PEAK OF FLIGHT

NEWSLETTER

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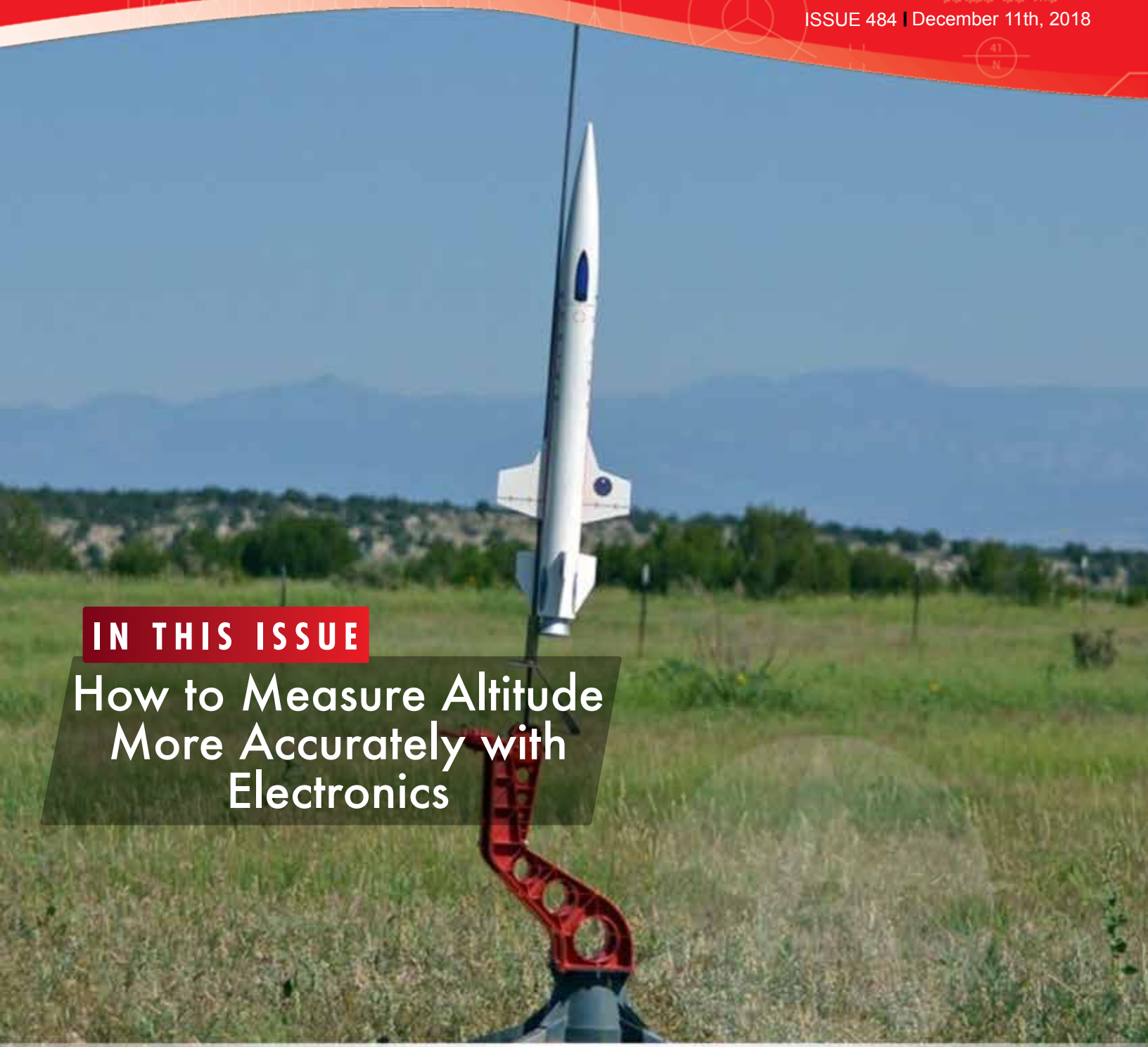

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PEAK OF FLIGHT

How to Measure Altitude More Accurately with Electronics

By Kenneth Karbon

Introduction

Here is the dirty little secret. Your altimeter is almost always wrong. Most rocketeers read the altitude report from their electronics and assume that is "real life." Not true. Barometric altimeters read pressure then simulate altitude with a model. Now you are thinking to yourself, "How can a measurement need a simulation?" Well, nothing is perfect in engineering, so assumptions need to be made in order to build a usable device.

Since altimeters read barometric pressure, the measurements are influenced by the local weather, such as storms, temperature, winds, and humidity. Pilots are keenly aware of these possible instrument errors, because they need to ensure safe take-offs, landings, and sharing of the airspace with other aircraft. However, the accuracy limitations of altimeters are rarely discussed in model rocketry.

This article will discuss ways to improve the accuracy of altimeters and also consider alternative electronic measurements like GPS. As a test case, I will use my personal best altitude flight which occurred on August 26, 2018 at the SMASH/MMAR club launch in Muskegon, MI. Shown in **Figure 1** is the familiar altitude vs. flight time plotted from the altimeter data download.

