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Using Video To Measure A Rocket's Speed

By Tim Van Milligan

For my NARAM 53 R&D report, I did a project on how to determine a rocket's orientation, height, speed, and acceleration from a video camera. This process has a number of uses. For example, TARC teams might want to use the data to back-track an accurate coefficient of drag from a model rocket's flight, or a NAR member might want to use the process for determining how a piston launcher affects the lift-off speed of their rocket. For teachers, this is a great project that they can duplicate in their classroom to demonstrate how speed is calculated from a change in position, and acceleration is determined from a change in speed.

It is all really cool stuff, and I had a lot of fun putting together this R&D report (I got to launch rockets!). In this article, I'll highlight the major sections of the report and skip all the back-ground work. If you would like to read the unedited version, you can download the full report at: ApogeeRockets.com/education/r_and_d_projects.asp. I also recommend gettting the full CD-ROM from NARTS that includes all the R&D projects that were presented at NARAM. You'll find them at: www.nar.org/NARTS/.

Equipment Needed

For starters, you're going to need a video camera and a tripod to sit it on. I used the Aiptek HD video camera. I bought it about two years ago for around $120. The reason I picked this camera was that it had a high-speed mode which allows it to take 60 video frames per second. This is twice the speed of an ordinary camera. The faster the speed, the more accurate your results will be. Because of this, I envy Chris Taylor, who had a 600 frame per second video camera at NARAM, and was getting some great videos for his website: www.NARAMlive.com. Check out his YouTube channel at: www.youtube.com/user/naramlive53.

Photo 1: Inexpensive video camera used in this project.

However, even a regular video camera will yield reasonably good data if you set it up correctly on the field.

The other unique piece of equipment you'll need is a long rod or pole to use as a reference length. The longer the pole, the better, because it will allow you to track more of the flight, for more data to analyze. I used a 5 foot long launch rod.

You'll also need to mount the pole/rod vertically in front of the video camera. For this, I used the Odd'l Rockets "Adeptor" Tripod Launch Pad Adapter (www.ApogeeRockets.com/oddl_adeptor.asp) to mount the rod to a second tripod.

One last thing that really helps is to mark distance measuresments on the pole. I used a spacing of 10 cm on the pole, because it was far enough apart to distinguish in the video. To make the marks, I simply wrapped the pole in masking tape, and colored alternating sections of the pole with a black permanent marker (see Photo 2). For lack of a spiffy name, I simply called this rod the "Vertical Divider Pole".

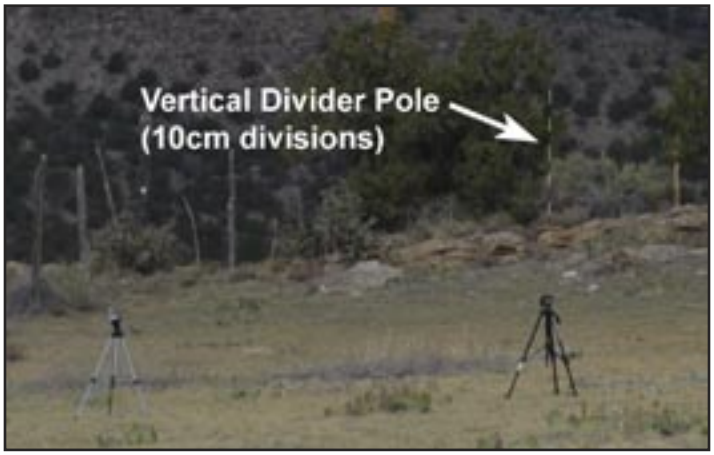

Photo 2: The Vertical Divider Pole set up in front of the video camera.

The final piece of equipment is a tape measure. You'll need it to measure some ground distances, which I'll talk about next.

Launch Site Set-Up

Set-up of the equipment is pretty easy. Basically, you'll

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put the Vertical Divider Pole in front of the video camera, so that the image in the viewfield of the camera shows the full length of the pole. In the distance, directly behind the Vertical Divider Pole, is the launch pad.

Figure 1 shows the basic set-up, and the two ground measurements you'll have to make: 1) the camera's distance from the launch pad, and 2) the distance the vertical divider pole is from the front of the camera lens.

