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What Is The Relationship Between Altitude And Weight In A Model Rocket?

Abstract:

This experiment was designed to find a function of payload weight for altitude. The same rocket was launched a repeated number of times with the same engine and varying amounts of weight. After performing experimentation, it was calculated that the altitude in meters could be predicted with the equation $A=2.8W^2-70.6W+310.3$, with weight expressed in the unit ounces.

EDITOR'S NOTE: The author of this paper is Mr. Jonathan Betz, a freshman at Thomas Jefferson High School in Falls Church, Virginia.

Introduction:

Aerodynamics, the science with which this project deals, is the study of the forces acting upon an object as it moves through a fluid, such as air. Most often, aerodynamics is applied to studying heavier-than-air craft, such as airplanes.

The four main forces acting upon such an object are lift, gravity, thrust and drag. Lift is the force acting on an object perpendicular to its velocity vector. Gravity is the force which pulls an object towards the center of the earth. For a rocket, thrust is the force which propels an object along its velocity vector. Thrust is opposed by drag, the force which slows an object moving through a fluid.

Governing most of the work done in aerodynamics are the laws of motion developed in the seventeenth century by Sir Isaac Newton. Also, his concept of a fluid's resistance to motion, known as viscosity, has an effect on work concerning aerodynamics.

In 1738, Daniel Bernoulli applied Newton's laws of motion to fluids. In his work he formulated what is known as Bernoulli's Law, which states that the sum of the dynamic pressure and the static pressure must always equal a given constant value, without regard to frictional losses. A bit more simply stated, this means that if the outward, or static, pressure of a fluid decreases, the dynamic pressure, or pressure against an object blocking the flow of the fluid, must increase enough that their sum remains the same. This brings us to the main point of Bernoulli's Law, that if a fluid speeds up, some of the static pressure must be traded off to allow for the increase in dynamic pressure.

An airfoil, the cross-sectional shape of an airplane wing, utilizes this in order to achieve flight. An airfoil is shaped like this:

This shape is used in order to increase the speed of the airflow over the top of the airfoil. When this happens, the air pressure on the underside of the airfoil exceeds the air pressure on the upper side of the airfoil. This creates an imbalance in pressure which is what causes lift.

Purpose:

The purpose of this experiment was to find a mathematical equation for predicting the altitude that a model rocket will attain with any given weight. More importantly, this experiment outlined a procedure for finding such a relationship for any model rocket.

Hypothesis:

While conducting background research, no reference to any relationship between altitude and weight in a heavier-than-air craft that accounted for all factors could be found. However, information from Estes Model Rocket Co. contained formulas for predicting altitude which did not account for aerodynamic drag or air resistance, and these formulas showed that qualitatively, a relation between altitude and weight would be parabolic in nature. However, a quantitative hypothesis as to the relationship between altitude and weight could not be made.

Procedure:

To find a relationship between altitude and payload weight, an Estes Nova Payloader model rocket was launched 6 times with each of 7 different payload weight values. Then, using the average values, an equation was derived to represent the average rocket behavior. The engines used in the rocket have a thrust range between 0.56 and 1.12 Pound-Seconds. For further information on the materials and methods, refer to Appendix 3.

Results:

For the data collected in the experiment, refer to Appendix 1. These data are displayed in various ways in Appendix 2.

Figure 1 in Appendix 2 shows the average altitude for each of the weights for the first day, the second day, and a combined average. The fourth bar shows an average using only values that fall within 1 standard deviation value. Interestingly, this graph shows that on the first day there was an altitude increase between 3 and 3.5 ounces. Most likely, this is due simply to chance. Figure 2 is very similar, but shows only the values for combined and combined adjusted averages. The discrepancy mentioned about day 1 flights is no longer evident when the values are averaged with values from day 2 flights. Figure 3 is just a simple line graph showing the values for the combined adjusted average. This graph is what first suggested that a relation between altitude and weight would be parabolic in nature. Figure 4 shows both the combined adjusted average and the parabolic curve fit to the combined adjusted average values. Figure 5 shows the combined adjusted average of the flight altitudes and calculated flight altitude using calculations from Estes Model Rocket Co.