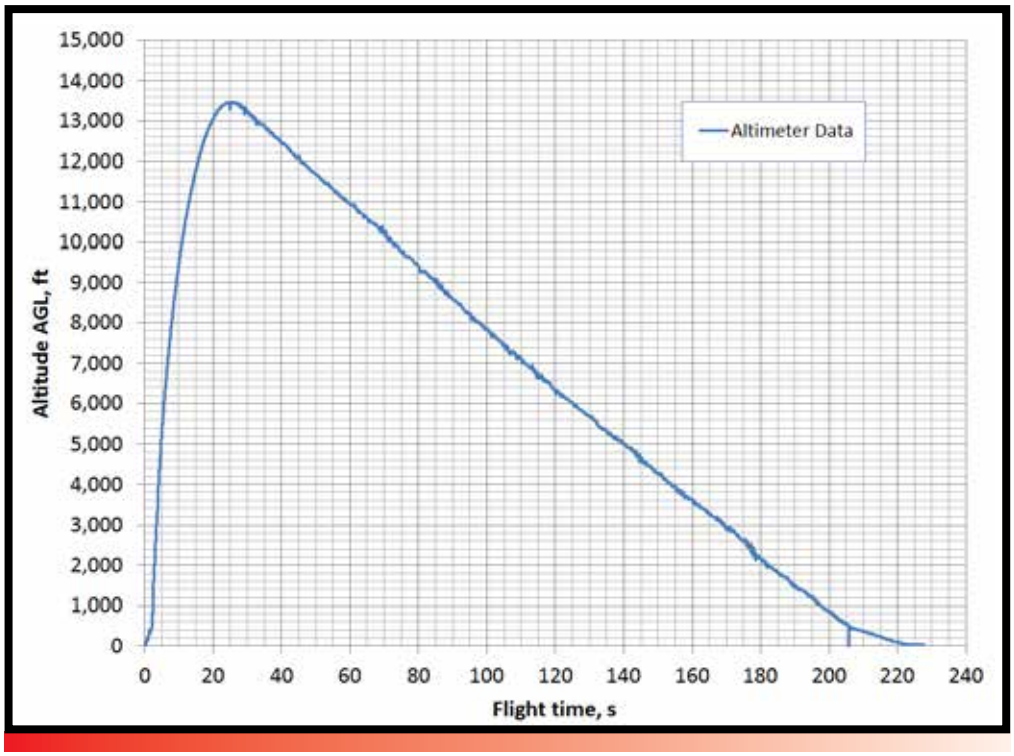

Figure 1: Altitude curve measured by barometric altimeter

Barometric Altimeter Models

Barometric altimeters have firmware or software programmed with a "Standard Atmosphere" model. This is a hypothetical column of air that is thought to represent average yearly conditions at the Earth's mid-latitudes. Through tables and formulas, the model estimates how the pressure, temperature, density, and viscosity of the atmosphere change over a range of altitudes or elevations. There are various models governed by different world organizations, such as the International Standard Atmosphere, and the US Standard Atmosphere, but the parameters are mostly identical in each. The altimeter measures air pressure then looks up the altitude from the model.

However, who flies a real rocket in hypothetical air? The atmospheric conditions on the day you launch a rocket are rarely, if ever, the same as the model used in your altimeter. This creates measurement error. Have you ever noticed how the launch site elevation reported by your altimeter is not identical to the elevation printed on a map? Perhaps you have seen this ground elevation measurement change from day to day or even hour by hour. This is all due to the deviations in real weather from the model.

Barometric altimeters usually report the difference in elevation between the ground and the rocket's flight, which is referred to as the altitude Above Ground Level (AGL). This subtraction is a good thing, because it tends to cancel out the errors between the real atmosphere and the modeled atmosphere. Thus, the altimeter gives reasonably good measurements for hobby rocketry. However, errors can still persist, especially at greater altitudes, on very hot or very cold days, or during other weather anomalies. If you are going for an altitude record, you can use this info to your advantage!

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About this Newsletter

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Global Positioning System (GPS) Models

A GPS tracker in your rocket can do more than just help you find it on the ground. In addition to latitude and longitude coordinates, GPS also records altitude during the flight. However, GPS measurement also requires simulation models, and it is important to know what elevation model is being used.

Your GPS device actually measures altitude with respect to the "ellipsoid." The ellipsoid is a mathematical, 3D shape used to approximate the Earth's surface. It looks similar to a flattened sphere, as in **Figure 2**.

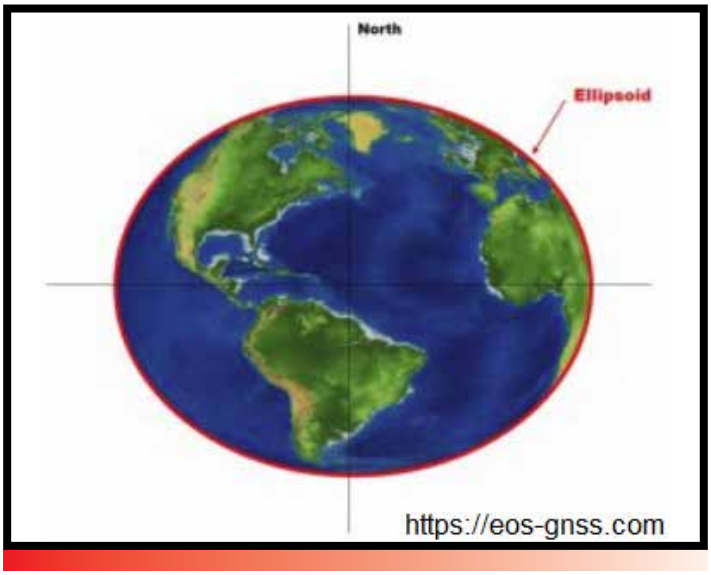

Figure 2: The ellipsoid model of Earth

While very accurate, the smooth ellipsoid does not exactly represent the earth's undulating surfaces. A more practical earth surface is modeled with a "geoid" (**Figure 3**), and it is very similar to sea level references. Elevation from the geoid or Mean Sea Level (MSL) is the "orthometric height." Orthometric height is what is needed for practical field measurements like determining model rocket altitude!

