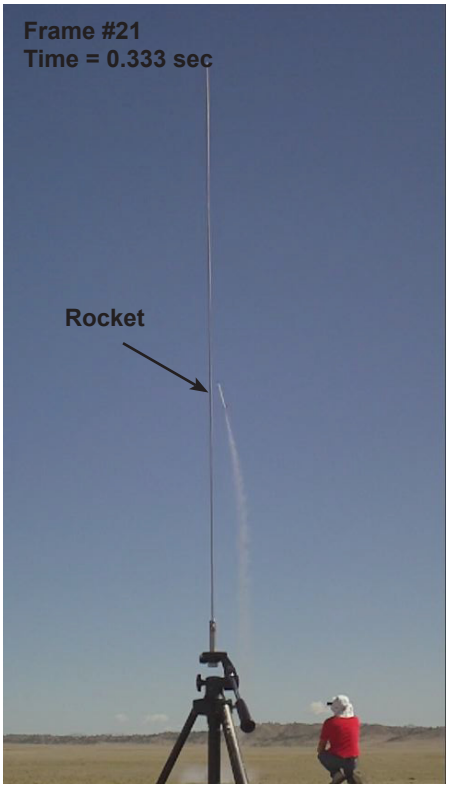

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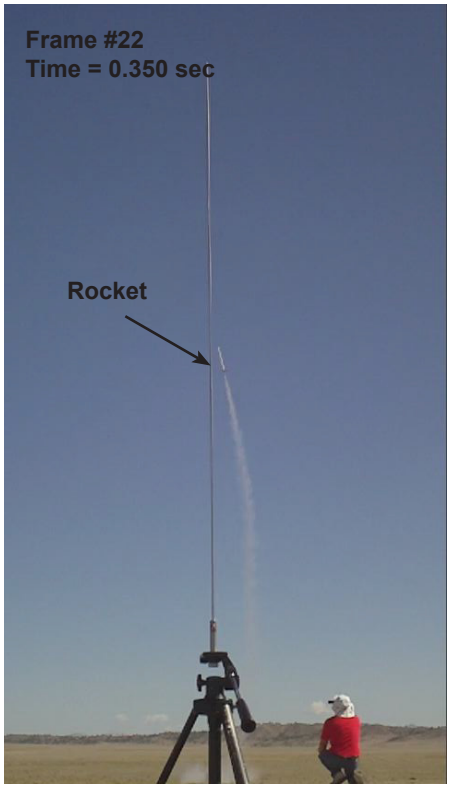

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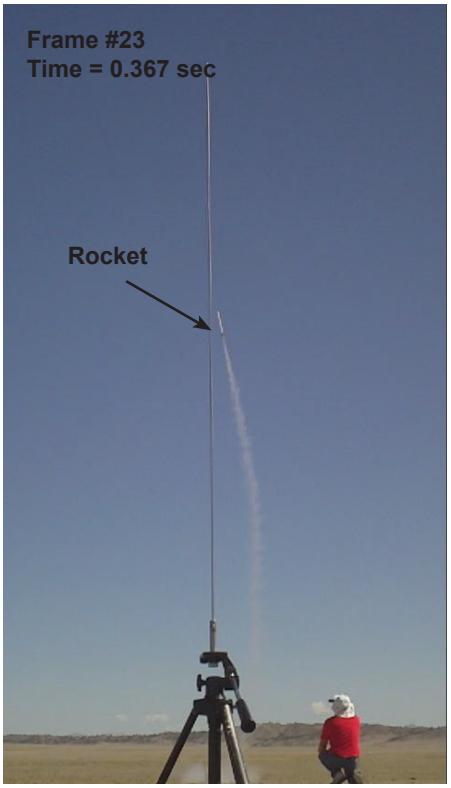

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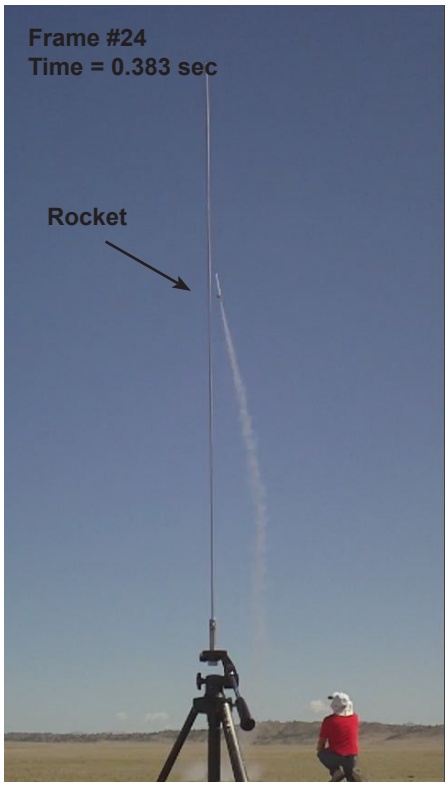

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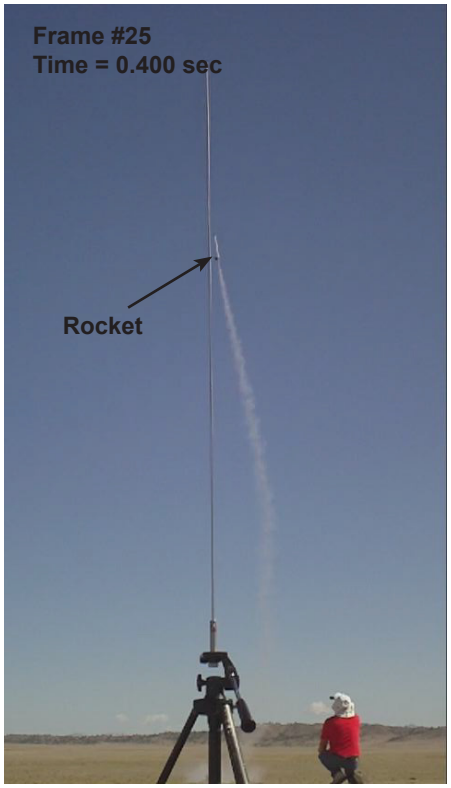

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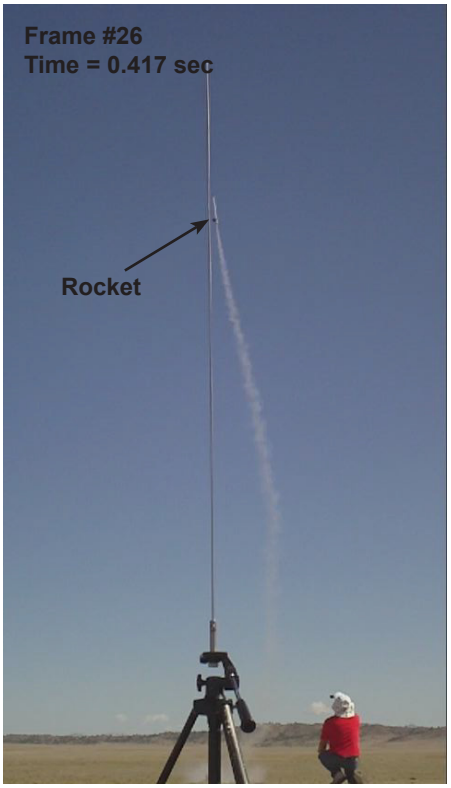

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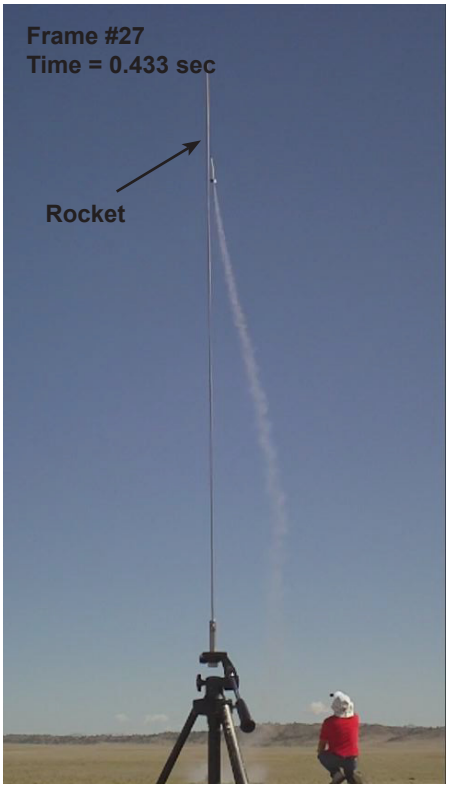

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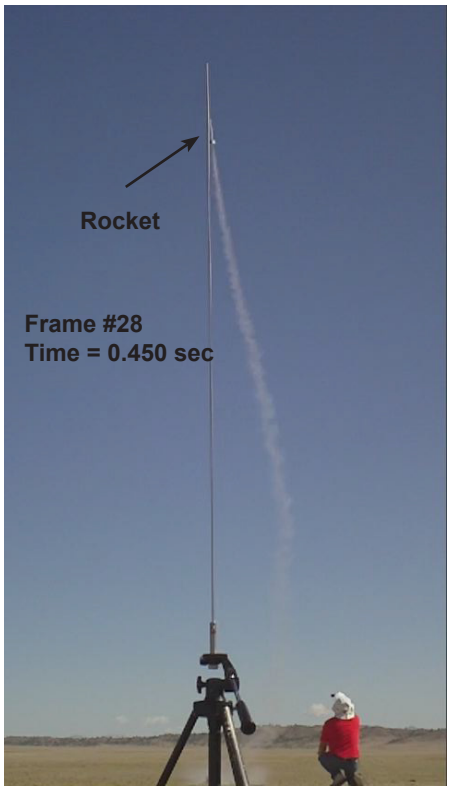


