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Using Rocketry Components To Teach Collegiate Engineering Analysis

By Todd H. Treichel

AltimeterOne Electronic Altimeter Used In Collegiate Engineering Analysis Project

A recent outreach presentation to high school students concluded with one high school student commenting to me that his older brother was studying to be an engineer. The discussion lead to a phone call I received about the possibility of setting up an independent study project where a real-life process could be analyzed using statistical methods. At the university level a sixteen week semester may seem like a long time. However, in the design, development, and manufacturing world of aerospace a readily available project that can be finished in one semester is sometimes difficult to originate on short notice. This is when I turned to the very same topic I was presenting at an area high school, barometric pressure and altitude.

The science of rocketry has numerous parallels to the aerospace industry and provides an excellent opportunity for learning math and science with practical application. No matter what the industry an engineering student may choose to work in someday, the creativity and levels of experimentation are endless. A benefit to both mentor and student is that the topic under study, whether it is an entire rocket system or a subassembly, can be managed to an appropriate level of complexity as to allow enough time for a final capstone paper and presentation at the end of the semester. Too many times I've seen where a student is at the mercy of a company timeline where engineering and process changes cause further delay in executing experiments that must be completed on time to meet academic deadlines.

When designing a system for space flight, a failure cannot be tolerated. Unlike an automobile that can be returned to the service center for repair, once launched, a space system is nearly impossible to repair and if astronauts or robots are involved, the task becomes very expensive and difficult. Therefore, space systems must function when launched and continue to function throughout the respective product life-cycle (days, month, or years depending on mission). For this reason, engineers spend a great deal of time performing experiments and analyzing data to make informed decisions about how to best design space systems for the stated mission. Sensors of numerous types are used in a wide variety of space system hardware; temperature sensors, hydrogen sensors, oxygen sensors, carbon dioxide sensors, and pressure sensors to name a few. An engineer cannot simply select a sensor and design it into a flight system. An approved parts lists is often referenced where components are selected based on qualification data and or historical flight performance. When a new part is selected using performance capabilities stated by the manufacturer, objective evidence of these performance characteristics must be verified before inclusion into the system design. Design verification is another term used to describe a series of evaluations and tests used to validate a component and ensure that it is fit for use in its intended environment. The test methods, sample sizes, and acceptance criteria should be clearly specified during conceptual planning of a product or process, and the design should be validated. Some common factors for evaluation are:

- Dimensional wear, material fatigue, assembly process

Figure 1. AltimeterOne under test. Reading shows 29,420 feet.

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variation
- Variation of critical characteristics throughout the range of the stated tolerances
- Contamination
- Environmental aging and extreme environmental conditions
- Extreme usage, such as maximum loads or long duty cycles.

In review of the bulleted list above, variation of critical characteristics throughout the range of the stated tolerances was selected as the research question to evaluate the stated altimeter capability of zero to 29,500 feet. This article will summarize how an AltimeterOne (www.ApogeeRockets.com/AltimeterOne.asp) was used in collegiate study and statistically analyzed for sensor accuracy using linear regression and correlation.

Atmospheric Pressure.

Before an analysis of the AltimeterOne can begin, we must review the environment in which our sensor is intended to operate. The pressure of the atmosphere at any point is due to the weight of air above it (gravity pulling downward). As you increase in altitude the air particles around you become fewer, so the less atmosphere or pressure is exerted on you. As you enter into space, the amount of pressure becomes less and less and constitutes a vacuum. The opposite effect occurs when you drop below sea-level. Inward pressure increases on you as you descend lower (this is why deep-sea divers use rigid diving suits or diving bells that are controlled internally at approximately 14 pounds per square inch (PSI)). Atmospheric pressure can vary significantly depending on the elevation of the soil you are standing on and weather. Atmospheric pressure can change with changes in weather patterns, so it must be noted that measuring altitude with barometric pressure is not free from difficulties. On an afternoon full of weather changes, like an approaching cold front, air pressure can change by as much as 1 PSI or more, which relatively speaking could skew an altitude reading of up to 130 feet (40 meters) or more. In theory, an altimeter thinks this decrease in pressure is due to an increase in altitude and will read higher than you really are and the opposite is true when weather conditions improve causing the altimeter to read lower than you really are. Rocket flights are relatively short in duration so barometric pressure changes are not of great concern and the AltimeterOne scales to zero during power-up and can be reset during times of continuous use.