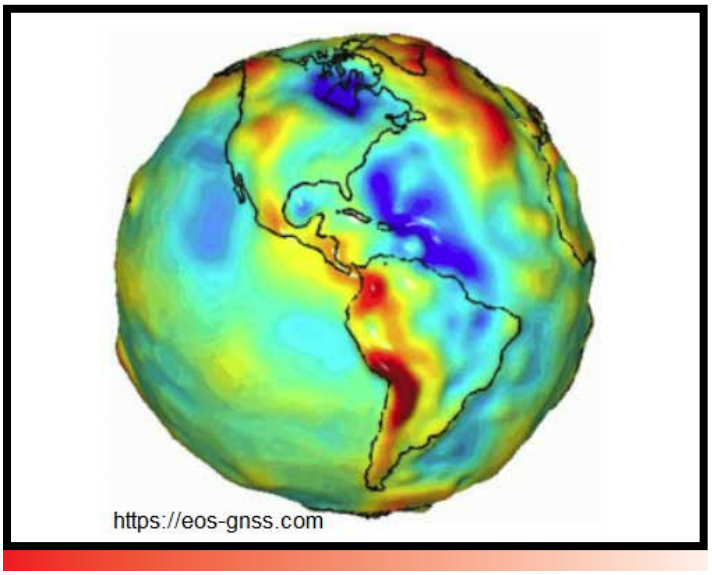

Figure 3: A geoid model of Earth

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The relationship between the ellipsoid and geoid is roughly shown in **Figure 4**. The difference between them, called the geoid height, N, is really a complex calculation and varies around the world, as shown in **Figure 5**. In the continental United States, N varies between -40 and -20 meters or so. Thankfully, your rocket GPS receiver takes care of these conversions behind the scenes and reports the orthometric height, H, above Mean Sea Level. GPS accuracy heavily depends on the orientation of satellites at that moment. Vertical error is more than horizontal error, and it could be on order of 10 to 20 meters.

Extracting Altitude from GPS Data

Your rocket GPS device may include software for plotting and post-processing the flight data. Less-expensive models typically do not, but you can still do it yourself using the raw data that the transmitter reports back to the receiver. This data may be stored in the GPS transmitter's memory or streamed in real-time to the GPS receiver base station. You need some type of logging software in the base station to capture the data stream. A simple terminal emulator like Putty or TeraTerm will work, but there are also some nifty freeware like MapSphere, VisualGPS, and ucenter.

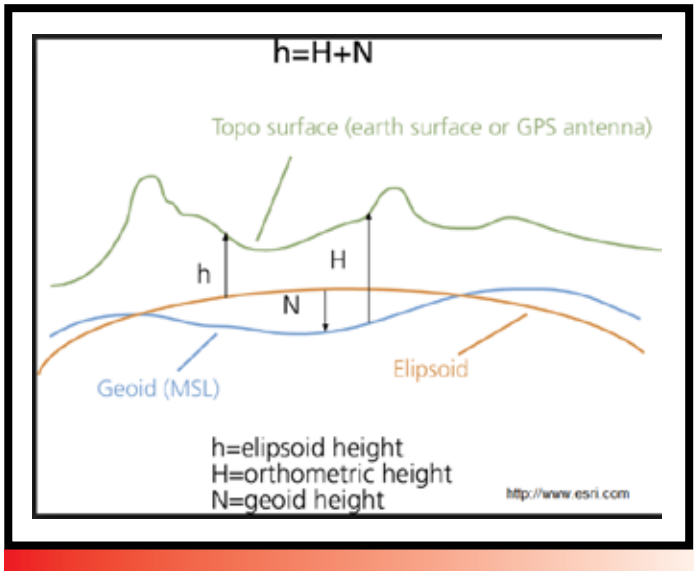


Figure 4: Difference between ellipsoid and geoid models

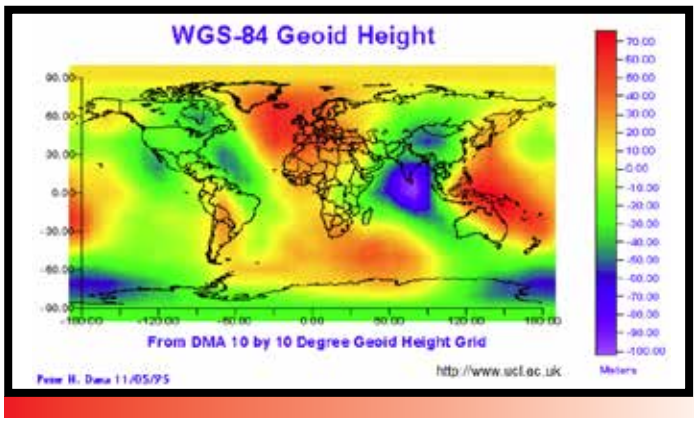
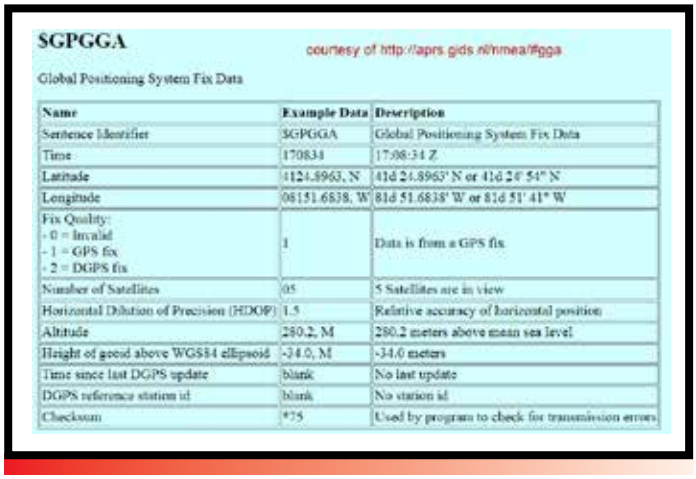


Figure 5: The geoid height (undulation) around the world

GPS uses the National Marine Electronics Association (NMEA) communication standard for positioning devices. There are many NMEA "sentences" that can be recorded by a GPS unit, but the most useful is the $GPGGA format as shown in **Figure 6**.