Photo 35

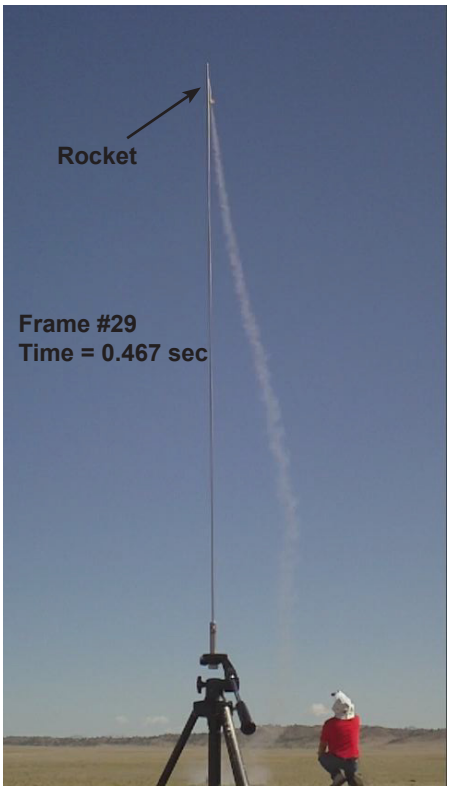


Photo 36

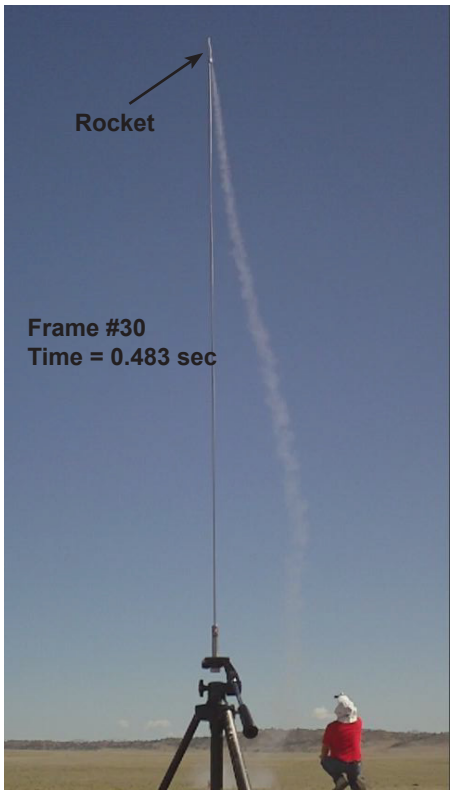


Photo 37

and temperature at launch. For these initial flights, I was at the Hartsel, Colorado launch site, which is the field used by Tripoli Colorado. The unique thing about this field (other than the terrific views, and lack of trees), is that the base ground elevation is at 8,736 feet above sea level, which is probably the highest regularly used club launch site in the world. At this altitude, the rockets fly high and fast because the air is so thin. But the downside is that they also drop like rocks. I did have two rockets that broke a fin on landing. Fortunately, they were each a clean break, and I was able to glue it back on to the rocket without altering too much the aerodynamic characteristics of the vehicle.

For the most part, the flights went uneventful. But due to time constraints, and a wind that was getting stronger as the day went on, I was only able to get 10 flights into the air. I was hoping to launch each rocket twice for a total of12 flights.

Post Processing of the Video

To view the video after it was downloaded into the computer, I used the Apple QuickTime software. There is a free version available from Apple Computer (www.Apple.com/quicktime) that will work on both Windows and Mac computers. The nice feature about QuickTime is that it the native video format from the Aiptek camera is QuickTime, so it plays the .mov format video without any secondary post-processing. It also lets you step through the video frame-by-frame (using the arrow keys on the computer keyboard).

Photo 38: Image of QuickTime Player. The scene is sideways because the camera was oriented sideways.

The video camera was mounted sideways on the tripod, so as to get as much vertical “real-estate” into view as possible. When played back, the rocket would be sideways as shown in Photo 38. Therefore, to make measurements, the video frames would have to be rotated 90°. This wasn’t too much of a problem, because I had to take a screen shot of each video frame anyway. Then each image would be opened up in a drawing program and rotated, so it would look like the Photos #8 through 37 shown here in this report.

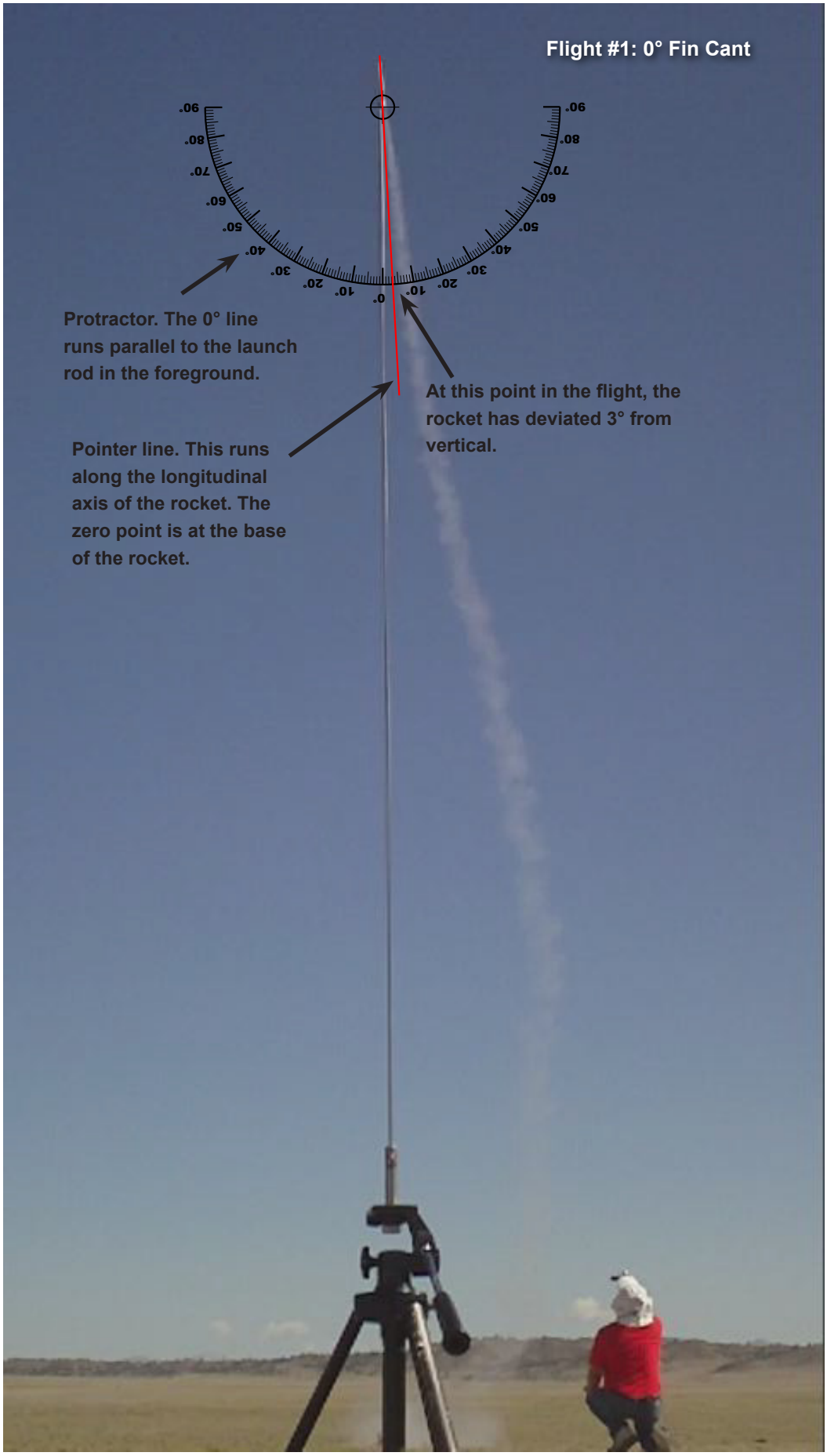
Note: the “Pro” version of QuickTime, which can be purchased for around $30, allows you to quickly export all the frames in picture format, so you don’t actually have to make screen shots one-at-a-time. This saves a lot of time during post-processing of the videos.

Adding Annotations to the Video Images

The rocket appears in the video field-of-view for about 30 frames, when the camera was set to record at a frame rate of 60 frames-per-second (technically 59.94 frames/sec). Therefore, each frame was taken at approximately 0.017 seconds apart. That is how the time was determined for each video frame.

To add text annotations and call-outs to the images, I opened up the individual frame images in a drawing program. The software I like personally is Adobe Illustrator. Bue there is a free open-source equivalent (for both mac and windows) called InkScape (http://inkscape.org/). Both are called “vector graphics” program.

The reason for a vector-graphics based program is that it allows you to make precise measurements of the lines you draw. But you can also add simple text annotations as well, which is what I used in the first series of images. Since much of the work was repetitive, I used copy-past a lot to make the images look similar.



The main benefit of using the vector graphics program is that I was able to quickly create a protractor in the drawing program, and overlaid this on the screen images from the video, as shown in Photo 39. From this, I could make direct angular measurements of the orientation of the rocket as it deviates from its vertical flight path. These are shown in the Photos #40 to 48 beginning on the next page.

It was from these images that I was able to add the flight path angle to the flight data chart shown in Chart 1A and 1B on pages 17 and 18.

Photo 39: A protractor was created in the vector program, and overlaid on the screenshot of frame from the launch. From this, you can get an orientation of the rocket's trajectory at any point in the flight.

Photo 40

Photo 41

Photo 42

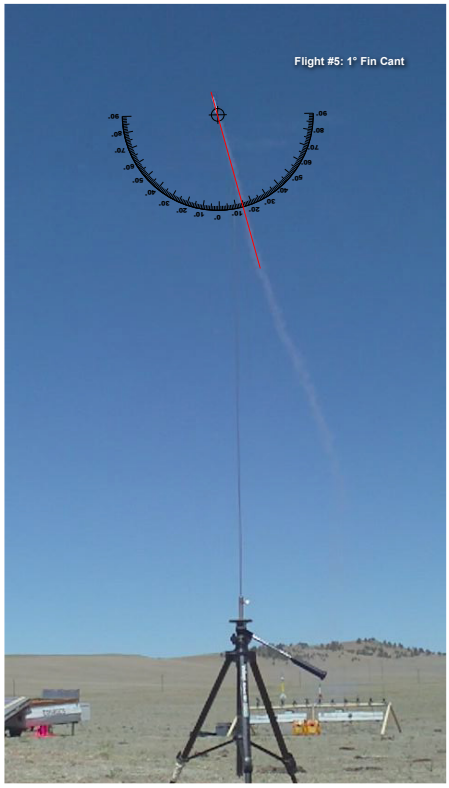


Photo 43

Photo 44

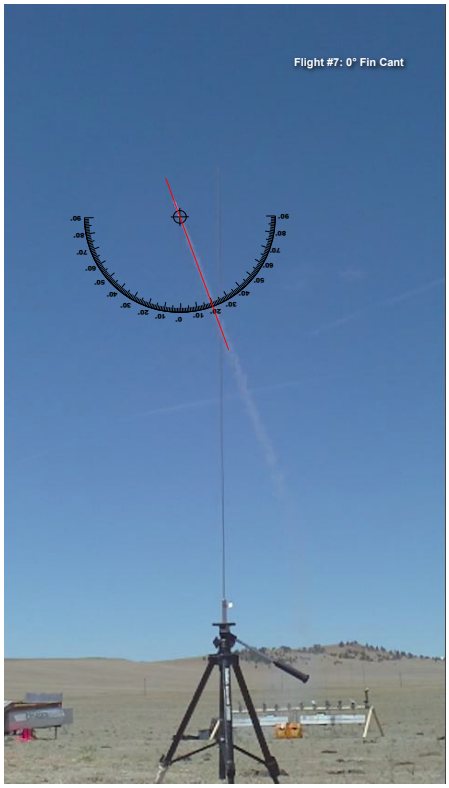


Photo 45

Photo 46

Photo 47

Photo 48

	Flight #1	Flight #2	Flight #3	Flight #4	Flight #5
Fin Cant Angle	0°	1°	3°	0°	1°
Rocket #	1	3	5	2	4
Motor Used	B6-6	B6-6	B6-6	B6-6	B6-6
Apogee Alt.	464 ft	426 ft	488 ft	467 ft	422 ft
Top Speed	163 mph	146 mph	182 mph	158 mph	147 mph
Burn Time	0.8	0.8	2.5	0.8	0.8
Peak Accel	22.0 G	18.3 G	22.3 G	22.9 G	19.6 G
Avg Accel	8.8 G	8.7 G	3.6 G	8.8 G	8.4 G
Coast 2 Apogee	4.7 sec	4.4 sec	3.1 sec	4.4 sec	4.4 sec
Apogee 2 Eject	2.2 sec	2.9 sec	2.8 sec	2.6 sec	2.1 sec
Ejection Alt.	386 ft	305 ft	378 ft	365 ft	352 ft
Descent Speed	14 mph	18 mph	16 mph	14 mph	12 mph
Flight Dur	24.5 sec	19.3 sec	24.1 sec	24.4 sec	27.1 sec
Temp	77° F	78° F	78° F	75.6° F	79.5° F
Wind	2.4 mph	5.0 mph	5 mph	5 mph	5 mph
Flight Path Angle	3°	14°	0°	7°	14.5°
Comments	2 sheets of quest wadding. Motor lot code: A033010. Fin broke off on landing and was glued back on.				