Conclusions:

As I hypothesized, there seemed to be a parabolic relationship between altitude and weight as suggested by Figure 3. Using the data from maximum, medium, and median weights, I was able to find that when launching a Nova Payloader model rocket with a B4-4 engine, the altitude of the rocket can be predicted by the equation $A=2.8W^2-70.6W+310.3$, where A is the rocket's altitude in meters and W is the weight of the rocket in ounces. This equation yields about an 11% margin of error. This margin of error can possibly be attributed to experimental error and uncontrollable variables such as weather conditions and engine thrust consistency.

Appendix 1
Data

MODEL ROCKET TEST DATA
FLIGHT TRIAL ALTITUDE VS. GROSS WEIGHT

Set #1, Total Rocket Weight = 2.0 Oz.

Launch	Day 1	Day 2	Combined
1	143.5	189.0	
2	156.0	179.5	
3	209.5	198.5	
Range	66.0	19.0	66.0
Average	169.3	189.0	179.3
STD DEV	35.0	9.5	25.3
+/- 1 SDU			204.6 : 154.0
ADJ AVE			180.7

Set #2, Total Rocket Weight = 2.5 Oz.

Launch	Day 1	Day 2	Combined
1	198.5	156.0	
2	101.0	143.5	
3	137.5	137.5	
Range	97.5	18.5	97.5
Average	145.5	145.7	145.6
STD DEV	49.3	9.4	31.7
+/- 1 SDU			177.3 : 113.9
ADJ AVE			143.6

Set #3, Total Rocket Weight = 3.0 Oz.

Launch	Day 1	Day 2	Combined
1	109.0	127.0	
2	81.5	113.0	
3	101.0	113.0	
Range	27.5	14.0	27.5
Average	97.2	117.7	107.4
STD DEV	14.1	8.1	15.2
+/- 1 SDU			122.6 : 92.2
ADJ AVE			109.0

Set #4, Total Rocket Weight = 3.5 Oz.

Launch	Day 1	Day 2	Combined
1	109.0	90.5	
2	113.0	101.0	
3	90.5	84.5	
Range	22.5	16.5	28.5
Average	104.2	92.0	98.1
STD DEV	12.0	8.4	11.4
+/- 1 SDU			109.5 : 87.1
ADJ AVE			97.8

Set #5, Total Rocket Weight = 4.0 Oz.

Launch	Day 1	Day 2	Combined
1	66.5	57.5	
2	42.5	44.5	
3	42.0	42.5	
Range	24.5	15.0	24.0
Average	50.7	48.2	49.3
STD DEV	14.0	8.1	10.3
+/- 1 SDU			59.6 : 39.0
ADJ AVE			45.8

Set #6, Total Rocket Weight = 4.5 Oz.

Launch	Day 1	Day 2	Combined
1	32.5	40.5	
2	37.0	40.5	
3	37.0	39.0	
Range	4.5	1.0	8.0
Average	35.5	40.0	37.8
STD DEV	2.6	0.9	3.0
+/- 1 SDU			40.8 : 34.8
ADJ AVE			38.8

Set #7, Total Rocket Weight = 5.0 Oz.

Launch	Day 1	Day 2	Combined
1	22.5	37.0	
2	23.5	31.5	
3	10.5	32.5	
Range	13.0	6.0	27.0
Average	18.8	33.6	26.2
STD DEV	7.2	2.9	9.5
+/- 1 SDU			35.7 : 16.7
ADJ AVE			27.5

MODEL ROCKET TEST DATA
AVERAGE ALTITUDE VS. GROSS WEIGHT

Weight	Combined Average	Standard Deviation	Adjusted Average
2.0 Oz	179.3	25.3	180.7
2.5 Oz	145.6	31.7	143.6
3.0 Oz	107.4	15.2	109.0
3.5 Oz	98.1	11.4	97.8
4.0 Oz	49.3	10.3	45.8
4.5 Oz	37.8	3.0	38.8
5.0 Oz	26.2	9.5	27.5