$GPGGA courtesy of http://aprs.gids.nl/nmea/#gga

Global Positioning System Fix Data

Name	Example Data	Description
Sentence Identifier	$GPGGA	Global Positioning System Fix Data
Time	170834	17:08:34 Z
Latitude	4124.8963, N	41d 24.8963' N or 41d 24' 54" N
Longitude	08151.6838, W	81d 51.6838' W or 81d 51' 41" W
Fix Quality: - 0 = Invalid - 1 = GPS fix - 2 = DGPS fix	1	Data is from a GPS fix
Number of Satellites	05	5 Satellites are in view
Horizontal Dilution of Precision (HDOP)	1.5	Relative accuracy of horizontal position
Altitude	280.2, M	280.2 meters above mean sea level
Height of geoid above WGS84 ellipsoid	-34.0, M	-34.0 meters
Time since last DGPS update	blank	No last update
DGPS reference station id	blank	No station id
Checksum	*75	Used by program to check for transmission errors

Figure 6: $GPGGA definition

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Figure 7 shows a snapshot of the base station console as it received NMEA sentences from the GPS transmitter onboard my rocket. You can see many different sentence types, but I highlighted the $GPGGA sentences in yellow. The critical data I am going to use for analysis is highlighted in green: the UTC time and the altitude in meters above Mean Sea Level. In this time interval of the flight, the rocket is descending under drogue. Also note the geoid height for my location is -34.6 m.

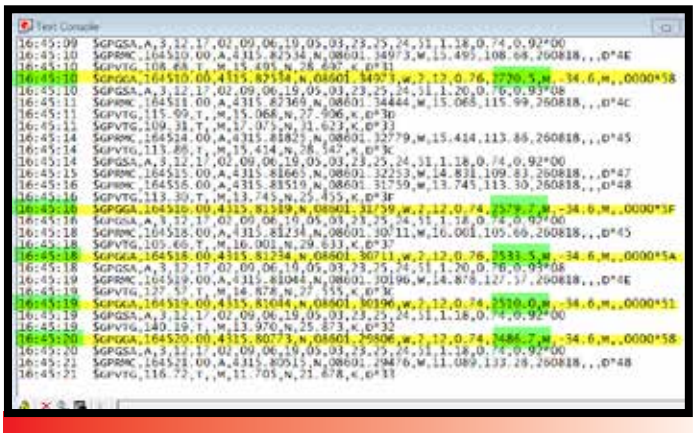

Figure 7: Streaming NMEA sentences from the GPS transmitter

Perhaps your GPS converts tracks into KML format, like that used by Google Earth. No worries, this is also simple text from which you can extract time and altitude as shown in green in **Figure 8**. There is a lot of header and footer info in a KML file, but in the middle are the important coordinate recordings of longitude, latitude, and altitude over time.

From here, you need to be handy with parsing and editing these GPS text files in order to plot altitude vs. flight time and do other analysis. Microsoft Excel has various functions to help with this.

The time stamp in these files is recorded as hour:minute:second UTC, which is the abbreviation for Coordinated Universal Time. UTC is a time standard used in aviation, radio, and weather forecasting. It is the time of day recorded at 0° longitude, which passes through the Royal Observatory Greenwich, London, and is the reference line for the world time zones.