Chart #1A: Flight data combining information from the AltimeterTwo with Flight Path Angle from the video.

	Flight #6	Flight #7	Flight #8	Flight #9	Flight #10
Fin Cant Angle	3°	0°	1°	3°	3°
Rocket #	6	1	3	5	6
Motor Used	B6-6	B6-6	B6-6	B6-6	B6-6
Apogee Alt.	403 ft	420 ft	400 ft	470 ft	440 ft
Top Speed	153 mph	151 mph	157 mph	183 mph	163 mph
Burn Time	1.9 sec	.8 sec	.8 sec	2.3 sec	2.0 sec
Peak Accel	20.1 G	20.5 G	20.6 G	21.5 G	20.9 G
Avg Accel	3.7 G	9.0 G	9.3 G	3.6 G	3.7 G
Coast 2 Apogee	3.1 sec	4.2 sec	4.0 sec	2.7 sec	3.2 sec
Apogee 2 Eject	2.7 sec	1.5 sec	2.1 sec	1.6 sec	2.0 sec
Ejection Alt.	284 ft	385 ft	311 ft	448 ft	387 ft
Descent Speed	17 mph	20 mph	17 mph	15 mph	16 mph
Flight Dur	18.9 sec	19.4 sec	19.9 sec	26.4 sec	23.0 sec
Temp	79.6° F	78° F	79° F	79.3° F	82.3° F
Wind	9 mph	12.5 mph	12 mph	10 mph	10 mph
Flight Path Angle	27.3°	19.5°	28.5°	1.5°	19°
Comments	Broke fin on landing. Split in half.				

Chart #1B: Flight data combining information from the AltimeterTwo with Flight Path Angle from the video.

Conclusions from the Initial Flights

Because of the gusty wind conditions on the launch day, the data I was getting back was inconsistent. I was expecting the non-rotating rocket to fly higher when the wind was calm, but then weathercock into the wind during breezy conditions. For the most part, this was true.

I was expecting the rotating rockets, those with the canted fins to fly lower, but straighter. Again, looking at the data in Charts 1A and 1B, this seemed to be a reasonable conclusion. But then I was getting some inconsistent data from the rocket with the 3° fin cant. On several occasions, it was flying *higher* than the rocket with the 0° fin cant.

If you compare rockets launched in similar wind conditions, the flights with the canted fins were straighter, which can be seen in the data and the video images (Photos 40 to 48). The conclusion you could make from this is that: if you want a straighter flight, especially in windy conditions, the fins should be canted so that the rocket spins at lift-off. The higher the cant angle, the straighter the flight. This would be useful in TARC competition rockets, where you need to have a consistent trajectory from flight-to-flight. The spinning will be the key to preventing excessive weathercocking.

But to make a prediction on the data I took as to how much deviation or how much reduction in altitude you'd get from a canted fin rocket, I wouldn't recommend it. There is still too much randomness in the data because of the number of flights is too limited. There is some problems that need to be overcome, and that would take a lot more flights, maybe in the hundreds. Actually, a better and cheaper way would be to put the rockets in a wind tunnel and measure the forces on the model. At that point you could make accurate predictions as to how the effect canting the fins would be on the flight of the model.

The biggest variables with using actual launches is the wind acting on the rocket. When I was launching, I did take a wind-speed measurement, but then the rocket would sit on the pad while I was waiting for the LCO at the club launch to get my rocket into the air. Often, it was several minutes later before the launch occurred. With that long wait, and the gustiness of the air, the wind speed measurements were not as accurate as I would have liked.

Ideally, you would want to take the wind speed measurement at the instant of launch. But I was more concerned with turning on the video camera right before launch. I was worried about the camera battery going dead from being on too long (especially with a lot of flights during the day). So I would turn it on right before launch, and then rush back and tell the LCO to push the launch button. This way, I would conserve the battery power, and limit the amount of video that I'd have to sort through during the post-processing portion.

The other issue that I discovered based on looking at the flight data is that it appears that there was some unknown force acting on the rockets that I couldn't account for. This is a straight-forward experiment, and the spinning rocket shouldn't fly higher than the non-spinning rocket in calm wind conditions. The reason is that it takes energy to cause the rocket to rotate and to maintain rotation. This energy loss is noted in the form of extra drag, and this extra drag should make the spinning rockets fly lower.

But since I had a couple of flights where the spinning rocket flew higher than the non-spinning rocket (and by a significant amount), the conclusion I came to is that the rocket motors are inconsistent. Based on my experience in making black-powder motors, this seems logical. It is difficult to make every motor have the same thrust curve and the same total impulse. There is too much variability in the motors to assume that the motors are a non-factor. This can be seen in the data by looking at the burn times of the motors. I used B6-6 motors throughout the flights, and they should all have similar burn times. A typical burn time for a B6 motor is about 0.8 seconds. But on many flights, the altimeter was recording burn times of over 2.0 seconds as seen in Charts 1A and 1B. This is a HUGE deviation that leads me to the motor being the most inconsistent variable in the experiment.

The other factor that I found is significant to the trajectory of the rocket is the launch rod length. I was launching off a 3-foot long launch rod during the test launches. Normally I use a 4 foot rod, but the club only had a 3-foot rod. Because the rocket was long and nose heavy (due to the payload bay, altimeter weight, and ballast mass), it was susceptible to weathercocking. I noticed that my daughter's rocket was weathercocking to the point where the chute was ejecting at a low altitude (too low). On my rockets, it wasn't as much of a concern, since I wanted some weathercocking. But I would have still preferred a longer rod to even out the lift-off speed of the rocket (again due to the variabilities in the thrust curve at ignition).

During the post-processing of the video after the launches, I did make several discoveries that I should have thought about earlier. First, the flight path angles should actually be taken at a “specific” altitude, or at a specific time during the flight – especially if your goal is to make apples-to-apples comparisons between the launches. In my images shown previously (Photos 40 through 48), the rockets were at different altitudes.

I was thinking about this problem as I was reviewing the video on the launch field (just to make sure everything was working). Then it hit me. *I should be treating the video camera as a tracking scope.*

If the video camera were thought of as a tracking scope, then the first thing you would do is to make distance measurements from the launch pad to the scope, so you would have a baseline distance.

I did not take a baseline measurement on my first series of launches. DOOH!

It was at this point that I knew I’d have limited success with my experiment to see the effects of spinning on a rocket. I wasn’t getting a complete picture of the launch, even with all the data I was already recording.

The Revised Experiment

The problem (and hence my experiment changed) now became: ***“How to get altitude data from a video recording of launch?”***

The first thought I had was to mount a camera on a tripod and get some reference distances in the field-of-view, so that I could make simple trigonometry measurements.

I did set up a situation like this, as shown in Photo #49. The baseline and the rocket both have to be shown in the

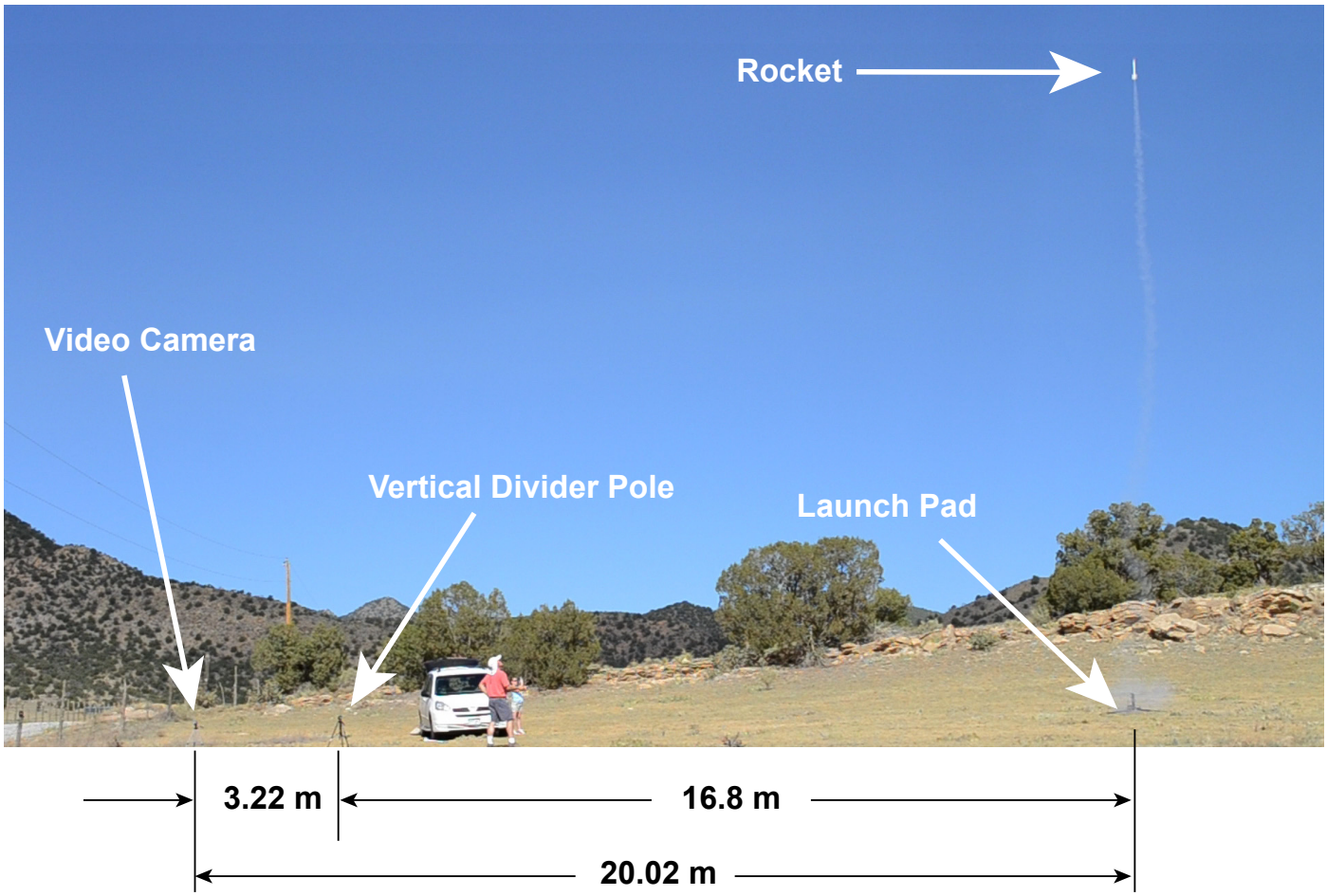


Photo #49: Range layout in order to use an HD camera to make altitude measurements (Method #1).

video frame for this to work.