Appendix 2
Graphs

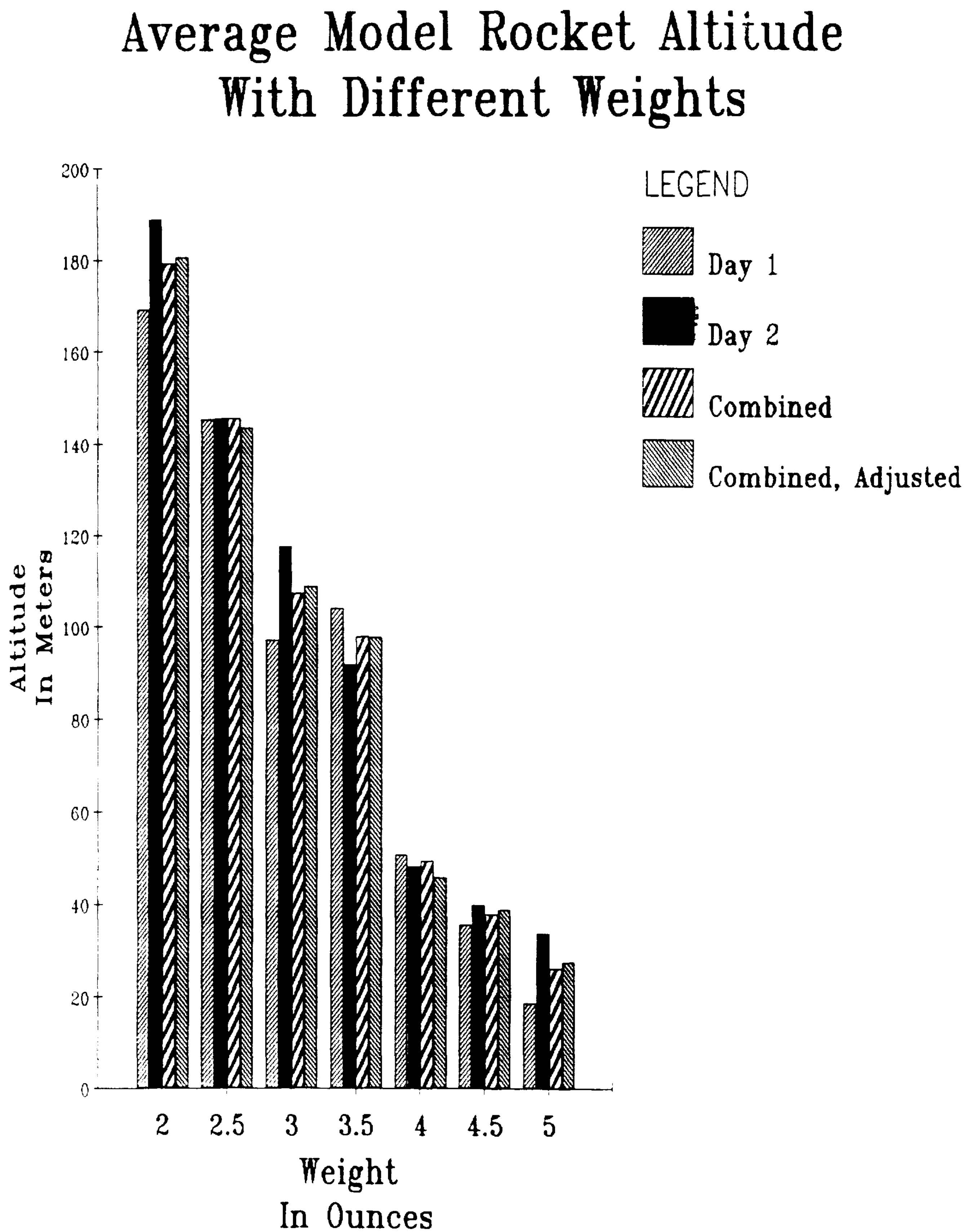

Average Model Rocket Altitude
With Different Weights
LEGEND
Day 1
Day 2
Combined
Combined, Adjusted
Altitude
In Meters
200
180
160
140
120
100
80
60
40
20
0
2
2.5
3
3.5
4
4.5
5
Weight
In Ounces