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://earth.google.com/kml/2.0">
<Placemark>
  <name>gps</name>
  <Style id="khStyle690">
    <LineStyle id="khLineStyle694">
      <color>ff00ffff</color>
      <width>4</width>
    </LineStyle>
  </Style>
<MultiGeometry id="khMultiGeometry697">
<LineString id="khLineString698">
<tessellate>1</tessellate>
<altitudeMode>absolute</altitudeMode>
<coordinates>
-86.032178,43.263397,00204 <!-- 0 sats:4 UTC 16:05:34 -->
-86.032197,43.263398,00207 <!-- 15 sats:4 UTC 16:05:35 -->
-86.032228,43.263403,00211 <!-- 30 sats:4 UTC 16:05:36 -->
-86.032238,43.263408,00213 <!-- 45 sats:4 UTC 16:05:37 -->
-86.032262,43.263413,00216 <!-- 60 sats:4 UTC 16:05:38 -->
-86.032270,43.263415,00218 <!-- 75 sats:4 UTC 16:05:39 -->
-86.032262,43.263410,00216 <!-- 90 sats:4 UTC 16:05:40 -->
-86.032260,43.263410,00216 <!-- 105 sats:4 UTC 16:05:41 -->
-86.032273,43.263412,00217 <!-- 120 sats:4 UTC 16:05:42 -->
-86.032278,43.263415,00218 <!-- 135 sats:4 UTC 16:05:43 -->
-86.032292,43.263415,00219 <!-- 150 sats:4 UTC 16:05:44 -->
-86.032302,43.263415,00221 <!-- 165 sats:4 UTC 16:05:45 -->
```

Figure 8: KML format of a GPS track

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Your GPS starts recording from the time you turn it on, not the start of rocket flight. To plot data from the start of flight (like RockSim and altimeters) you need to skip over all the GPS recordings while the rocket is on the ground or waiting on the pad. **Figure 9** shows an Excel file of the GPS recordings from start up, with launch finally occurring on line 304 where the altitude begins to increase from ground level. I set 17:12:36 as time zero and begin counting the flight seconds from there.

	A	B	E
3	UTC	flight time, s	MSL, m
297	17:12:29		271
298	17:12:30		271
299	17:12:31		271
300	17:12:32		271
301	17:12:33		271
302	17:12:34		271
303	17:12:35		271
304	17:12:36	0	271
305	17:12:37	1.00	305
306	17:12:38	2.00	380
307	17:12:39	3.00	466
308	17:12:40	4.00	598
309	17:12:41	5.00	802
310	17:12:42	6.00	1020
311	17:12:43	7.00	1242
312	17:12:44	8.00	1485
313	17:12:45	9.00	1705
314	17:12:46	10.00	1856

Figure 9: Start of flight in the GPS altitude data

My GPS unit reports position every second, but sometimes the GPS loses lock during high acceleration, or the receiver misses some transmissions. As a result, the data is not always nicely spaced in 1 second intervals. To get the correct flight time, you must use the difference in UTC time from one recording to the next. However, when you subtract hour:minute:second data formats in Excel, the outcome looks very strange. I finally realized that this subtraction result is returned in units of days. Simply multiplying by 24 hrs/day *60 min/hr *60 s/min gets us back to seconds.

When measuring rocket altitude, the height above the launch site ground, not sea level, is what we need to analyze. So, height above MSL needs to be converted to height AGL. To do this, I simply average the altitude above MSL recorded by my GPS while the rocket is waiting on the pad (about 5 minutes). I call this the ground value. I then subtract the ground value from every altitude in my data. This gives AGL measurements that can be compared to RockSim or altimeters.

The rocket launch used for this article took place at the SMASH/MMAR club launch in Muskegon, MI on August 26, 2018. **Figure 10** shows the satellite view of the range head. Plotted in green is the GPS track I made while walking from my car, to the LCO table, and then out to the launch pads. The launch pad cluster of points contains the last 5 minutes of averaging prior to launch to determine the ground elevation, which worked out to be 209.3 m above MSL with a standard deviation of 1 m.

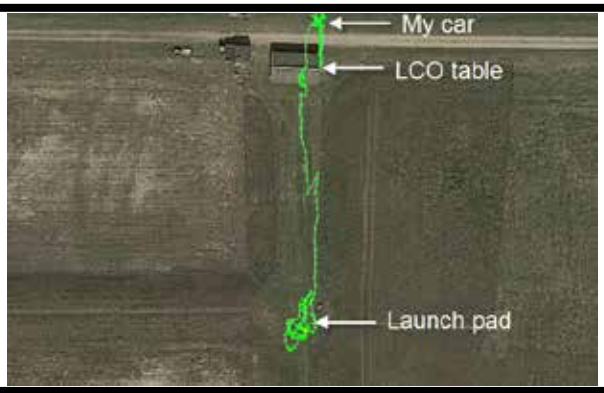

Figure 10: Satellite view of the range head

Comparison of GPS to Altimeter Altitude

For my flight, I collected GPS data in two ways. The first was via the flash memory storage on the GPS transmitter onboard the rocket. This data was in the form of KML downloaded after the flight. The second was collected in real time by recording the NMEA sentences transmitted to the GPS receiver base station. Both data sets were processed and formatted in Excel with the methods mentioned above.

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Figure 11 plots the two GPS altitude curves along with the barometric altimeter curve mentioned in the Introduction. The GPS transmitter onboard the rocket lost lock for the first 15 seconds of flight and restarted recording to memory at 12,000 ft. The base station receiver lost the signal for the first minute or so and didn't begin reading until the rocket was descending under drogue at 11,200 ft. The reason for these delays is that GPS modules do not hold up well to high acceleration at the beginning of rocket flight (42 G in this case) and lose connection to the satellites. Once the rocket begins to slow down near apogee and during parachute descent, the GPS signals regain lock. Even if the GPS was recording from lift off, the 1 Hz sampling rate would be far too coarse for accurate measurement of the rocket moving at high speed.