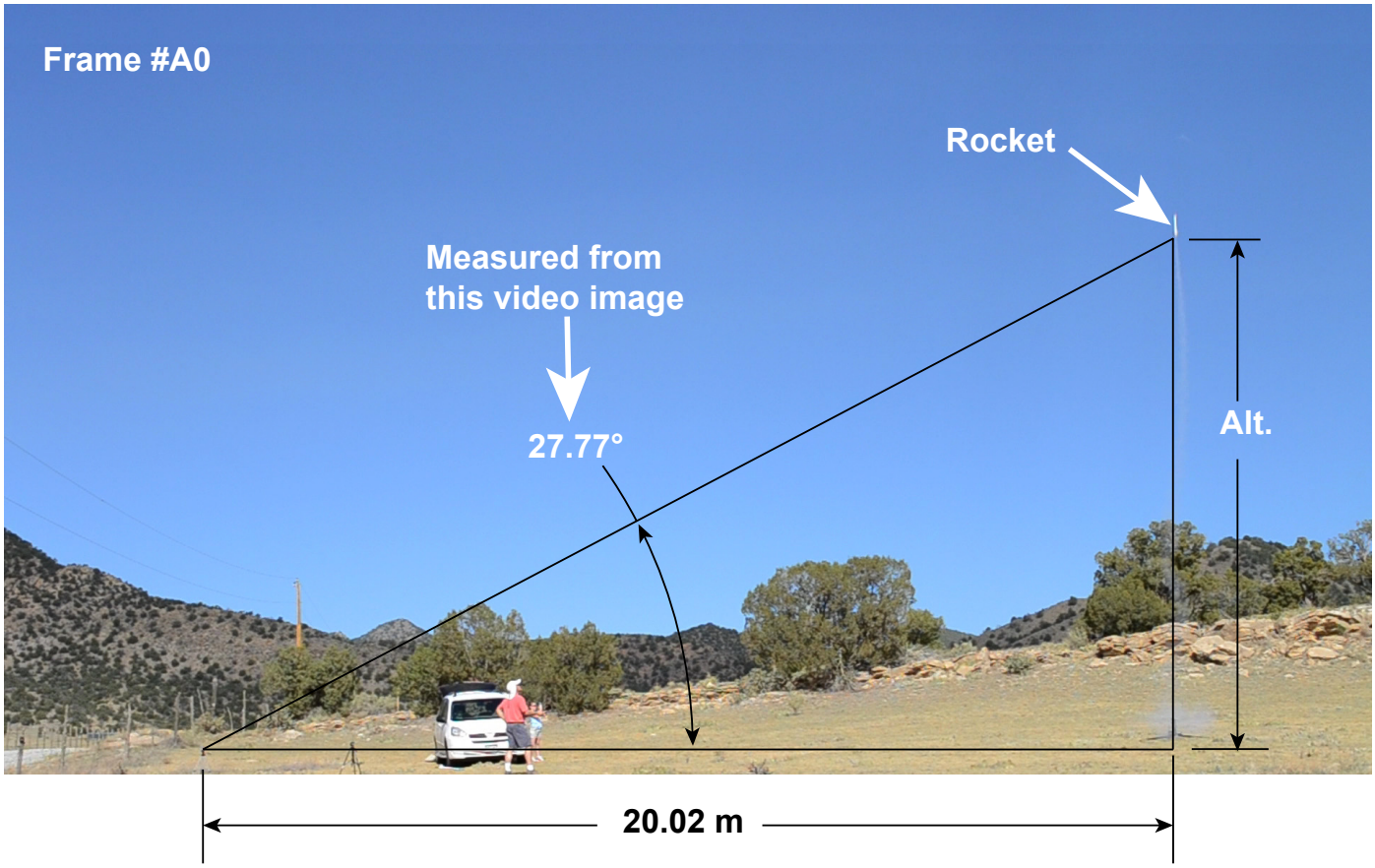
But to get accurate resolution, you really do need a HD video camera. Otherwise, your images may look a little fuzzy, and measurements would be more difficult. But it could be done.

I did have a HD video camera, but as I mentioned before, the frame-rate on my HD camera was much lower than in old-style wide-screen mode. It dropped from 60 frames a second to under 30. That means that the rocket would be seen in fewer frames before it flew out of view. One way to compensate for this is to move the camera further back from the launch pad, so that it takes in a wider field of view. But that means that the rocket will look smaller in the image, and make it harder to make distance measurements. It is a trade-off that the experimenter will have to decide it if makes sense for them.

The images (Photos #49 through #52) do show that you can get some nice usable data using this method. Again, the technique is to import the video into the computer, and then make screen captures of the individual video frames. These are then imported into a drawing program so you can annotate the flight and make the measurements accurately. Here, we are only measuring the baseline and the angle from the frame. These are used with a little bit of trigonometry to find the altitude of the rocket. I did three frames so you could see how the process completed.

However, the big drawback is that the rocket must fly nearly perfectly straight as shown in the photo on this page. If it veers off of the vertical line, then your altitude measurements will be off. It is a lot like single-station tracking using an inclinometer.

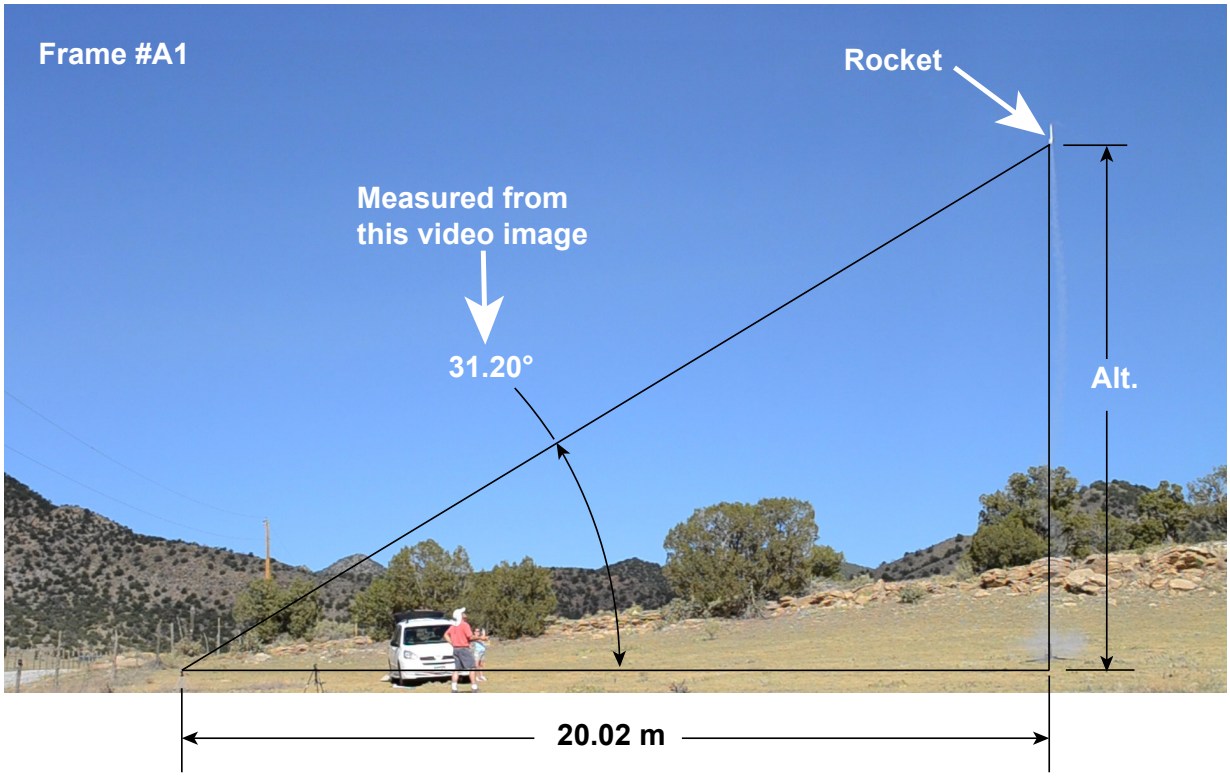
If the rocket is to veer off course, it would be best if it went side-to-side from the perspective of the camera. You could then adjust your trigonometry to compensate for the deviation. In other words, your baseline will change. But in the video fame, you'd see this and could easily make adjustments.



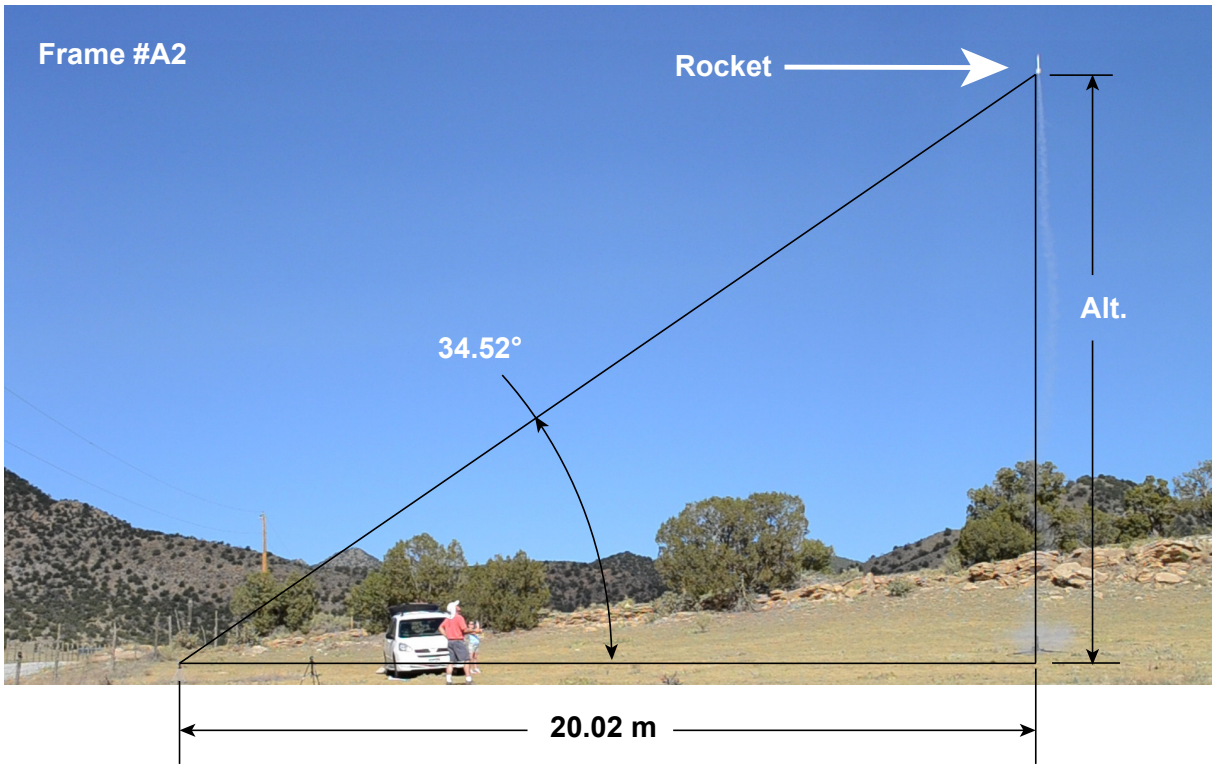
Frame #A0 Alt. = 20.02 m (tan 27.77°)
= 10.54 m

Photo 50: Altitude Determination Method #1 showing video image frame #A0. At this point, the rocket is 10.54m high.