What we desire to find in Figure 1 is the "Rocket Altitude." We'll compute this value by first finding the distance the rocket moves in the video frame (called the "frame distance"). At that point, it is a simple matter of using similar triangles to actually find the rocket's altitude. There is really

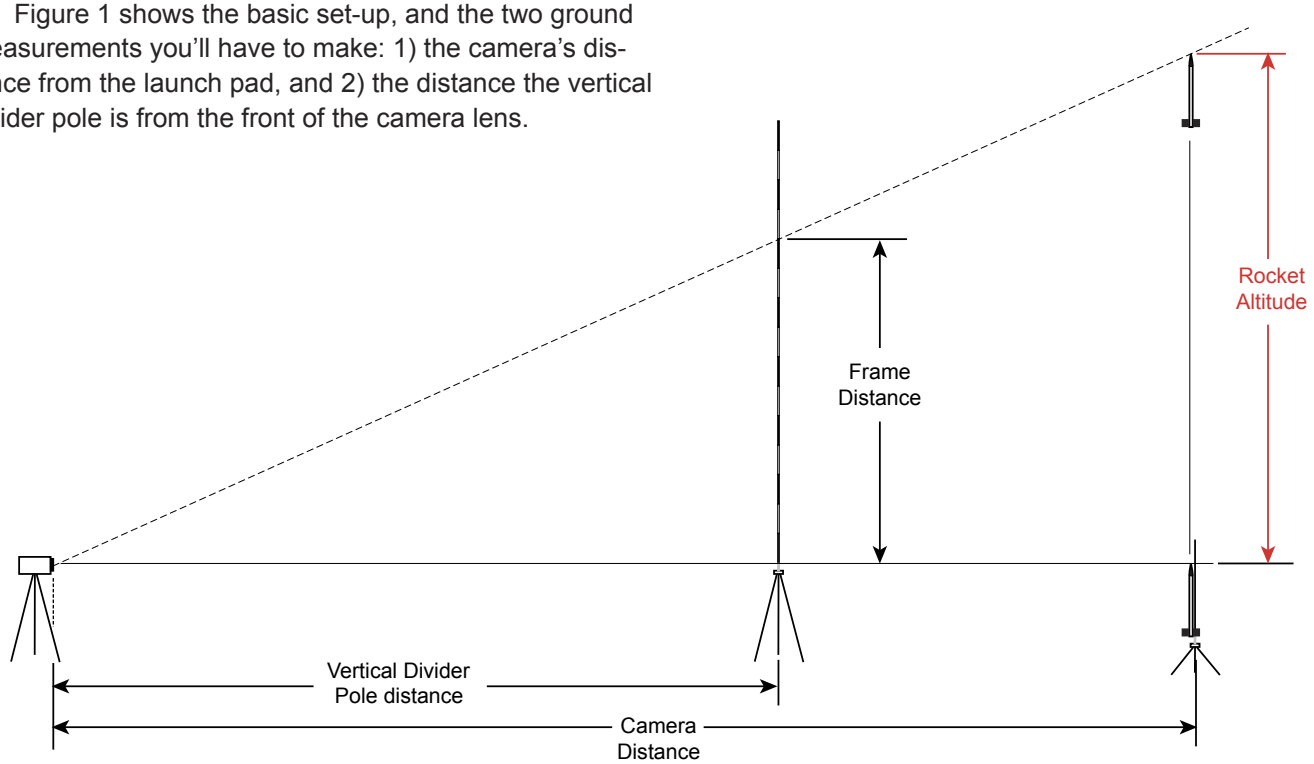

Figure 1: Range layout, showing where to position the camera and the Vertical Divider Pole. You'll measure the two distances from the front of the camera lens.