Atmospheric pressure is often measured using a mercury barometer, where mercury (represented as Hg on the chemical periodic table) is used to measure and determine atmospheric pressure. In the aerospace industry the subject of altitude testing can become quite challenging when it comes to communicating the amount of pressure, or in the case of vacuum, differential pressure. It is not uncommon to hear scientists recording air pressure in millibars, where one millibar equals 1/1000 of a bar. The bar and the millibar are metric units and the non-metric unit of pressure is

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the Pascal (Pa), which equals 1/100 of a millibar. This can become quite tricky because as you move higher in altitude and transition into space vacuum, aerospace engineers and NASA personnel begin to change their terminology and reference space vacuum in Torr (1 Torr = 1013.25 millibars). What you need to know for the purpose of this analysis is that atmospheric pressure at sea level averages 1 atmosphere (atm) or 1 Torr or 1013 millibars, which equals 29.2 inches (760 millimeters) of mercury. In case you find yourself tossing around such terminology and need to interpret atmospheric pressure and altitude, the reference chart in Table 1 has been created for cross reference.

The functional make-up of a mercury barometer (see Figure 2 on the next page) is why atmospheric pressure is often referenced in inches or millimeters. A mercury barometer has a glass tube that is at least 33 inches (approximately 84 centimeters) in height, closed at one end with an open mercury-filled reservoir at the base. The weight of the mercury creates a vacuum in the top of the tube causing the mercury in the tube to adjust until the weight of the mercury column balances the atmospheric force exerted on the reservoir. High atmospheric pressure places more force on the reservoir, forcing mercury higher in the column and low pressure allows the mercury to drop to a lower level in the column by lowering the force placed on the reservoir. Pressure is recorded as the level of mercury height in the vertical column or glass tube.