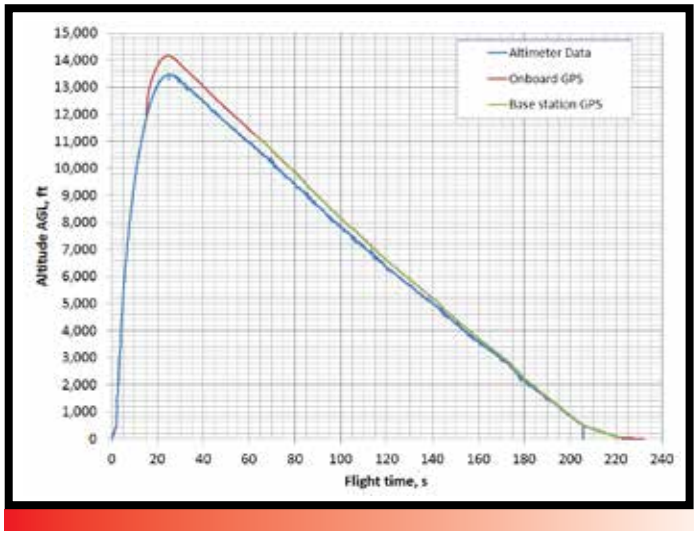

Figure 11: Altimeter and GPS altitude curves

I am happy to see the onboard GPS (red curve) and base station GPS (green curve) lay on top of each other. This confirms that the KML and NMEA data agree with each other, and I processed them both correctly. Most notable is the difference in max altitude from GPS as compared to the altimeter (blue curve). The GPS apogee is greater by about 700 ft. or 5%. This difference diminishes as the rocket descends, and all measurements are nearly equivalent as the rocket lands to the ground.

Atmospheric Soundings

The NOAA National Weather Service (NWS) takes upper air observations with radiosondes. The radiosonde is a small, expendable, instrument suspended below a large balloon. As the radiosonde rises, sensors send pressure, temperature, relative humidity, and wind speed measurements back to a base station via radio transmitter. NWS takes observations two times a day at 92 stations; 69 in the continental United States (**Figure 12**).

Figure 12: Atmospheric sounding locations

The University of Wyoming conveniently makes the daily NWS and other upper air soundings available through their webpage http://weather.uwyo.edu/upperair/sounding.html. Soundings dating back to 1973 can be retrieved. For my August 26, 2018 rocket launch in Muskegon, MI, the station in Green Bay, WI (KGRB) was the closest in distance. Also, I hypothesized that since both Muskegon and Green Bay lie on the shores of Lake Michigan, they may have similar upper air conditions due to the strong influence of the big body of water.

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Figure 13 shows a short list of the measurements made at KGRB at time 12Z. “Z” or “Zulu” time is a military time designation identical to UTC +0, the time at 0° longitude. The UWY data is given at 0Z (midnight) and 12Z (noon) each day. I figured that 12Z in London on August 26 was the nearest time to my launch in Michigan. This can get a little tricky, especially with Daylight Saving Time. If your launch time is late in the afternoon in the Eastern Time Zone, the nearest atmospheric sounding may actually be time stamped as 0Z of the next day. Figure 14 is a table to convert times.

72645 GRB Green Bay Observations at 12Z 26 Aug 2018

PRES hPa	HGHT m	TEMP C	DWPT C	RELH %	MIXR g/kg	DRCT deg	SKNT knot	THTA K	THTE K	THTV K
1000.0	136									
992.0	214	16.0	15.4	96	11.21	0	0	289.8	321.5	291.8
987.0	257	17.6	17.5	99	12.91			291.8	328.5	294.1
982.0	300	19.8	18.3	91	13.66			294.5	333.7	296.9
968.0	423	21.0	17.5	80	13.17			296.9	335.1	299.2
925.0	810	18.8	15.3	80	11.95			298.5	333.6	300.7
901.0	1036	17.2	14.5	84	11.65			299.1	333.4	301.2
885.0	1189	18.2	9.2	56	8.32			301.7	326.6	303.2
874.0	1297	18.4	7.4	49	7.44			303.0	325.5	304.4
850.0	1535	17.4	8.4	55	8.20			304.4	329.2	305.9
840.0	1636	17.0	7.0	52	7.53			305.0	328.0	306.4
813.0	1915	17.6	-3.4	24	3.68			308.5	320.2	309.1
793.0	2127	17.0	-1.0	29	4.51			310.0	324.4	310.9
783.0	2235	16.8	-3.2	25	3.87			310.9	323.4	311.7
753.0	2566	14.8	-6.2	23	3.21			312.3	322.8	312.9
746.0	2645	13.8	0.8	41	5.47			312.0	329.4	313.0
740.0	2713	13.2	2.2	47	6.10			312.1	331.4	313.2
700.0	3177	8.8	-0.2	53	5.42			312.2	329.4	313.2
693.0	3260	8.0	0.0	57	5.55			312.2	329.9	313.2
677.0	3452	6.6	-1.4	57	5.13			312.7	329.1	313.7
663.0	3624	5.8	-10.2	31	2.67			313.7	322.6	314.2
623.0	4130	2.4	-13.6	30	2.16			315.4	322.8	315.9
579.0	4715	-3.1	-12.1	50	2.62			315.7	324.5	316.2
545.0	5192	-5.7	-26.7	17	0.79			318.1	321.0	318.2

Figure 13: Sounding measurements

Barometric Altimeter Correction

To make the altimeter measurements in your rocket more accurate, the sounding data can be used instead of the default Standard Atmosphere model. The key information is in the first two columns of **Figure 13**: pressure and height. This is the actual barometric pressure reading at a given altitude above sea level. In this particular file, recordings are made up to 34,000m!

Some altimeters log and export their pressure measurements, making it easy to apply the conversion to altitude with the sounding data. If your altimeter only shows altitude data, you must “undo” the altitude calculation made by the altimeter and recover the raw pressure measurement. This is the approach I had to take with this particular flight.