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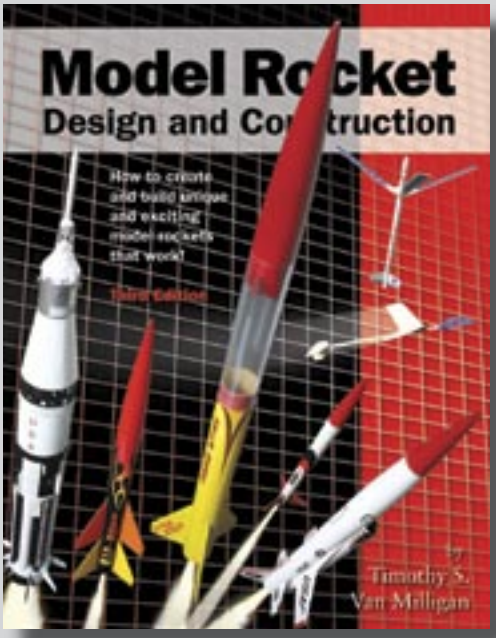

Model Rocket Design and Construction

By Timothy S. Van Milligan

New 3rd Edition Now Shipping!

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

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

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no trigonometry or hard math involved at all. Just a little bit of mulitplication and division.

The one thing you should try to do is to make sure that the camera lens, the zero point on the vertical divider pole and the tip of the nose cone are all on the same plane (see Figure 1). This greatly reduces error in the results. You could use the base of the rocket as a reference point, but I used the nose tip because it was easy to see in the video, and because the it was higher up in the air and closer to the level at which the camera lense was located. It was just more convenient.

Photo 3 shows a picture of what the camera sees. The rocket is partially obscured by the vertical divider pole and its tripod. The tip of the nose cone is just barely seen to the bottom left.

Note that the camera must be oriented sideways on the tripod, so that the aspect ratio of the image has more vertical orientation. When you play the video back, the rocket will look like it is going horizontal. So you'll have to rotate the image later. I've already done this in Photo 3 so that it looks like it is in the proper launch orientation.

When everything is set up and the camera is turned on, you can go ahead and simply launch the rocket. Just remember, if your camera has a high-speed mode, make sure to turn it on, and note the actual frame rate.

Post Processing

Launching is the easy part of this process. Now you'll have to take your camera back home and do the post-processing.

To view the video after it was downloaded into the computer, I used Apple's QuickTime software. There is a free version available from Apple

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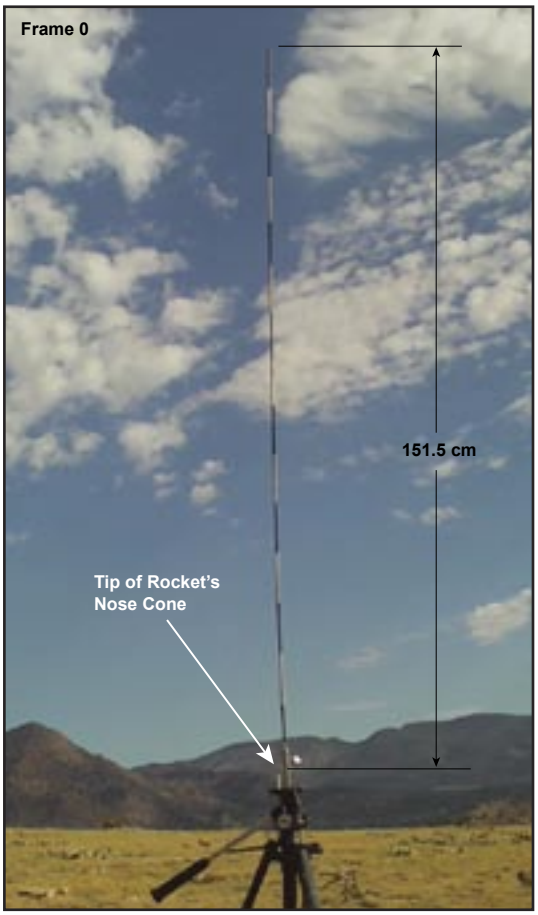

Photo 3: The video camera's field of view (turned sideways to get more vertical distance).

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Computer (www.Apple.com/quicktime) that will work on both Windows and Mac computers. The nice feature about QuickTime is that 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).

As said before, the video camera was mounted sideways on the tripod to get as much vertical "real-estate" into view as possible. When played back, the rocket flies sideways. Therefore, to make the "Frame Distance" 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.