Feet	Miles	Meters	F	C	Hg. Vacuum	In. Hg. Abs.	mm Hg. Abs.	PSIA	Kg / sq. cm	kPa A	Millibars	atm	Torr
656,000	124.3	200,000	-58	-50	29.919	$9.43X10^{-8}$	$2.40X10^{-6}$	$4.64X10^{-8}$	$3.15X10^{-9}$	0	0.01	0.00	0.0016
150,000	28.4	45,720	5	-15	29.877	0.043	1.09	0.021	0.00014	0.15	1.46	0.00	1.09
100,000	18.9	30,510	-51	-46	29.591	0.329	8.36	0.162	0.011	1.12	10.67	0.01	8
90,000	17.1	27,459	-57	-49	29.4	0.52	13.2	0.255	0.018	1.76	17.33	0.02	13
80,000	15.2	24,408	-62	-52	29.0927	0.8273	21	0.406	0.029	2.8	28.00	0.03	21
70,000	13.3	21,357	-67	-55	28.595	1.325	33.7	0.651	0.046	4.49	45.33	0.04	34
60,000	11.4	18,306	-70	-57	27.785	2.135	54.2	1.05	0.0738	7.24	71.99	0.07	54
55,000	10.4	16,781	-70	-57	27.208	2.712	68.9	1.33	0.0935	9.17	91.99	0.09	69
50,000	9.5	15,255	-70	-57	26.476	3.444	87.5	1.69	0.119	11.65	115.99	0.11	87
45,000	8.5	13,730	-70	-57	25.545	4.375	111.1	2.15	0.151	14.82	147.99	0.15	111
40,000	7.6	12,204	-70	-57	24.362	5.558	141.2	2.73	0.192	18.82	187.98	0.19	141
35,000	6.6	10,679	-66	-54	22.86	7.06	179.3	3.47	0.244	23.93	238.65	0.24	179
30,000	5.7	9153	-48	-44	21.017	8.903	226.1	4.37	0.307	30.13	301.31	0.30	226
25,000	4.7	7628	-30	-34	18.8	11.12	282.4	5.46	0.384	37.65	375.97	0.37	282
20,000	3.8	6102	-12	-24	16.16	13.76	349.5	6.76	0.475	46.61	466.63	0.46	350
15,000	2.8	4577	6	-14	13.03	16.89	429	8.29	0.583	57.16	571.95	0.56	429
10,000	1.9	3050	23	-5	9.34	20.58	522.7	10.1	0.71	69.64	695.94	0.69	522
9000	1.7	2746	27	-3	8.53	21.39	543.3	10.5	0.738	72.4	723.94	0.71	543
8000	1.5	2441	31	-1	7.69	22.23	564.6	10.91	0.767	75.22	751.94	0.74	564
7000	1.3	2136	34	1	6.82	23.1	586.7	11.34	0.797	78.19	781.27	0.77	586
6000	1.1	1831	38	3	5.93	23.99	609.3	11.78	0.828	81.22	811.93	0.80	609
5000	0.95	1526	41	5	5.02	24.9	632.5	12.23	0.86	84.33	843.93	0.83	633
4500	0.86	1373	43	6	4.55	25.37	644.4	12.46	0.876	85.91	858.59	0.85	644
4000	0.76	1220	45	7	4.08	25.84	656.3	12.69	0.892	87.49	874.59	0.86	656
3500	0.66	1068	47	8	3.59	26.33	668.8	12.93	0.909	89.15	891.92	0.88	669
3000	0.57	915	48	9	3.1	26.82	681.2	13.17	0.926	90.81	907.92	0.90	681
2500	0.47	763	50	10	2.6	27.32	693.9	13.41	0.943	92.46	925.25	0.94	694
2000	0.38	610	52	11	2.1	27.82	706.6	13.66	0.96	94.19	941.25	0.93	706
1500	0.28	458	54	12	1.59	28.33	719.6	13.91	0.978	95.91	958.59	0.95	719
1000	0.19	305	55	13	1.06	28.86	733	14.16	0.996	97.63	975.92	0.96	732
500	0.09	153	57	14	0.54	29.38	746.3	14.43	1.015	99.49	994.58	0.98	746
0	Sea Level	0	59	15	0	29.92	760	14.696	1.0333	101.33	1013.25	1.00	760
-500	-0.09	-153	61	16	-0.55	30.47	773.9	14.96	1.052	103.1	1030.58	102.00	773
-1000	-0.19	-305	63	17	-1.1	31.02	787.9	15.23	1.071	105	1050.58	1.04	788
-1500	-0.28	-458	64	18	-1.66	31.58	802.1	15.51	1.091	106.9	1069.24	1.06	802
-2000	-0.38	-610	66	19	-2.22	32.14	816.4	15.78	1.109	108.8	1067.91	1.05	816
-2500	-0.47	-763	68	20	-2.78	32.7	830.6	16.06	1.129	110.7	1106.57	1.09	830
-3000	-0.57	-915	70	21	-3.35	33.27	845.1	16.34	1.149	112.7	1126.57	1.11	845
-3500	-0.66	-1068	71	22	-3.92	33.84	859.5	16.62	1.169	114.6	1146.57	1.13	860
-4000	-0.76	-1220	73	23	-4.5	34.42	874.3	16.9	1.188	116.5	1165.23	1.15	874
-4500	-0.86	-1373	75	24	-5.08	35	889	17.19	1.209	118.5	1185.23	1.17	889
-5000	-0.95	-1526	77	25	-5.66	35.58	903.7	17.48	1.229	120.5	1205.23	1.19	904

Table 1. Vacuum reference chart.

Altitude Testing

Using the functional concept of a mercury barometer (see Figure 3), altitude testing can be performed in

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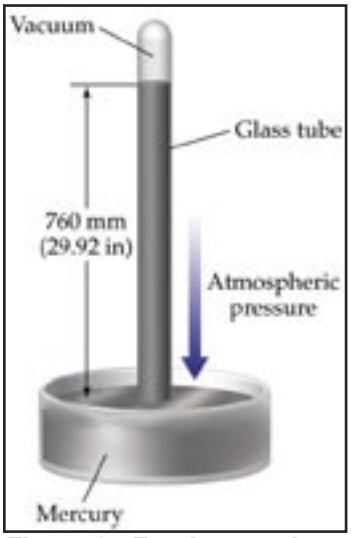

Figure 2. Fundamental make-up of a mercury barometer.

a laboratory using a manometer to simulate various differential pressure environments. As shown in Figure 4, commercial airliners travel in the troposphere layer of the earth's atmosphere. It is important to note that at 4.6 km (15,000 ft) the Federal Aviation Administration (FAA) requires supplemental oxygen for pilots and passengers and a typical altitude for a commercial airliner is approximately 35,000 feet, which equates to 22.86 inches of mercury. NASA often launches weather balloons to gather important science data about the atmosphere and these balloons can fly as high as 41.1 km (137,000 ft), and the International Space Station (ISS) orbits the Earth at an altitude of about 403 km (1,322,178 ft). The U.S. definition of space flight is anything higher than 264,000 feet (80.5 Km).