	Standard Time								Daylight Saving			
UTC	Guam	HI	AK	PST	MST	CST	EST	AST	PDT	MDT	CDT	EDT
Diff	+10	-10	-9	-8	-7	-6	-5	-4	-7	-6	-5	-4
00	10a	2p*	3p*	4p*	5p*	6p*	7p*	8p*	5p*	6p*	7p*	8p*
01	11a	3p*	4p*	5p*	6p*	7P*	8p*	9p*	6p*	7p*	8p*	9p*
02	12N	4p*	5p*	6p*	7p*	8p*	9p*	10p*	7p*	8p*	9p*	10p*
03	1p	5p*	6p*	7p*	8p*	9p*	10p*	11p*	8p*	9p*	10*	11p*
04	2p	6p*	7p*	8p*	9p*	10p*	11p*	12M	9p*	10p*	11p*	12M
05	3p	7p*	8p*	9p*	10p*	11p*	12M	1a	10p*	11p*	12M	1a
06	4p	8p*	9p*	10p*	11p*	12M	1a	2a	11p*	12M	1a	2a
07	5p	9p*	10p*	11p*	12M	1a	2a	3a	12M	1a	2a	3a
08	6p	10p*	11p*	12M	1a	2a	3a	4a	1a	2a	3a	4a
09	7p	11p*	12M	1a	2a	3a	4a	5a	2a	3a	4a	5a
10	8p	12M	1a	2a	3a	4a	5a	6a	3a	4a	5a	6a
11	9p	1a	2a	3a	4a	5a	6a	7a	4a	5a	6a	7a
12	10p	2a	3a	4a	5a	6a	7a	8a	5a	6a	7a	8a
13	11p	3a	4a	5a	6a	7a	8a	9a	6a	7a	8a	9a
14	12M%	4a	5a	6a	7a	8a	9a	10a	7a	8a	9a	10
15	1a%	5a	6a	7a	8a	9a	10a	11a	8a	9a	10a	11a
16	2a%	6a	7a	8a	9a	10a	11a	12N	9a	10a	11a	12N
17	3a%	7a	8a	9a	10a	11a	12N	1p	10a	11a	12N	1p
18	4a%	8a	9a	10a	11a	12N	1p	2p	11a	12N	1p	2p
19	5a%	9a	10a	11a	12N	1p	2p	3p	12N	1p	2p	3p
20	6a%	10a	11a	12N	1p	2p	3p	4p	1p	2p	3p	4p
21	7a%	11a	12N	1p	2p	3p	4p	5p	2p	3p	4p	5p
22	8a%	12N	1p	2p	3p	4p	5p	6p	3p	4p	5p	6p
23	9a%	1p	2p	3p	4p	5p	6p	7p	4p	5p	6p	7p

AST - Atlantic, AK - Alaska time, HI - Hawaii time, *The previous day, %The next day

Conversion table courtesy National Weather Service Southern Region Headquarters

Figure 14: Time conversion table

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I wrote a computer code to calculate the properties of air (temperature, pressure, density) as a function of altitude according to the 1976 US Standard Atmosphere. This is the model used by most altimeters. I implemented the computer code as a Visual Basic for Applications (VBA) module in Excel. There are many forms of equations for the Standard Atmosphere, but one simple estimate for pressure p at altitude h is given by **Figure 15**. This equation is valid only up to 11 km (the troposphere).

$$p = p_0 \left(1 - \frac{Lh}{T_0}\right)^{\frac{gM}{RL}}$$

p_0 = sea level standard atmospheric pressure, 101.325 kPa

T_0 = sea level standard temperature, 288.15 K

g = earth-surface gravitational acceleration, 9.80665 m/s²

L = temperature lapse rate, 0.0065 K/m

R = ideal (universal) gas constant, 8.31447 J/(mol·K)

M = molar mass of dry air, 0.0289644 kg/mol

https://en.wikipedia.org/wiki/Density_of_air

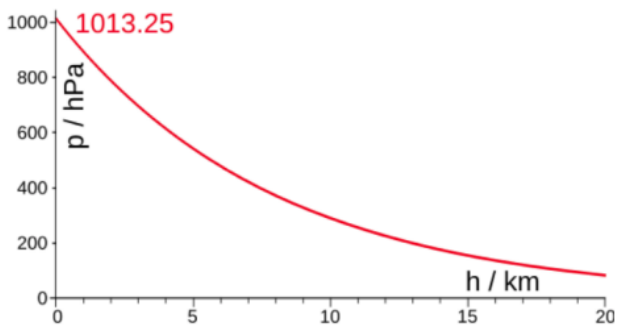

Figure 15: Pressure equation in the troposphere

Figure 16 shows the first few lines of my altimeter flight data loaded into Excel. The altimeter only gives me the ground reference elevation, the sample number, and altitude AGL measured in feet. I know that this particular device samples at 20 Hz, so I can determine the flight time increment to be 0.05 seconds. In columns D and E, I must convert to meters and altitude above mean sea level to be consistent with the equations. Finally, in column F, I find the raw pressure measurement from the altitude reported by the altimeter via the equation in **Figure 15**. Now that I have the pressure measurement during the rocket flight, I can convert that to a better altitude estimate using actual atmospheric sounding data and not the hypothetical Standard Atmosphere model.

	A	B	C	D	E	F
14	Altimeter Data					
15		Ground, ft ---> 644				
16	sample no.	flight time (s)	Altitude AGL (ft)	Altitude above MSL (ft)	Altitude above MSL (m)	pressure from 1976 US Std Atm (Pa)
17	1	0.00	0	644	196.3	98989
18	2	0.05	19	663	202.1	98921
19	3	0.10	0	644	196.3	98989
20	4	0.15	19	663	202.1	98921
21	5	0.20	19	663	202.1	98921
22	6	0.25	39	683	208.2	98849
23	7	0.30	39	683	208.2	98849
24	8	0.35	58	702	214.0	98781
25	9	0.40	77	721	219.8	98713
26	10	0.45	77	721	219.8	98713
27	11	0.50	97	741	225.9	98641
28	12	0.55	116	760	231.6	98573
29	13	0.60	116	760	231.6	98573

Figure 16: Altimeter data and pressure calculation

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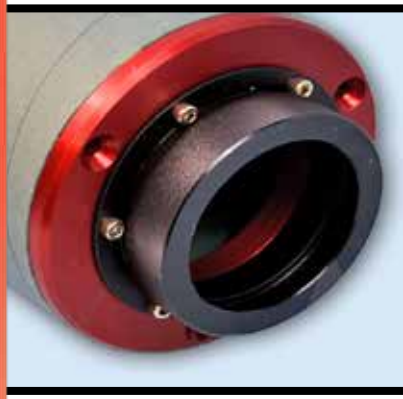

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Let's consider the pressure of 98,641 Pa (986.41 hPa) computed at time = 0.5 s. Taking that value to the Green Bay sounding table shows that it falls between 987 and 982 hPa and thus between the heights of 257 and 300 meters as highlighted in **Figure 17**. Experienced engineers familiar with lookup tables know what to do next: interpolate between these values. There are many ways to get this done. I used the FORECAST() function in Excel. The "corrected" altitude for 986.41 hPa interpolates to 262.1 m above MSL as seen in **Figure 18**.

72645 GRB Green Bay O

PRES hPa	HGHT m	TEMP C	DWPT C	RELH %
1000.0	136			