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

In the video I made, the rocket appears in the 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 will be how you'll determine the time step for each video frame (1/59.94 = 0.017 seconds).

To add text annotations and call-outs to the images (as shown in Photo 3), I opened up the individual frame images in a drawing program. The software I like personally is Adobe Illustrator. But 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. 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-paste a lot to make the images look similar.

Next, I annotated the image (see Photo 4 on the next page), 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 secondary scale by dividing one black band into 10 parts. See the arrow shown in Photo 4. Each division should then be 1 cm apart. 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 to add 1.5 cm to the measurements to get the actual height. That's why the scale on the right side of the Vertical Divider Pole has such odd looking numbers on it.

Having the drawing annotated to show this skewing of the data was very helpful in making measurements.

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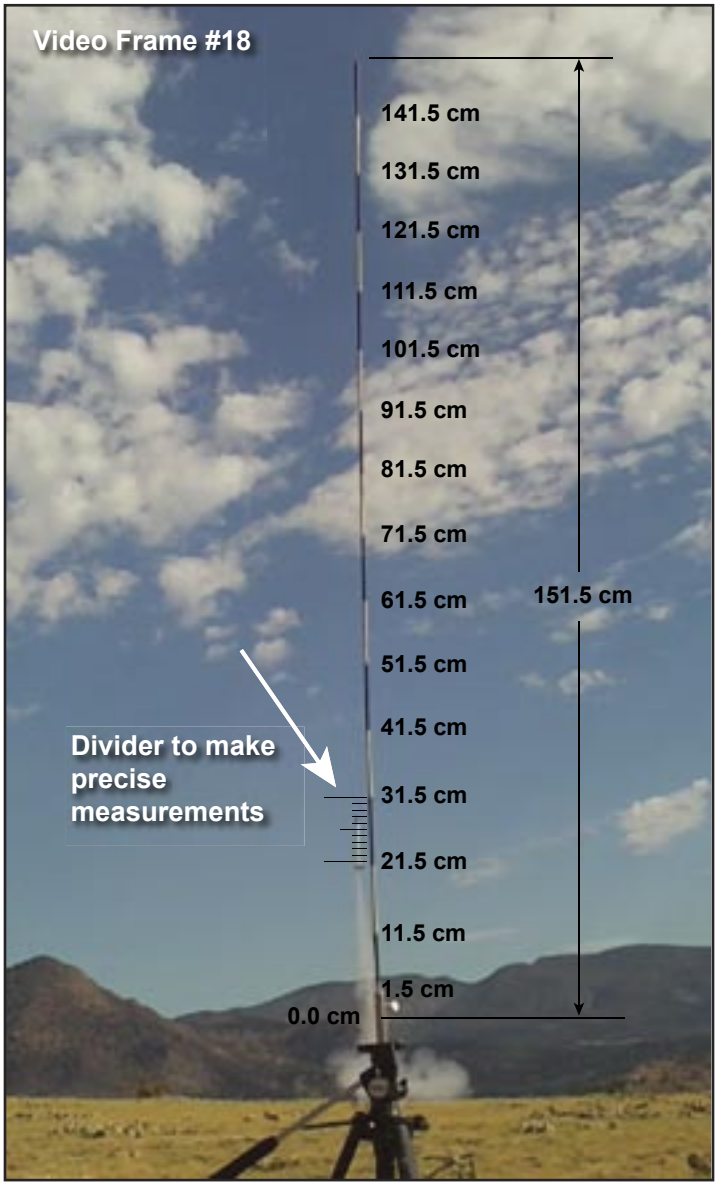