The higher the mission altitude requirement, the more sophisticated the test equipment becomes to perform altitude simulation testing. For the purpose of testing the AltimeterOne a specialized vacuum pumping system and vessel was used to perform a correlation study between

Figure 3. Inches of mercury scaled to altitude in aerospace laboratory.

inches of mercury (Hg Vacuum) and altitude readout. Similar to atmospheric pressure acting against the mercury illustrated in Figure 2, a vacuum pumping system was used to simulate differential pressure relative to ambient air pressure in Madison, Wisconsin (1016.4 millibars or 29.98 inches of mercury). In other words, the calibrated reference for ground-level altitude was

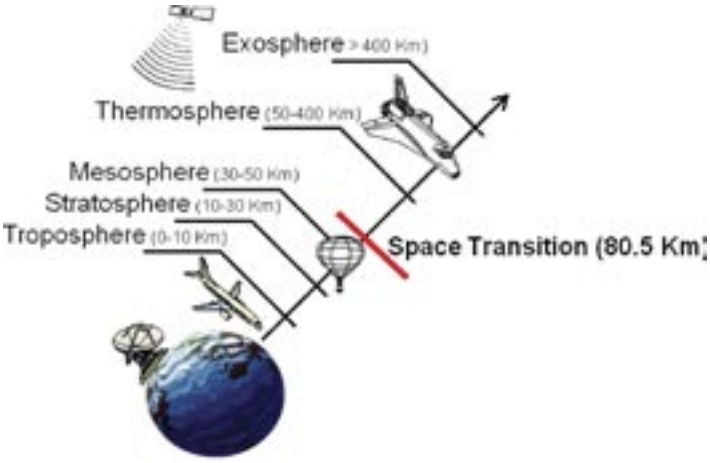

Figure 4. Layers of the atmosphere in reference to mission altitude requirements.

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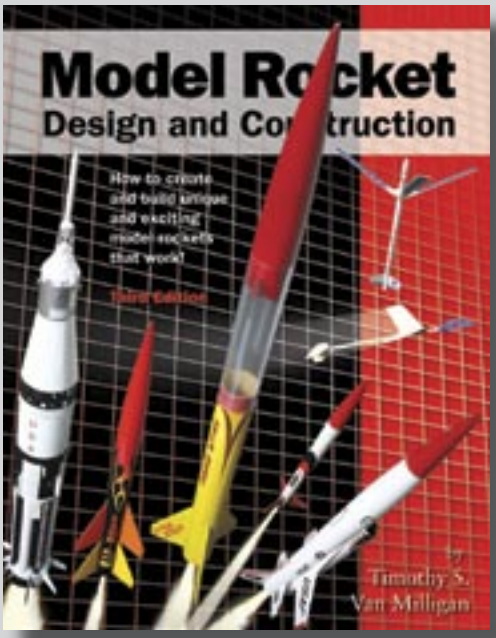

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Altitude (Feet)	Set Point	Hg (Vacuum)
0	1	0.00
250	2	0.22
500	3	0.54
1000	4	1.06
2000	5	2.1
4000	6	4.08
6000	7	5.93
8000	8	7.69
10000	9	9.34
15000	10	13.03
20000	11	16.16
25000	12	18.8
30000	13	21.02

Table 2. Vacuum set points for altitude test environment.

zero, and increases in altitude were made by creating enough vacuum (± 2%) inside the chamber to cause mercury to rise in accordance with the referenced altitude (see Table 2). Please note that we are interested in studying the magnitude of change across the tolerance range of the altimeter and not looking to study a specific altitude. Inches of mercury (Hg) were controlled using the equipment illustrated in Figure 5, at an ambient temperature of 24 degrees Celsius (75 degrees Fahrenheit).

Figure 5. Specialized vacuum chamber for altitude testing.