992.0	214	16.0	15.4	96
987.0	257	17.6	17.5	99
982.0	300	19.8	18.3	91
968.0	423	21.0	17.5	80
925.0	810	18.8	15.3	80

Figure 17: Interpolating in the table

The corrected altitude is 98.2 ft. AGL, just a foot more than the altimeter reported. So, what's the big deal? Well, the errors can grow at higher altitudes, depending how much the real local atmosphere differs from the model. My Excel sheet continues on in this fashion, correcting the altimeter altitude with the sounding table through the entire flight. (For Excel users, the functions MATCH() and INDEX() are handy here for the interpolation tasks.) **Figure 19** plots the correction percentage vs. altitude for this flight, as it grows from zero to almost 5% at apogee.

	B	C	F	L	M	N
14	Altimeter Data			Corrected Data		
15	Ground, ft ---> 644					
16	flight time (s)	Altitude AGL (ft)	pressure from 1976 US Std Atm (Pa)	Corrected Altitude above MSL from sounding data (m)	Corrected Altitude AGL from sounding data (m)	Corrected Altitude AGL from sounding data (ft)
17	0.00	0	98989	232.1	0.00	0.0
18	0.05	19	98921	238.0	5.87	19.3
19	0.10	0	98989	232.1	0.00	0.0
20	0.15	19	98921	238.0	5.87	19.3
21	0.20	19	98921	238.0	5.87	19.3
22	0.25	39	98849	244.2	12.04	39.5
23	0.30	39	98849	244.2	12.04	39.5
24	0.35	58	98783	250.0	17.91	58.7
25	0.40	77	98713	255.9	23.77	78.0
26	0.45	77	98713	255.9	23.77	78.0
27	0.50	97	98641	262.1	29.93	98.2
28	0.55	116	98573	267.9	35.78	117.4
29	0.60	116	98573	267.9	35.78	117.4

Figure 18: Corrected altitude at flight time = 0.50 seconds

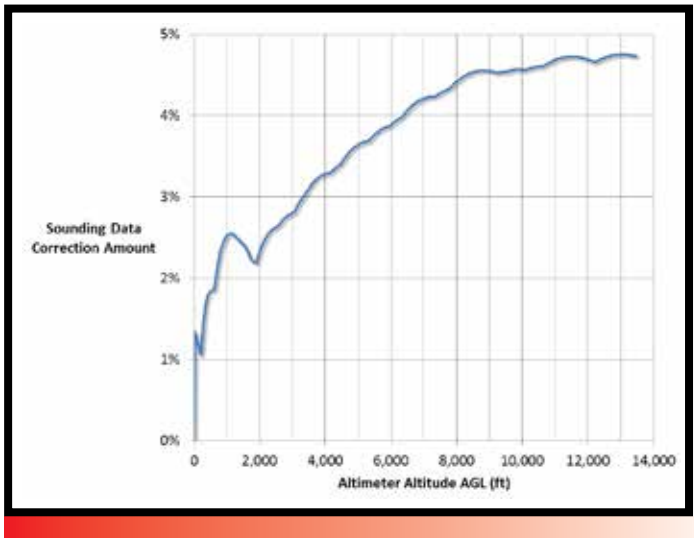

Figure 19: Altimeter correction vs. altitude

The data here emphasizes a little known fact. If the actual temperature is much warmer than the Standard Atmosphere base temperature of 288.15 K (59° F), then the altimeter will report an altitude that is too low. Indeed, the ground temperature at my launch was 84° F, and the altimeter was short by 5% at apogee. For those of you who fly in the desert, the error can be 10% or more. The reason is that on a hot day, the air column

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expands, raising each pressure level to an altitude that is greater than the altimeter thinks. Conversely, in very cold temperatures, the altimeter will report a higher altitude than reality. If you want to win an altitude contest by altimeter, then fly on a cold day!

Comparison of GPS, Altimeter, and Corrected Altimeter Altitude

Plotting the corrected altimeter altitude vs. flight time in zoomed **Figure 20** reveals an interesting result. The correction increased apogee altitude AGL by nearly 5%. However, the corrected altitude (purple curve) is now almost identical to the GPS measurement near apogee and is perfectly aligned to GPS all the way down to the ground!

The altimeter error in this example is about 600 feet, which is far more than the 10-20 meters of possible GPS vertical error. I analyzed a few more of my flights in this fashion and found that altimeter apogee corrected with atmospheric sounding observations agree very well with my GPS apogee value. This leads me to believe that GPS can be a simpler and more accurate way to record peak altitude.

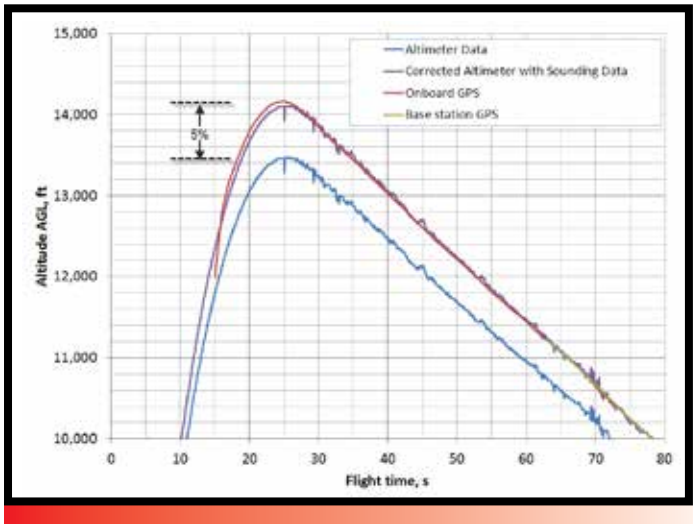

Figure 20: Altimeter, corrected altimeter, and GPS altitude curves

Summary

This article discussed the various simulation models used by electronic payloads to measure altitude. Data from a recent rocket flight illustrated the procedures to extract, process, and compare altitudes reported by the devices. In particular, barometric altimeters can be improved by substituting atmospheric sounding data recorded by weather stations around the world.

GPS measurements of peak altitude were found to be superior to uncorrected barometric altimeters and require no atmosphere assumptions. Granted, inexpensive GPS chipsets used in model rocketry may lose satellite lock and cannot resolve the entire flight profile with their coarse 1 Hz resolution. However, more robust GPS devices with higher sampling rates are in development. This technology continues to grow.

Computer simulations like RockSim perform better than altimeters when it comes to the flight environment. They use the same Standard Atmosphere models but allow for local weather adjustments by the user to make them more representative of the actual flying conditions. So, the next time your sim and altimeter differ, don't be so quick to blame RockSim. It may be your electronics.

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About The Author

Ken Karbon is a rocketeer from Michigan. He works in the auto industry, specializing in aerodynamics and CFD simulation.

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