Photo 51 and #52: Altitude Determination Method #1 showing video image frame #A1 and #A01. The rocket is getting higher... 12.13 meters and then 13.77 meters.



Frame #A1 Alt. = 20.02 m (tan 31.20°)
= 12.13 m



Frame #A2 Alt. = 20.02 m (tan 34.52°)
= 13.77 m

If the rocket came toward the camera, or went in a direction away from the lens, then you really couldn't tell how much to adjust your baseline distance.

My recommendation is that if you're setting up your camera, put it in a location cross-wind from the direction of the wind (not along the line of the wind).

In my images shown here (Photos #49 through #52), I was lucky enough to get a near-perfect vertical launch, so my baselines were pretty accurate.

To indicate the ends of the baselines, I stationed some tripods at a measured and known distance from the launch pad. Then during post-processing of the video, I just had to find those items in the frame to make a ratio of the distances to determine the altitude.

Finding the speed is then measuring the difference in altitude from one frame to the next, and multiplying it by the frame rate of the camera.

Speed = (distance change in altitude of the rocket from one frame to the next) X frame-rate of the video camera.

Method #2 For Calculating the Rocket's Speed From Video Images

I really liked using the pole situated between the camera and the launch rod to get a view of the amount of trajectory change that the rocket was experiencing (photos 8 through 37). What I needed is a way to determine how high the rocket was at any given point in the flight. This I felt could be accomplished if I could have some sort of gauge in the image to judge altitude against. Then it hit me that I could use the pole itself as the gauge. I already knew how long the launch rod was (I was using a 5-foot long rod). By making ratios to the length of the rod, and the position of the rocket in the field of view, I could find out how high the rocket was by using the law of similar triangles.

The more I though about this, I knew that "measurement error" could creep into the process, and if I could get finer graduations in the measuring stick, then I could get more accurate altitude measurements.

To solve this, I divided up the launch rod into alternating bands of contrasting colors (white and black). Each color band was exactly 10cm long as shown in Photo #53. To make the color bands, I simply wrapped the five-foot long rod with a piece of white masking tape, and used a black permanent marker to color 10cm bands on the rod. The result was quite professional looking, if I say so myself. I call the rod the "vertical divider pole." It is barely seen in Photos #49 through #52 and in #54.

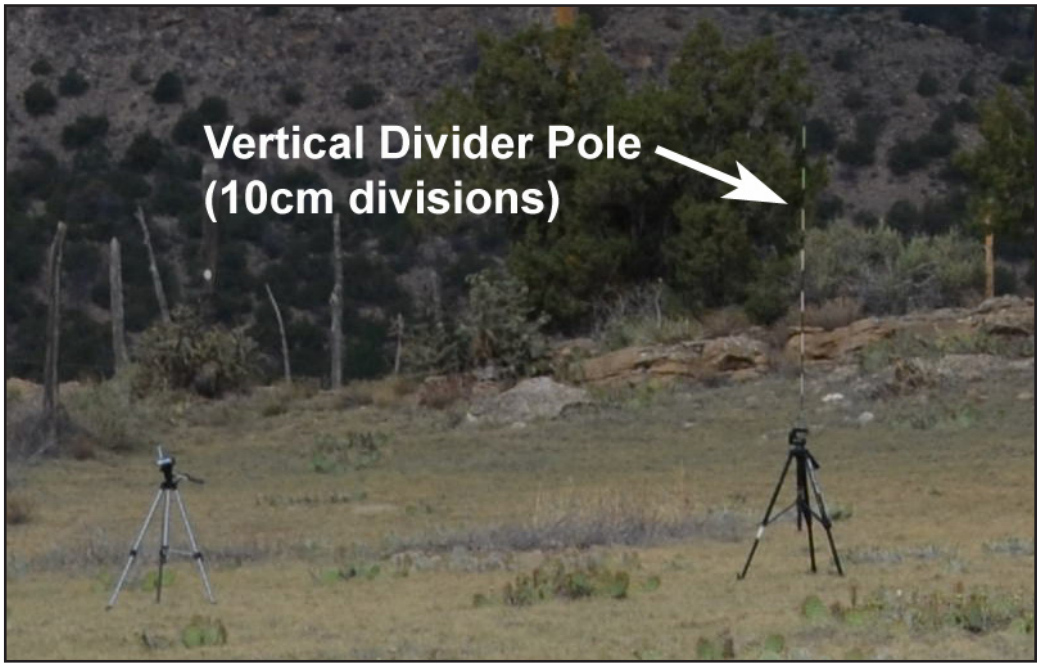


Photo #53: The vertical pole was given equal dividers by coloring it contrasting colors. This "Vertical Divider Pole" was stationed in line between the camera and the launch pad.

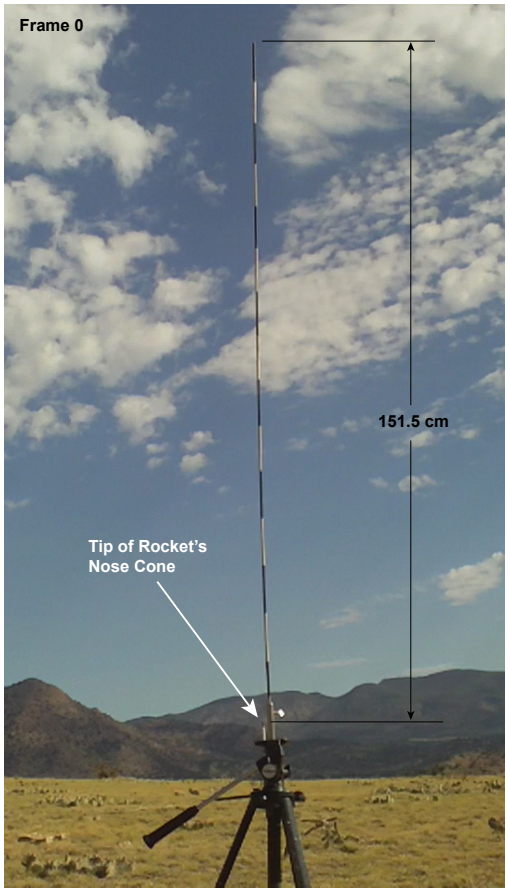


Photo #54: Image from the video camera showing the vertical divider pole, and the tip of the nose cone. The distance from the tip to the top of the rod was 151.5 cm.

How would this work to make altitude measurements?

If you look at the set-up from the side, you would get something that looks like Drawing #3. Basically, we get two triangles, each sharing a common point.

By doing a little bit of trigonometry, using the distance that the rocket appears to be climbing up against the vertical divider pole, we can then find the actual rocket altitude - or at least a pretty good estimation.

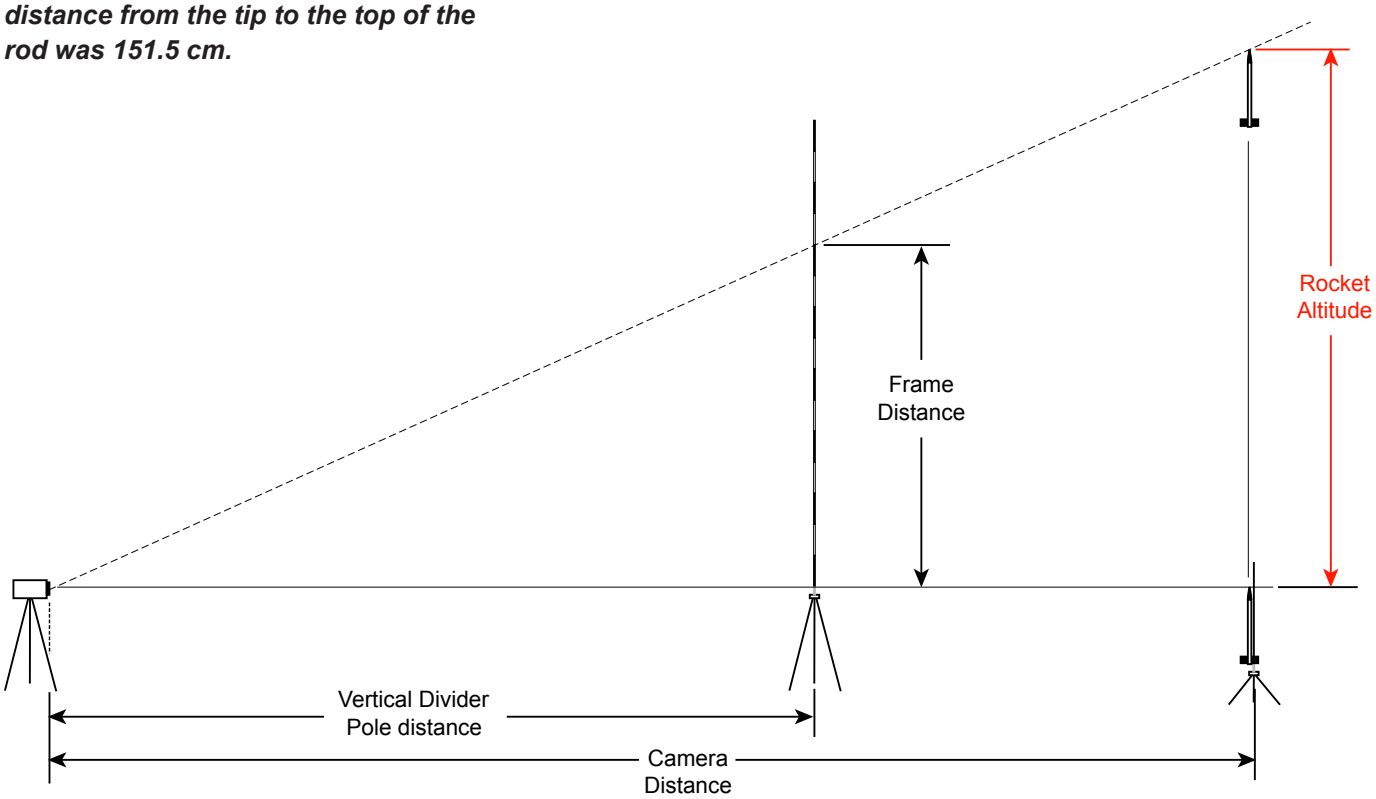
Second Round of Flight Tests

With the vertical divider pole in hand, I performed one simple launch to prove the system worked.