Altimeter Correlation Analysis

Earlier we discussed process capability and our desire to determine if the AltimeterOne device is capable of measuring the altitude range stated by the manufacturer (0 – 29,500 feet). We don't have access to a flight vehicle and a 29,500 foot tape measure to verify the capability of the altitude measurement process. A process can be defined as a unique combination of tools, materials, methods, and people engaged in producing a measurable output. There are two techniques engineers can use to study the relationship between two variables: (1) correlation analysis, which is used to measure the strength of relationship between two variables, and (2) regression analysis, which can be used for estimating one variable based on another. The mathematical and engineering term for this type of analysis is called linear regression and correlation and was the statistical method selected to for verification of the AltimeterOne device.

The variable used as the estimator is called the independent variable and the variable being estimated is called the dependent variable. In the case of this analysis, vacuum applied in Hg is the independent variable and the AltimeterOne value obtained is the dependent variable. In essence, we are suggesting that a rise in mercury is related to a higher altitude reading, and we want to analyze this relationship from ground level up to 30,000 feet. A useful tool for correlation analysis and regression is the scatter diagram. A scatter diagram depicts the relationship between two variables where the independent variable is represented on the horizontal axis (x-axis) and the dependent variable along the vertical axis (y-axis). Suppose we fired the same rocket five times using Apogee 24mm Single-Use Composite Rocket Motors (www.ApogeeRockets.com/composite_motors.asp) rated at 40 Newtons, and after each launch we removed an equal amount of mass from our payload bay. One would assume that there would be a correlation between higher mass and lower altitude. In theory, you might expect to see a scatter diagram looking something like what is illustrated in Figure 6.

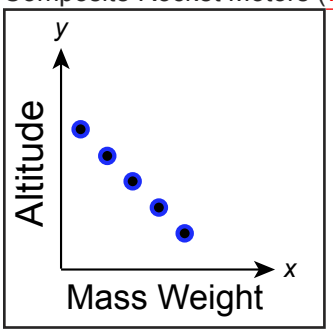

Figure 6. Scatter diagram showing negative correlation between rocket mass and altitude.

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A measure of the linear (straight-line) strength of the association between two variables is what we are most interested in and is called the coefficient of correlation. The coefficient of correlation is usually designated by the lower case r and may range from -1.0 to +1.0 where a value of -1.0 indicates a perfect negative correlation (as shown in Figure 6) and likewise a +1.0 indicates a perfect positive correlation. A coefficient of correlation of 0.0 indicates there is no relationship between the two variables under study. It must be noted that the degree of relationship strength is not contingent on the sign or direction of the coefficient of correlation. For example, an r value of -.65 represents the same degree of correlation as +.65.

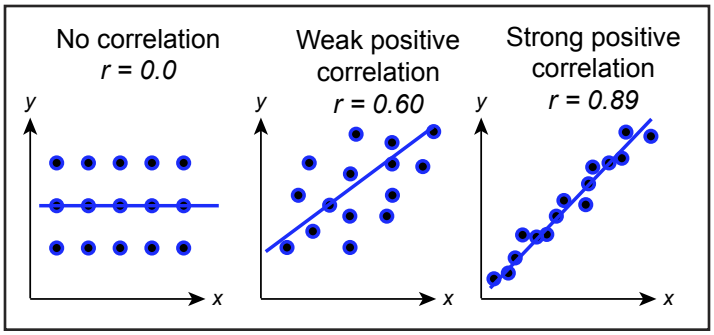

Figure 7. Interpretation of correlation coefficient and scatter diagrams.

Scientific prediction and correlation are closely related topics and an understanding of one requires and understanding of the other. The presence of zero correlation between two variables x and y can usually be interpreted to mean that there is no systematic relationship to each other. So it is better to predict something about the dependent variable from your independent variable than to guess. If we were designing a flight system that required several AltimeterOne devices to successfully perform from zero to 25,000 feet, your boss or future employer would not be too appreciative of a simple guess. Scientific data would provide the objective evidence needed to justify your design selection of the AltimeterOne device.

A straight line between any two points can be represented by the equation: y – a + bx where a is the intercept point where the line crosses the y axis, and b is the slope of the line (or the number of units that y increases when x increases). In predicting one variable based on knowledge of another, the equation is used to plot a straight line that best fits all the data. This line is called the regression line and the method for fitting a regression line to a set of data containing two variables is called the method of least squares. This is why there are fit lines plotted on the images in Figure 7. For the purpose of this article, statistical software was used to generate our regression line, and we recommend consulting a statistical reference book should you be interested in further reading on the subject of least of squares.