Figure 1

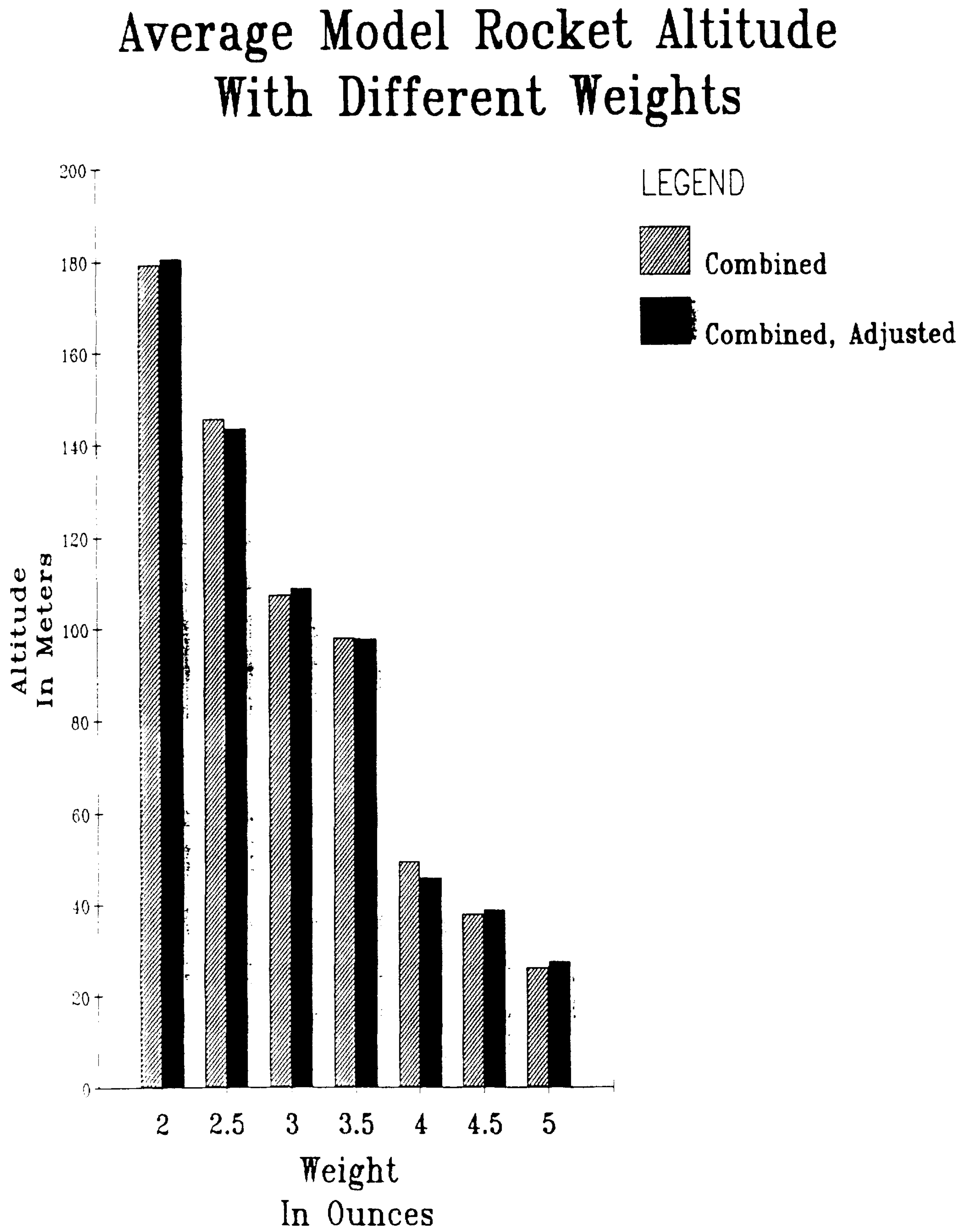

Average Model Rocket Altitude
With Different Weights
LEGEND
Combined
Combined, Adjusted
Altitude
In Meters
200
180
160
140
120
100
80
60
40
20
0
2
2.5
3
3.5
4
4.5
5
Weight
In Ounces