As with the first set of flight tests, I positioned the pole between the camera and launch pad, but this time I measured the distances before launching the rockets. In my case, the distance from the pad to the vertical divider pole was 16.80 meters, and the camera was another 3.22 meters further as shown in Photo #49. This put the Aiptek camera 20.02 meters from the launch pad.

Again, I pointed the lens to look directly at the pad, and also about the same level above the ground as the launch pad, and the zero point on the vertical divider pole.

With the video camera running at 60 frames per second, I launched the rocket. Since the rocket had 3° canted fins, it went nearly perfectly straight up as show in the photos (#49 through #52).



Drawing #3: The layout of Method #2 to determine a rocket's altitude and speed using a video camera.

Once the video was downloaded from the camera to the computer and I could see the results, I quickly realized that this process worked really well. The rocket stayed in the field of view for a good 28 frames following first-motion, and took a path that was parallel to the vertical divider pole.

Post Processing of the video from the Second Launch Day

The video post processing of the second launch day was much like the one from the first day of launches. It is downloaded from the camera to the computer and then played in the QuickTime software. Each frame is then captured and converted into a picture. As mentioned before, with the “pro” version of QuickTime, the video frames can be exported in one chunk to individual picture files, which saves a massive amount of time compared to screen shots.

The individual frame images were then opened in the vector drawing program (Adobe Illustrator, or Inkscape) for analysis.

One thing that I did different is to use the tip of the nose cone as the reference point as shown in Photo #54. In the first round of experiments, I used the base of the rocket to make measurements. I just made this change because it was easier to see the tip of the nose cone while the rocket was sitting on the pad awaiting launch. The tip of the nose cone at rest was now the “zero-altitude point.”

Next I annotated the image, so that I knew how high up each of the divisions on the vertical divider pole was. The first division was not at 10 cm, because the pole had to be fastened to the tripod. To find out where the first division was, I made a scale by dividing one black band into 10 parts. See the arrow shown in Photo #55 on the next page. Each part should then be 1 cm. I used this “scale” to find out where that first division was from the zero point. It turned out to be 1.5 cm from the zero point. So all my divisions in the image would have add 1.5 cm to the measurements to get the actual height.

Having the drawing annotated to show this skewing of the data was helpful to make measurement.

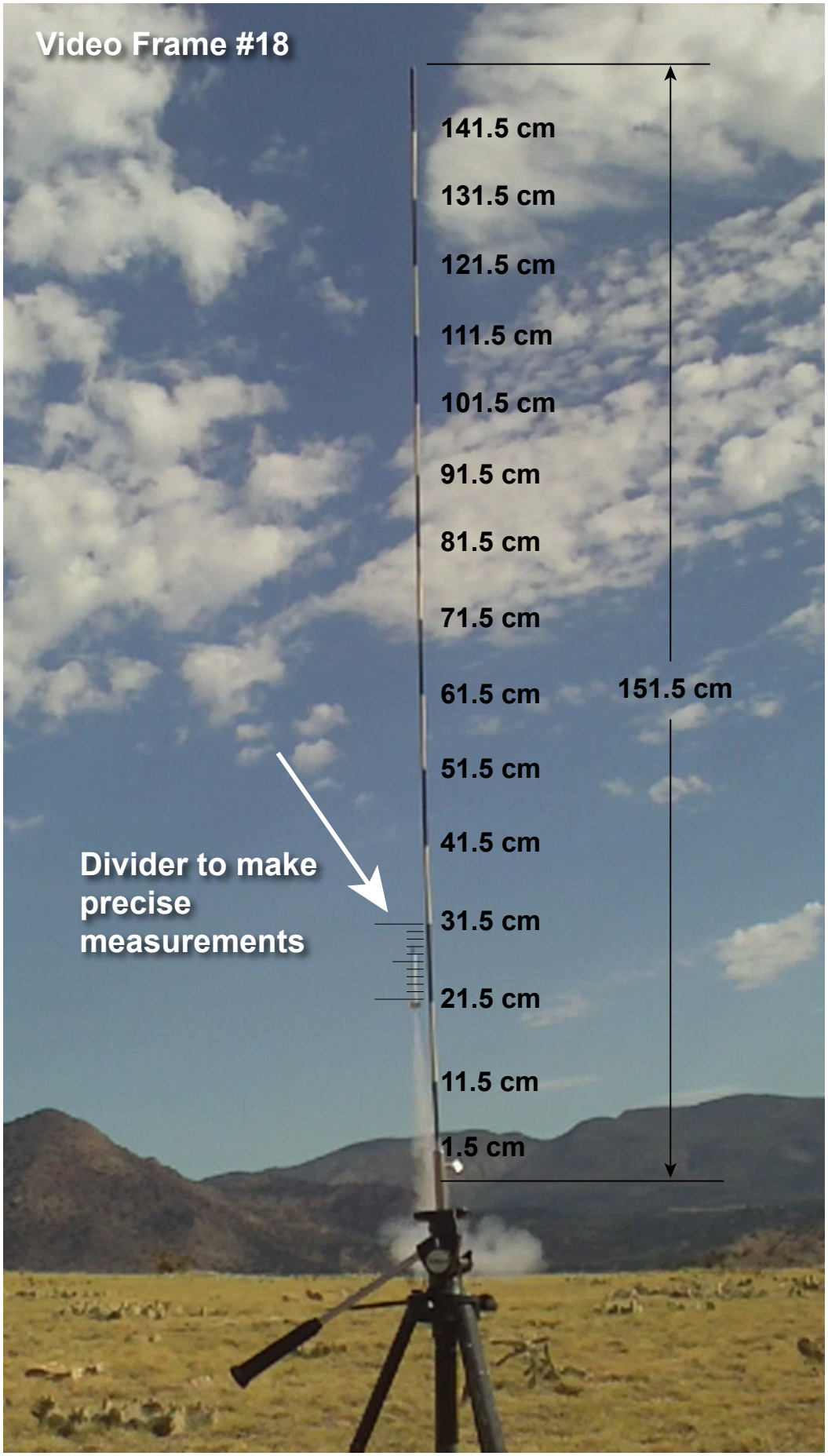


Photo #55: A still image taken from the video (Frame #18). The image has been annotated to show the height of the rocket compared to the height of the vertical divider pole. A divider (the small scale on the left side) was added to get finer measurements of the distance the rocket traveled.

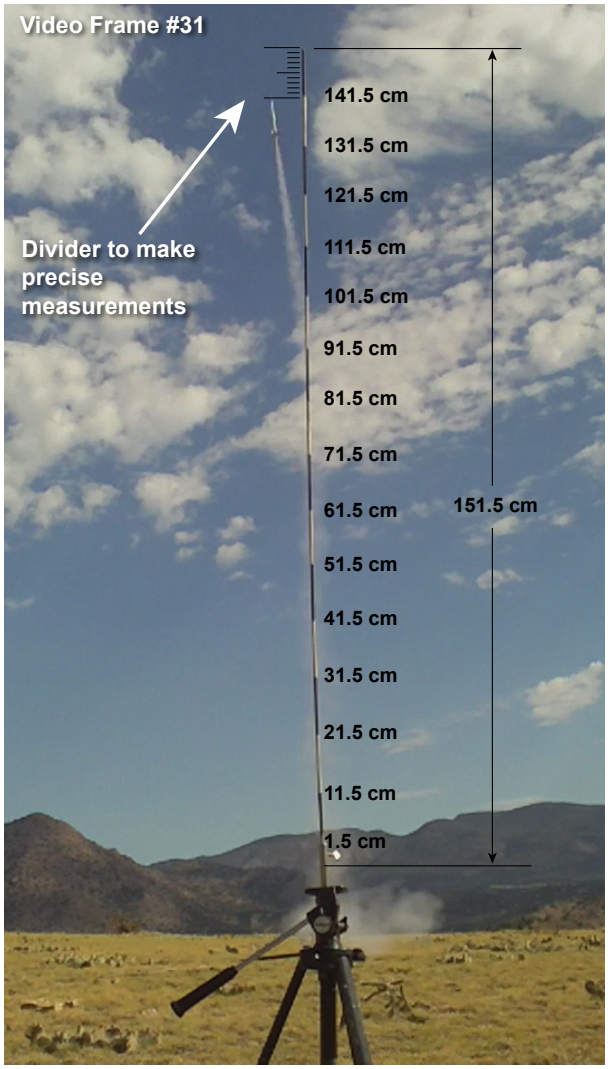


Photo #56: Another sample frame from the video showing the rocket's position compared to the vertical divider pole.

At that point, it was a matter of going through the frames one by one, and measuring how far up the tip of the nose cone had moved compared to the initial launch location. Photos #54 through #56 show a couple of frames from the video. As can be seen, I also used the cm-divider to get more precise measurements of the nose cone's position in altitude.

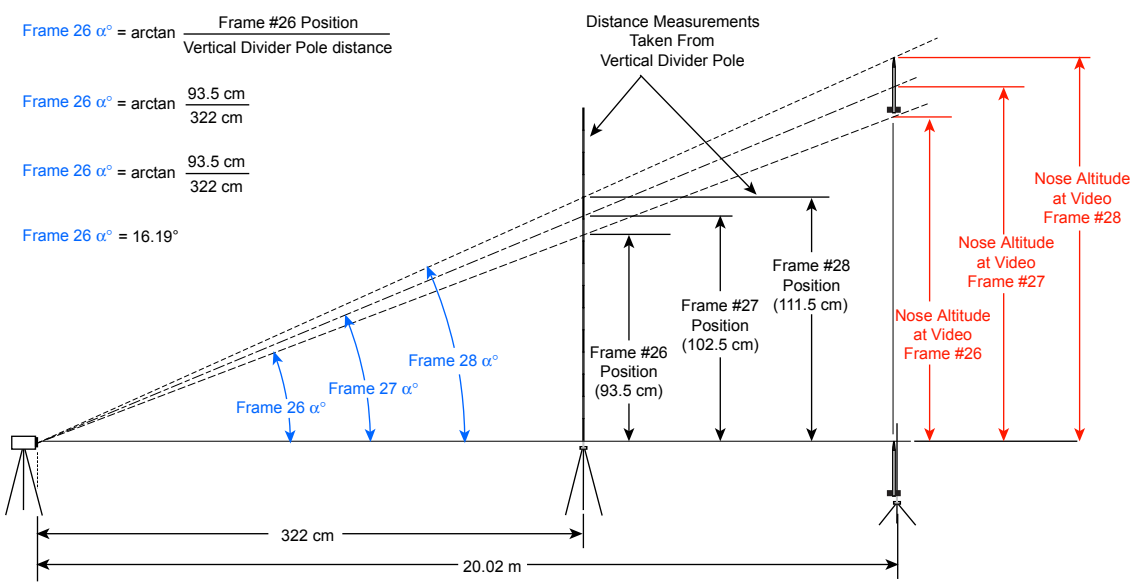
From here, I made a chart showing the position of the nose cone at each frame during the flight while the rocket was in the field of view. When the rocket rose above the vertical divider pole height, I just took the cm-divider, and slid it upward to make additional measurements. I put these measurements into a spreadsheet, as shown in Chart 2 on page 29.