The AltimeterOne was placed into a vacuum chamber and exposed to differential pressure levels in accordance with the Hg levels illustrated in Table 3. Likewise, corresponding altimeter altitude readings were recorded after venting the vacuum chamber to simulate rocket apogee. A scatter diagram and regression line were created using MINI-TAB statistical software (see Figure 8).

Sample	*x* (Hg)	*y* (Feet)
1	0.00	0
2	0.22	242
3	0.54	487
4	1.06	977
5	2.1	1972
6	4.08	3969
7	5.93	5943
8	7.69	7968
9	9.34	10040
10	13.03	15130
11	16.16	20050
12	18.8	24980
13	21.02	29420

Table 3. Data from AltimeterOne altitude test.

The coefficient of correlation was computed using the following formula, where $\sum xy$ is the sum of the product of the variables, $\sum x^2$ and $\sum y^2$ are the sum of squares for

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the variables, $\sum x$ and $\sum y$ and are the sums of the variables, and n is the sample size (see Table 4 for arranged data):

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2]\,[n(\sum y)^2]}}$$

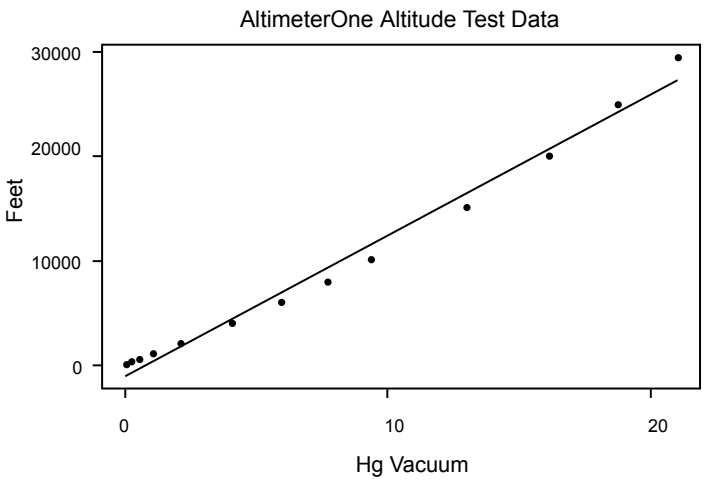

Figure 8. Scatter diagram from analysis data.

$$r = \frac{13\,(1821160) - (99.97)\,121178}{\sqrt{[13\,(1430) - (99.97)^2\,]\,[13(2340958080) - (121178)^2]}}$$

$$r = \frac{11560915}{11634980}$$

$$r = 0.993$$

Sample	x	y	x y	x^2	y^2
1	0	0	0	0	0
2	0.22	242	53.2	0.0	58564
3	0.54	487	263.0	0.3	237169
4	1.06	977	1035.6	1.1	954529
5	2.1	1972	4141.2	4.4	3888784
6	4.08	3969	16193.5	16.6	15752961
7	5.93	5943	35242.0	35.2	35319249
8	7.69	7968	61273.9	59.1	63489024
9	9.34	10040	93773.6	87.2	100801600
10	13.03	15130	197143.9	169.8	228916900
11	16.16	20050	324008.0	261.1	402002500
12	18.8	24980	469624.0	353.4	624000400
13	21.02	29420	618408.4	441.8	865536400
Total	99.97	121178	1821160	1430.3	2340958080

Table 4. Data table needed to compute totals and squared totals.

A calculated r of 0.993 suggest a strong positive correlation between the Hg vacuum set point and the AltimeterOne altitude reading. The *coefficient of determination* is the square of the *coefficient of correlation* which can be found by $0.993^2 = 0.987$ which indicates that 98.7 percent of the variation in altitude readings can be explained by the Hg vacuum set point. In other words, the AltimeterOne is doing precisely what the manufacturer says it should and meets critical characteristics throughout the range of the stated tolerances (0 to 29,500 feet).