Photo 4

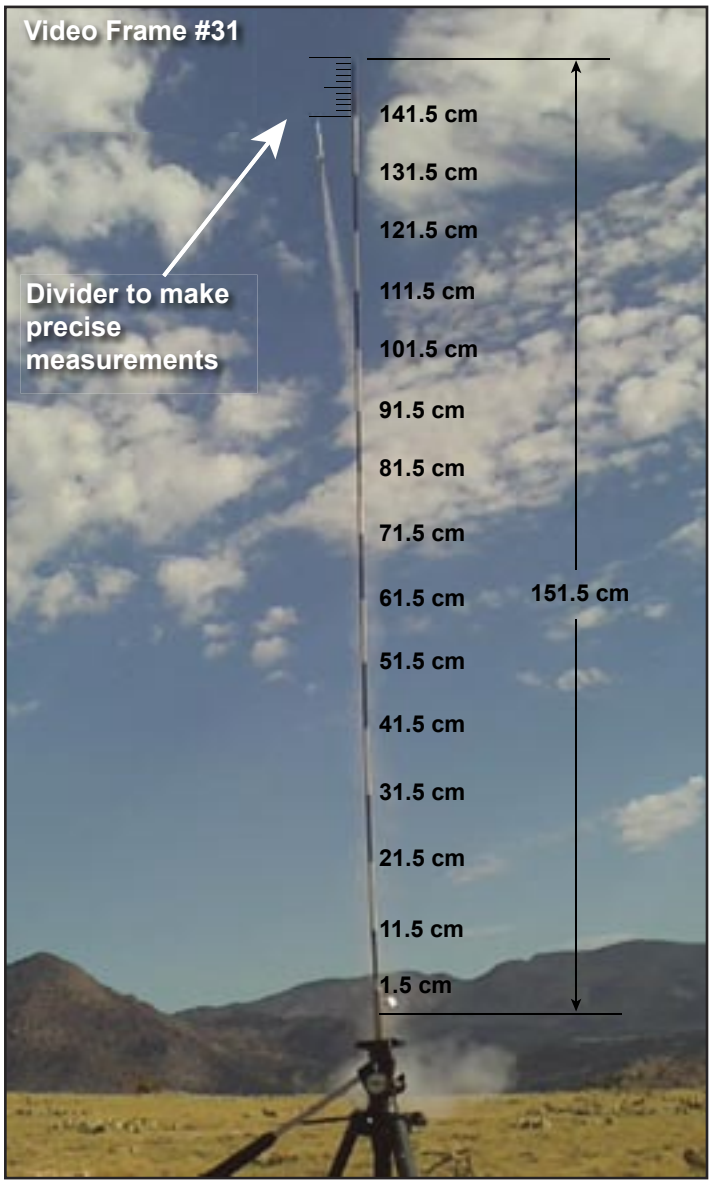

Photo 5

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www.ApogeeRockets.com/Newsletter_Guidelines.asp

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***From Previous Page* - Photo 4 (Left) and Photo 5: Still images taken from the video (frame #18 and frame #31). The images have 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.**

At this point, it is 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 4 and 5 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.

Obviously, you'll want to record the Frame Distance, so make a table showing the position of the nose cone at each frame during the flight while the rocket is in the field of view. When the rocket rises 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 Table 1 on the next page.