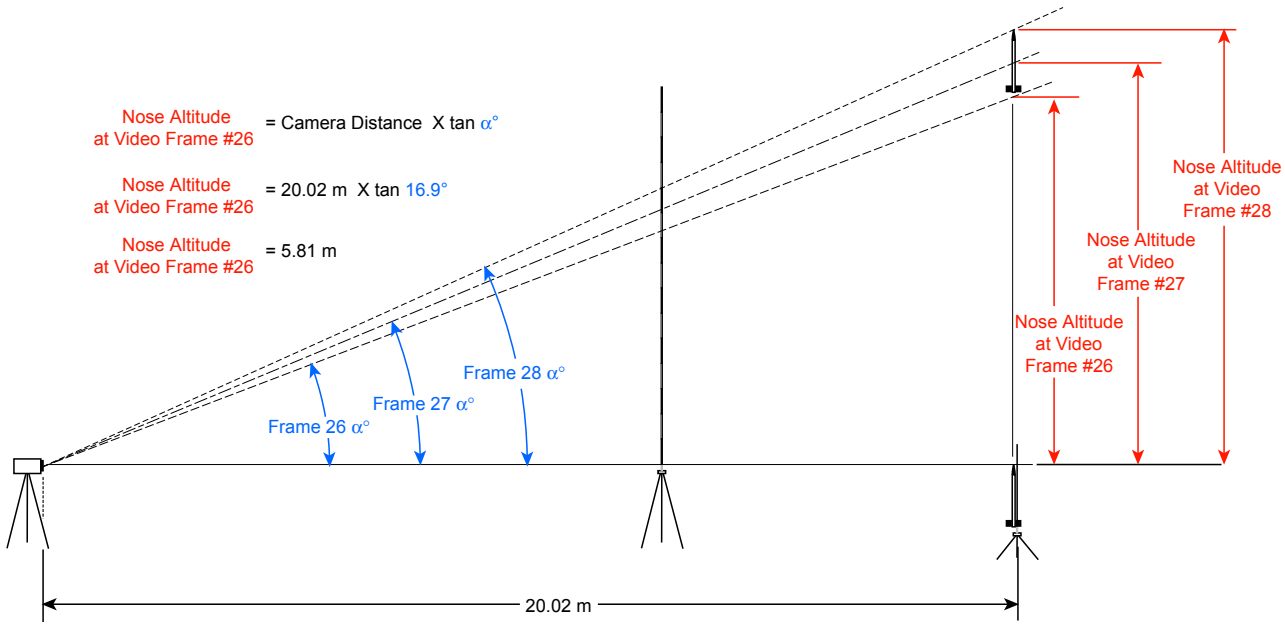
Once the divider heights were known for each frame of the video, I could then create a spreadsheet formula to calculate the actual height of the rocket off the pad in meters.

To derive the formulas for the spreadsheets, I've included a few drawings to explain the process. First, we have to find out the angle of the triangles where the apex is at the camera lens. (Drawing #3).

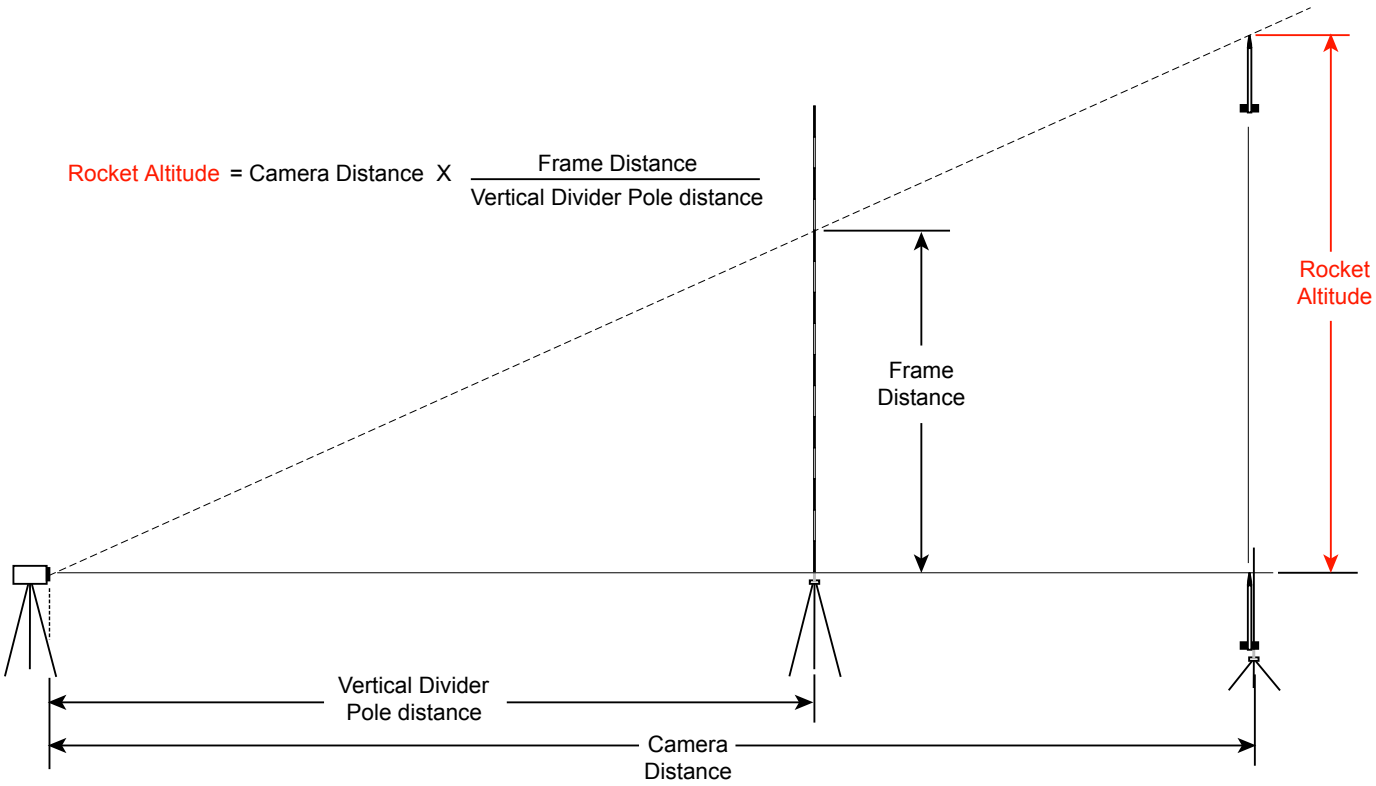
In Drawing #4, I have the distance measurements from video frames #26 through #28. In Drawings #5 and #6, we see how this leads to a formula that we'll plug into the spreadsheet (chart #2 on page 29) to find the altitude of the rocket at each point in the video.

Drawing #4 (below): The launch angle is the first part that needs to be computed from the distance measured in the video frames, and the baseline from the camera to the vertical divider pole. This same angle will be used to compute the altitude of the rocket.





Drawing #5: Once the launch angle is know, we can now use trigonometry to figure out the altitude of the rocket. Note that you have to calculate a new launch angle for each frame of the video to find the altitude of the rocket at that point in the flight.



Drawing #6: By doing some substitution of terms, we can get rid of all the trigonometry. The rocket's altitude is found using some simple multiplication and division. This formula is then plugged into the spreadsheet to make the process go faster.

Video Analysis

Camera Distance (m)		20.02			
Vertical Divider Pole Distance (m)		3.22			
Camera Frame Rate (frame/sec)		59.94			
Lift-off Time (s)		Measured Frame Distance (m)	Calculated Rocket Alt. (m)	Calculated Speed (m/s)	Acceleration (m/s/s)
-0.117	Frame #1 Distance	0	0.00	0.00	0
-0.100	Frame #2 Distance	0	0.00	0.00	0.00
-0.083	Frame #3 Distance	0	0.00	0.00	0.00
-0.033	Frame #4 Distance	0	0.00	0.00	0.00
-0.017	Frame #5 Distance	0	0.00	0.00	0.00
0.000	Frame #6 Distance	0	0.00	0.00	0.00
0.017	Frame #7 Distance	0.0025	0.02	0.93	55.84
0.033	Frame #8 Distance	0.0055	0.03	1.12	11.17
0.050	Frame #9 Distance	0.0075	0.05	0.75	-22.34
0.067	Frame #10 Distance	0.01	0.06	0.93	11.17
0.083	Frame #11 Distance	0.015	0.09	1.86	55.84
0.100	Frame #12 Distance	0.03	0.19	5.59	223.38
0.117	Frame #13 Distance	0.06	0.37	11.18	335.07
0.133	Frame #14 Distance	0.09	0.56	11.18	0.00
0.150	Frame #15 Distance	0.13	0.81	14.91	223.38
0.167	Frame #16 Distance	0.175	1.09	16.77	111.69
0.184	Frame #17 Distance	0.225	1.40	18.63	111.69
0.200	Frame #18 Distance	0.29	1.80	24.22	335.07
0.217	Frame #19 Distance	0.355	2.21	24.22	0.00
0.234	Frame #20 Distance	0.425	2.64	26.09	111.69
0.250	Frame #21 Distance	0.5	3.11	27.95	111.69
0.267	Frame #22 Distance	0.58	3.61	29.81	111.69
0.284	Frame #23 Distance	0.66	4.10	29.81	0.00
0.300	Frame #24 Distance	0.745	4.63	31.68	111.69
0.317	Frame #25 Distance	0.825	5.13	29.81	-111.69
0.334	Frame #26 Distance	0.925	5.75	37.27	446.76
0.350	Frame #27 Distance	1.025	6.37	37.27	0.00
0.367	Frame #28 Distance	1.115	6.93	33.54	-223.38
0.384	Frame #29 Distance	1.215	7.55	37.27	223.38
0.400	Frame #30 Distance	1.315	8.18	37.27	0.00
0.417	Frame #31 Distance	1.42	8.83	39.13	111.69
0.434	Frame #32 Distance	1.52	9.45	37.27	-111.69
0.450	Frame #33 Distance	1.63	10.13	40.99	223.38
0.467	Frame #34 Distance	Out of frame			
0.484	Frame #35 Distance	Out of frame			
0.501	Frame #36 Distance	Out of frame			

Chart 2: This shows the altitude, speed, and acceleration that were found using video analysis. The highlighted number will be used to compare against Rocksim's predictions (shown in chart 4)

I know had altitude and time from lift-off of each frame image. From this, the rocket's speed in each frame was calculated shown also in Chart 2. The formula that I plugged into the spreadsheet is: *Speed is equal to the distance traveled between frames multiplied by the frame rate of the camera.*

I also made an attempt to determine the acceleration of the rocket between video frames. This is the change in speed between frames divided by the time between frame images. Again, this is shown in Chart 2.