Conclusion

Whether you are a student or educator, rocketry pro-

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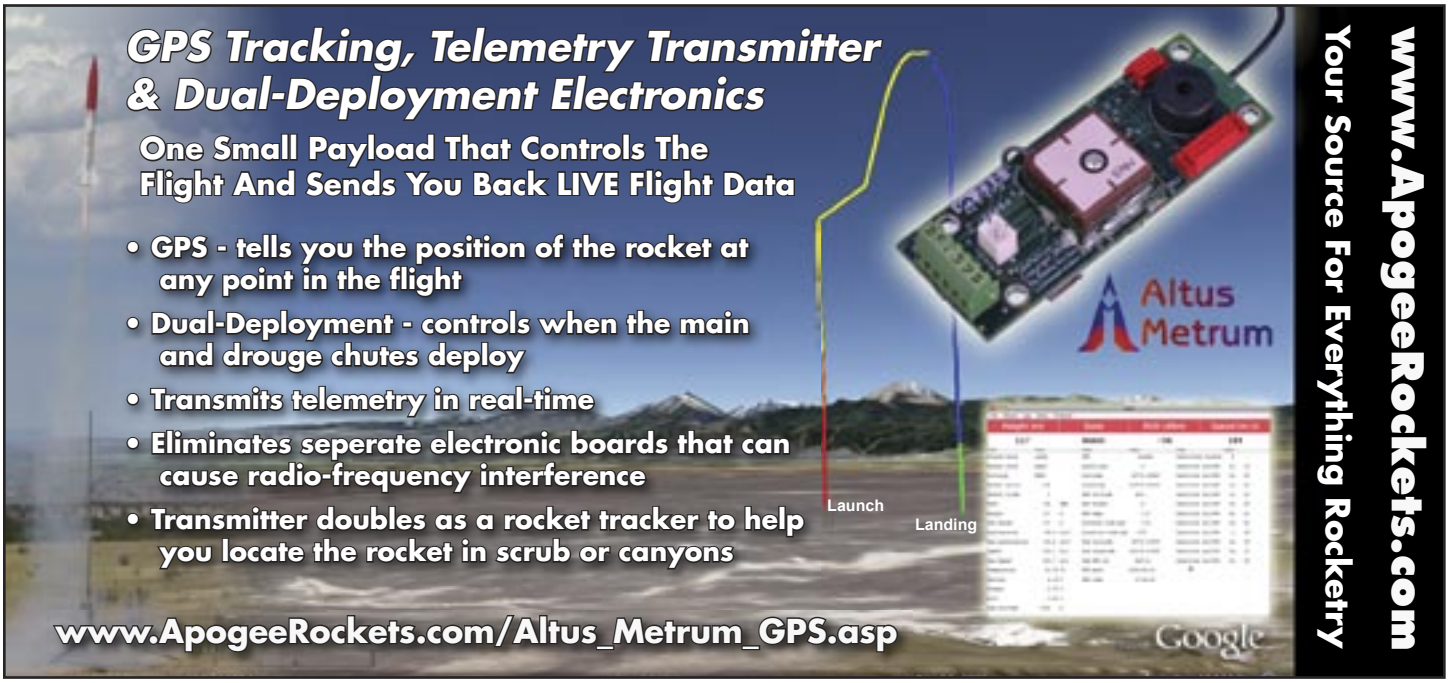

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Using Rocketry To Teach Technical Analysis

vides a host of opportunities to prepare future high-tech professionals. Verification and validation is a process used by design and development companies for checking that a product, service, or system meets specifications and that it fulfills its intended purpose. Using a statistical technique like the one described in this article will make for a great piece of reference material during a job interview or other similar presentation. It is one thing to say you learned something in class, but yet another to say you conducted the research, performed the analysis, and have a report containing evidence providing a high degree of assurance about your claim. I told my student to remember, "One test is worth a thousand expert opinions."

There is a business strategy called *Six-Sigma,* used by companies all over the world, which advocates the use of statistics for making process decisions and improvements. One such example is that in 1999 Lockheed Martin started the LM21 initiative, which stands for Lockheed Martin in the 21st Century and was the pioneer program for implementing Six-Sigma concepts for achieving company-wide improvements. Rockwell Collins has also implemented *Lean Manufacturing,* where statistical techniques are used for quality improvement in the design of military and space products. I suggest referencing *Developing Creativity Using Model Rockets to Teach the Techniques of Problem Solving* (www.ApogeeRockets.com/creativity_book.asp) and review the many educational outcomes from the process of preparing students for school and professional careers. The ability to define quality and quality improvement concepts is a coveted skill among graduating engineers.