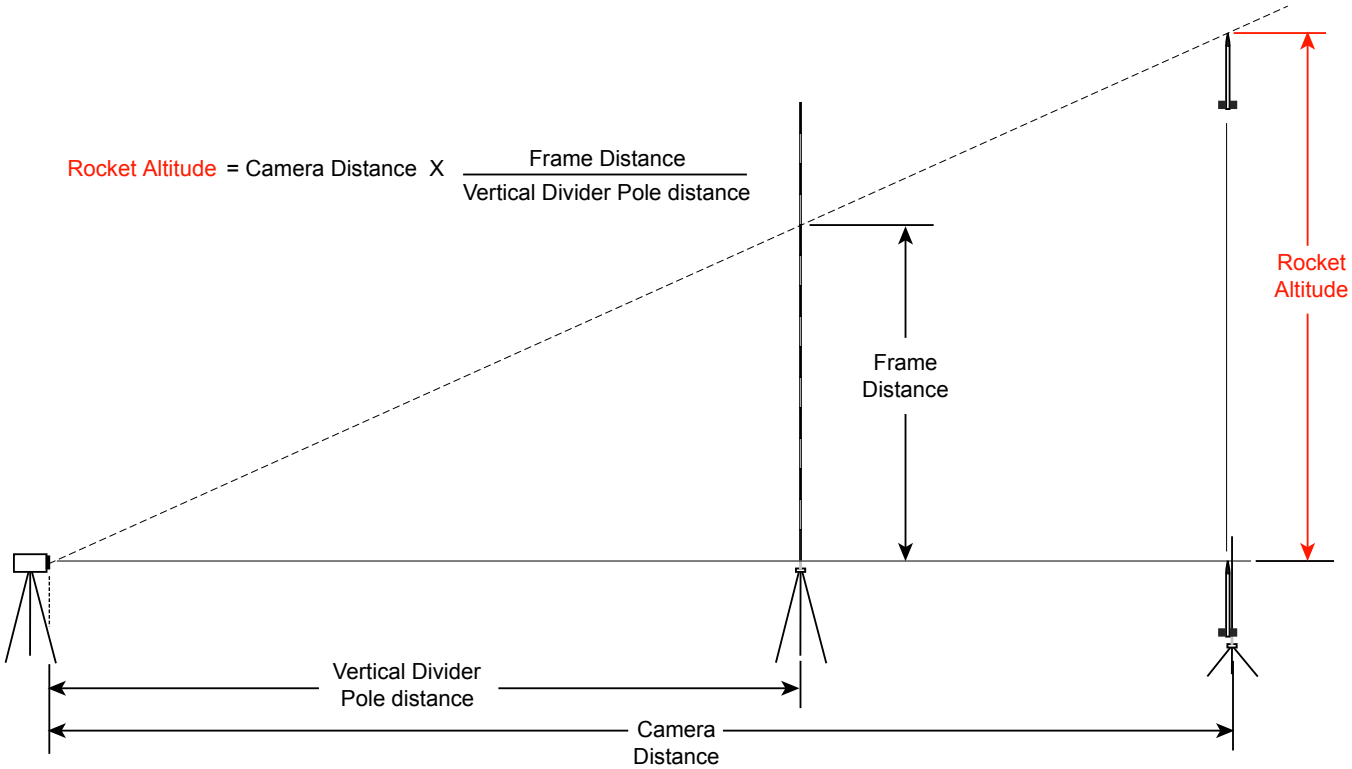

Figure 2: The rocket's altitude is found using the law of similar triangles. This formula is then plugged into a spreadsheet to make the process go faster.

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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. This is shown in Table 1.

I now had altitude and time from lift-off for each frame image. From this, the rocket's speed in each frame was calculated shown also in Table 1. 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 Table 1.

As can be 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 measure-

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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			

Table 1: Final data captured and computed from the video analysis.

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ments 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 (www.ApogeeRockets.com/rocksim.asp).

I input the rocket design into RockSim (Figure 3), and then used the AltimeterTwo data from the final flight (shown in Table 2) to tweak the design file. In other words, I knew how high the flight got (420 feet, as measured by the AltimeterTwo (www.ApogeeRockets.com/AltimeterTwo.asp), 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, which I used for this particular flight. What I wanted to do is to get RockSim to match the actual flight, so I could then compare it to the video analysis.

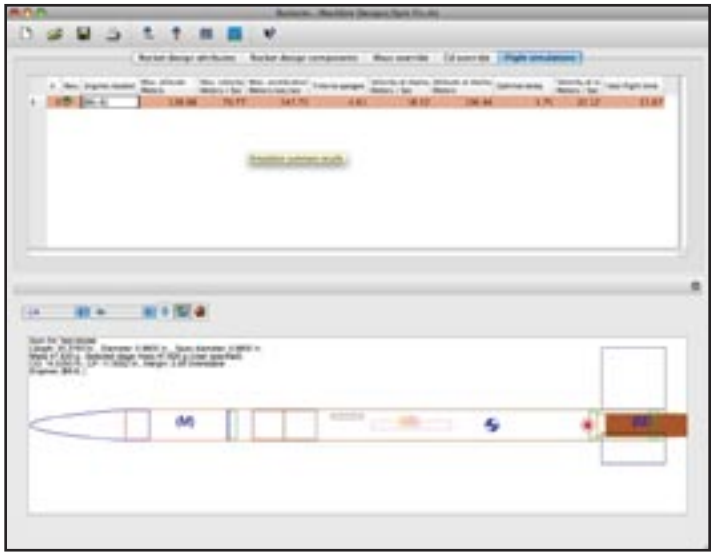

Figure 3: RockSim was used to compare the video analysis results with the theoretical values.