As can seen, the acceleration numbers are a little jumpy, and I'm not exactly sure why this is. Other than measurement errors, my best guess is that the motor is not burning consistently to match the expected thrust curve of the engine.

Comparison – How Accurate Is This Method Of Altitude and Speed Determination?

I don't have accurate speed and altitude measurements to compare against, as that would require some sort of sophisticated radar or Doppler measurement device. So I can't say how accurate this method is.

All I can do is compare against the theoretical values from an altitude prediction software like RockSim (http://www.apogeerockets.com/rocksim.asp).

I input the rocket design into RockSim, and then used the AltimeterTwo data from the final flight (shown in Chart 3) to tweak the design. In other words, I knew how high the flight got (420 feet, as measured by the AltimeterTwo, with a top speed of 152 miles per hour). The only real adjustment you can make in RockSim is to alter the Coefficient of Drag. In this case, I had to adjust it up to 1.60 to get it to fly to 422 feet on a B6-6 motor.

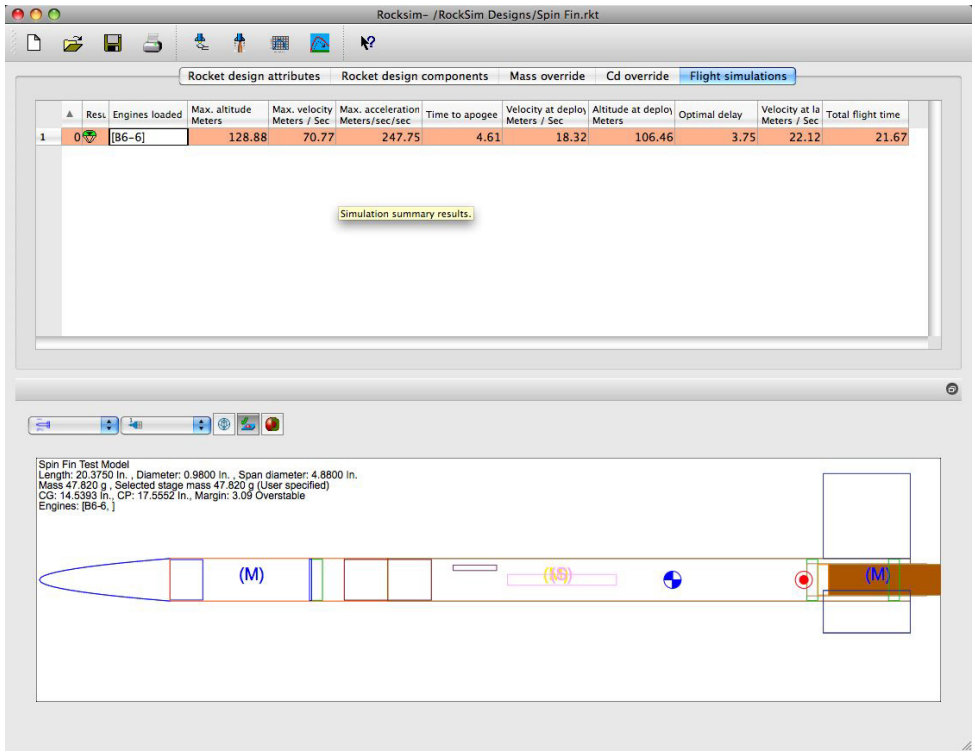


Photo #57: RockSim screenshot showing the estimation of altitude of the rocket using a B6-6 motor with a Cd of 1.6. This Cd value was entered to match the altitude data recorded by the AltimeterTwo payload.

Fin Cant Angle	3°
Rocket #	5
Motor Used	B6-6
Apogee Alt.	420 ft
Top Speed	152 mph
Burn Time	0.9
Peak Accel	20.2 G
Avg Accel	7.4 G
Coast 2 Apogee	4.6 sec
Apogee 2 Eject	-.4 sec
Ejection Alt.	416 ft
Descent Speed	13 mph
Flight Dur	26.5 sec
Temp	79° F
Wind	1.5 mph

Chart 3: AltimeterTwo data taken from the final flight that was used to compare the Video Analysis versus RockSim predictions.

Time	Altitude Meters	Velocity Meters / Sec	Acceleration Meters/sec/sec
0.000	0	0	0
0.028	0	0.055	19.291
0.055	0.01	0.748	49.278
0.083	0.052	2.422	91.026
0.110	0.157	5.358	141.633
0.138	0.364	9.71	191.391
0.165	0.71	15.452	245.231
0.193	1.232	22.119	244.65
0.220	1.922	27.516	176.442
0.248	2.739	31.538	140.998
0.275	3.654	34.848	123.363
0.303	4.656	37.782	110.142
0.330	5.733	40.422	102.237
0.358	6.88	42.858	94.838
0.385	8.091	45.101	89.188
0.413	9.363	47.247	86.577
0.440	10.692	49.321	83.927
0.468	12.077	51.322	81.249
0.495	13.517	53.256	79.323
0.523	15.008	55.146	77.773
0.550	16.552	56.994	76.191
0.578	18.145	58.797	74.583
0.605	19.787	60.548	72.333
0.633	21.477	62.235	70.019
0.660	23.212	63.858	67.711
0.688	24.99	65.409	64.325
0.715	26.81	66.85	60.267
0.743	28.668	68.181	56.283
0.770	30.561	69.449	55.94

Chart 3: This is RockSim's estimation of altitude, velocity, and acceleration for the time period for which the rocket was in the field of view of the video camera. The highlighted row is used to compare against the data obtained through video analysis.

Once RockSim's peak altitude matched the altitude read on the AltimeterTwo, I simply exported out the simulation data for the first few seconds of flight.

Chart 4 on the next page shows the results of the RockSim simulation data.

This data is now compared against the findings from my video analysis. I take a point at 0.3 seconds into the flight to make the comparison. At that point, RockSim predicts the rocket should be 4.65 meters high. From the video analysis, I measured the altitude to be 4.63 meters high – a difference of only 2 cm!

Velocity at 0.3 seconds should be 37.7 m/s as estimated by RockSim. From the video analysis, the speed was 31.68 m/s. While this is a little slower than anticipated, I was still pleased that it seemed to be in the ballpark.

The acceleration was also in the acceptable category as far as I was concerned. RockSim estimates 110.1 m/s/s, where the video analysis indicates 111.69 m/s/s.

Results Obtained

As shown through this report, using an inexpensive video camera, a home-made vertical divider pole, a tape measurer and some simple software, one can find out a lot about the initial trajectory of the rocket, including altitude, speed, and acceleration. This would be extremely useful for people that want to know more about the physical flight characteristics of their rockets, such as teachers and TARC teams.

Related R&D reports

No related R&D reports were found, nor were any done by this author on this subject of video analysis.

References:

69 Simple Science Fair Projects With Model Rockets by Timothy S. Van Milligan. ©1996. Apogee Components, inc. This book hinted at this method of finding speed of a rocket using a series of parallel bars indicate certain heights in the sky.

Model Rocket Design and Construction, Third Edition by Timothy S. Van Milligan. ©2008, Apogee Components, Inc.

Measuring the Speed of A Model Rocket in Flight by Chuck Mund. *Model Rocketeer Magazine*, May 1982.

Throw Your Rockets Out the Window by Tom Milkie. *Model Rocketry Magazine*, February, 1970.

Equipement Used

6 custom-built rockets (dimensions: 24mm diameter X 20.375 inches long, 29.6 g empty weight)

Jolly Logic AltimeterTwo altimeter (2)

B6-6 rocket motors (4 packs)

Aiptek HD video camera

4-foot long 3/16” diameter launch rod

Camera Tripod (2)

Odd’l Rockets Tripod Adapter (http://www.apogeerockets.com/oddl_adeptor.asp)

Quicktime Video Software (from Apple Computer)

Adobe Illustrator Software

Spreadsheet software (Microsoft Excel)

Extech Mini Termo-Anemoneter to take temperature and wind speed measurements

Facilities Used

No special facilities were required for this experiment.

Launches were conducted at the Tripoli Colorado launch site in Hartsel, Colorado, and a secret rocket launch location near Cañon City, Colorado.

Post-launch data analysis was done at my home.

Money Spent

$41.92	Estes B6-6 rocket engines at $10.48 per pack
$139.90	Jolly Logic Altimeter Two (2 req. at $69.95 each)
$12.00	Odd'l Rocket's Tripod Adapter
$35.00	Estimated amount to build 6 rockets.

$228.82	Total

Data Collected

The collected was presented in the body of this document.

Conclusions Drawn

Video analysis can really come in handy in not only determining speed and altitude (which might be found with accelerometer based payloads), but you also get the orientation and how the rocket reacts to disturbances. This information is something that you couldn't get from other forms of data acquisition.

Video analysis is also excellent as a teaching aid for teachers. It matches the physics with something real-world that students can see and get excited about.

Helpful tips when setting up a video camera to track a model rocket.

1. Don't be fooled by the smoke trail when watching the video. The wind, blowing the smoke, can make the trajectory seem worse than it actually is. A lot of the photos make it appear the rocket has started turning, but it is the wind blowing the smoke that gives it an optical illusion that the rocket has moved.

2. Make sure you measure the ground distances to the vertical divider pole and to the camera accurately. Also make sure that the camera is at the same level as the rocket when it is sitting on the pad. This will lessen the errors in finding altitudes.

3. The further back the camera is from the rocket, the longer the vehicle will remain in the lens' field-of-view. How-

ever, the rocket will be smaller in the video image and may be harder to distinguish.

4. The vertical divider pole should have as many divisions on it as possible (or practical). This will make it easier to make a comparison as to how high the rocket really is in the sky.

5. The closer to the pad the vertical divider pole is, the more accurate the measurements will be. But that really requires the use of a longer vertical divider.

6. If there is any wind, you want the camera and the vertical divider pole situated on a cross-wind orientation. You want the rocket to weathercock to the side on the field of view, and not come toward or away from the camera's position.

Further Work

From this procedure of measuring height and speed, it should be possible to back-track a coefficient-of-drag for a given rocket without having to stick a model into a wind tunnel.

Super-sonic flights – This method might be a reasonable way of determining whether or not a rocket achieved supersonic speed. This would be particularly useful in small rockets that can't tolerate additional weight of an accelerometer based payload to measure speed.