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Todd holds a BS and MS in manufacturing engineering and management and is level one certified with the National Association of Rocketry (NAR). He also is the coach for a grade school rocket team that plans to fly at the Rockets for Schools competition in Sheboygan, Wisconsin. Todd is married and has two children learning RockSim and a six year old who just finished a Payloader One.

The Rocket Project

By Dr. James Fullingim

Model rockets are a valuable tool in teaching numerous aeronautical applications in higher education curriculum. I have personally used them for over 15 years in my university aviation classes to demonstrate advanced forms of training aids in formal classroom settings. The course I utilize model rockets in is called Techniques of Instruction, which is an upper level university course to prepare students how to become flight instructors. Techniques of Instruction acquaints students with the fundamentals of teaching and learning in an aviation related environment. It also introduces construction skills, techniques of instruction and analysis of flight maneuvers.

Photo 1: Rockets are used to train teachers on how to become better instructors.

Model rockets are a perfect way to demonstrate how scaled down, three dimensional rockets utilize all of the basic principles of flight that exist in larger aircraft. Thrust, drag, lift and weight are demonstrated in theory and quite graphically when model rockets are taught in this particular course. My college students become completely absorbed in this project while achieving the goal of building a hands-on training aid that utilizes aeronautical principles taught in professional flight instruction. We call this activity the *rocket project.*

The rocket project consists of a two week course that is a part of designing training aids to better teach flight instructor lesson plans. The rocket project requires that a specific kit is to be built, weighed, performance calculated, launched using the same motor, altitude tracked and the results tabulated and compared.

On day one, simple skill-level 1 rocket kits (www.ApogeeRockets.com/Skill_lvl_1_kits.asp) are distributed to the class, along with detailed handouts and reprints from educational curriculum. These plans describe the aerodynamics and basic physics concepts utilized in aerospace applications. Numerous model rocket videos from various sources are also shown on the first day. The class is encouraged to study and even alter the fin design of their rocket kit. Tips for first time and more experienced rocketeers are provided on how to better finish the fins, as well as how to streamline the balsawood fins.

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The Rocket Project

Day two has hands on demonstrations on how to use provided custom plans to cut out new fins from balsawood stock, as well as how to sand and use sanding sealer to produce better airfoils. Painting techniques are also discussed.

Day three has each student weighing their rocket on a triple beam scale. With the measured weight, students use the original 1970 *Estes TR-10 Altitude Prediction Charts* to predict how high their rocket will fly, although using RockSim would be just as good and quicker if you're under a time cruch. Everyone uses the same motor. The B6-6 (www.ApogeeRockets.com/estes_items.asp) has been a favorite choice, as this is a good middle of the road choice for thrust, while providing a long tracking time for better recovery of the rocket. At the end of the calculations, students are required to orally announce how high their rocket will fly. Some good ol' rocket science intuition is encouraged at this point!

Day four is the launch day, weather permitting. The field is measured using the single-station technique described in Peak-of-Flight Newsletter 92 (http://www.ApogeeRockets.com/Education/Downloads/Newsletter92.pdf). This method has worked surprisingly well over the years and is quite accurate. Hand-held altitude trackers (www.ApogeeRockets.com/altitude_tracker.asp) are used, with measured angles being recorded by each tracker. Hand-held Motorola radios are used by the trackers and launch team to better synchronize the recording of each launch. The trackers rotate halfway through the launch so everyone will have their chance to launch their own rockets. At the end of the event, I collect all of the clipboards with the measured angles and calculate the altitudes.

Day five is the awards ceremony. The "best achieved altitude" and "comes the closest to the predicted altitude" winners are announced. There are other dubious awards, such as highest altitude, lowest altitude, greatest difference in predicted altitude, heaviest rocket, and most spectacular flight. Awards consist of new rocket kits, motors and certificates.

The benefits of the rocket project for college students can be measured by providing a project that is a hands-on experience with models, friendly competition between classmates, and a heightened awareness of aerodynamics and performance in a classroom activity.

See also: http://www.facebook.com/album.php?aid=301703&id=117992935984&ref=mf

www.ApogeeRockets.com/classroom_rocketry.asp