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

Table 2: Data recorded by the AltimeterTwo altimeter.

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.

Table 3 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 (Table 3) predicts the rocket should be 4.65 meters high. From the video analysis (Table 1), I measured

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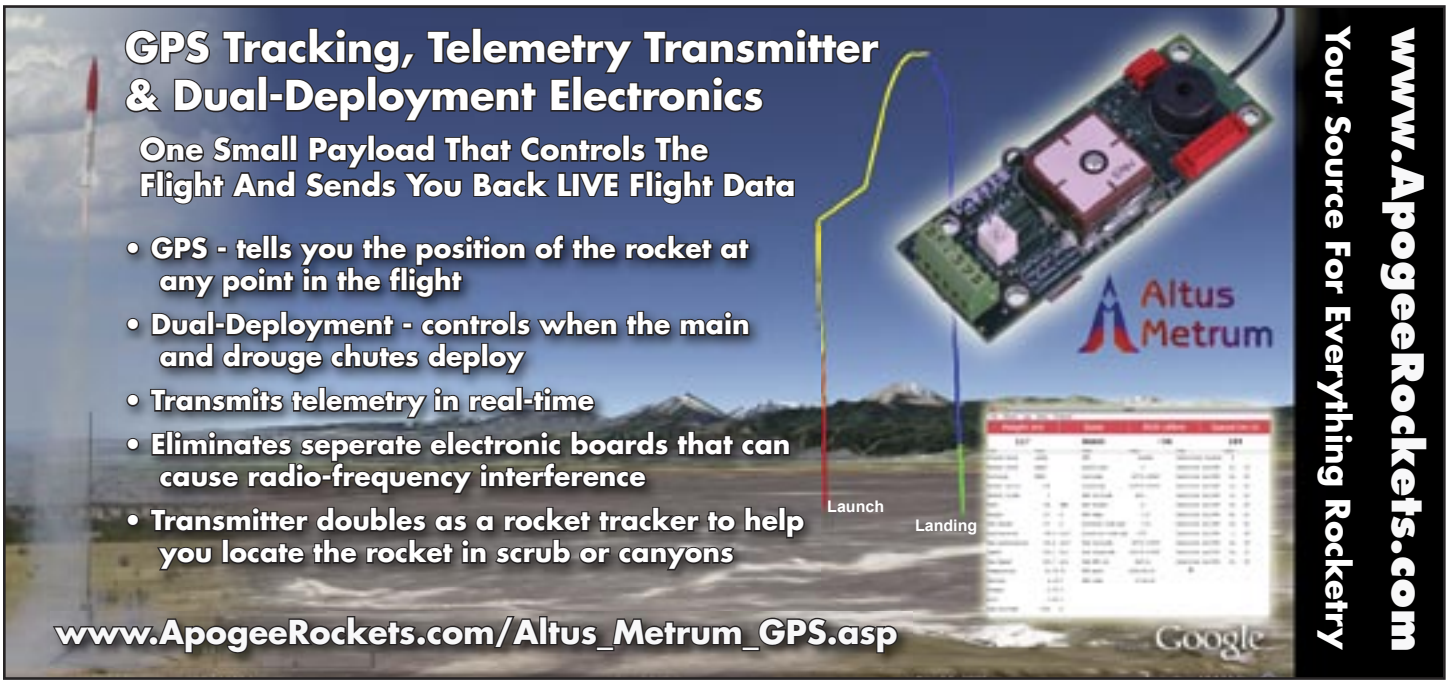

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the altitude to be 4.63 meters high – a difference of only 2 cm!

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.

Conclusion

I used RockSim to compare the video analysis results. But if you have a electronic payload that uses an accelerometer, you could also compare that data from the video analysis.

So in conclusion, I'd like to encourage you to give this a try. Video analysis is a great teaching tool for getting more "learning valule" out of your next launch. It allows you to extend the experiment from the launch field into the classroom.

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.

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

Table 3: The theoretical values from RockSim flight. Compare the values against Table 1 on page 8.