Figure 2

Average Model Rocket Altitude With Different Weights

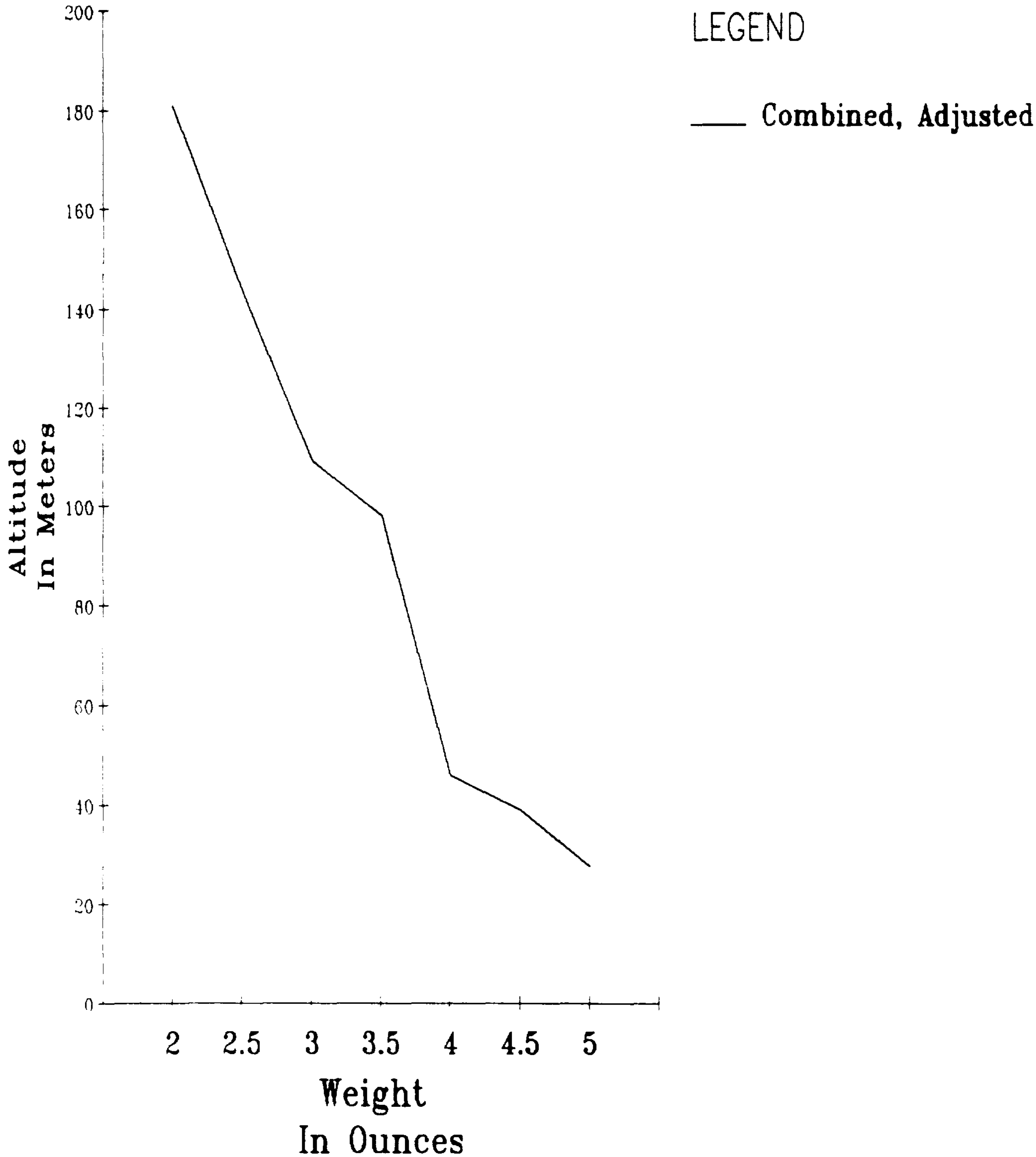
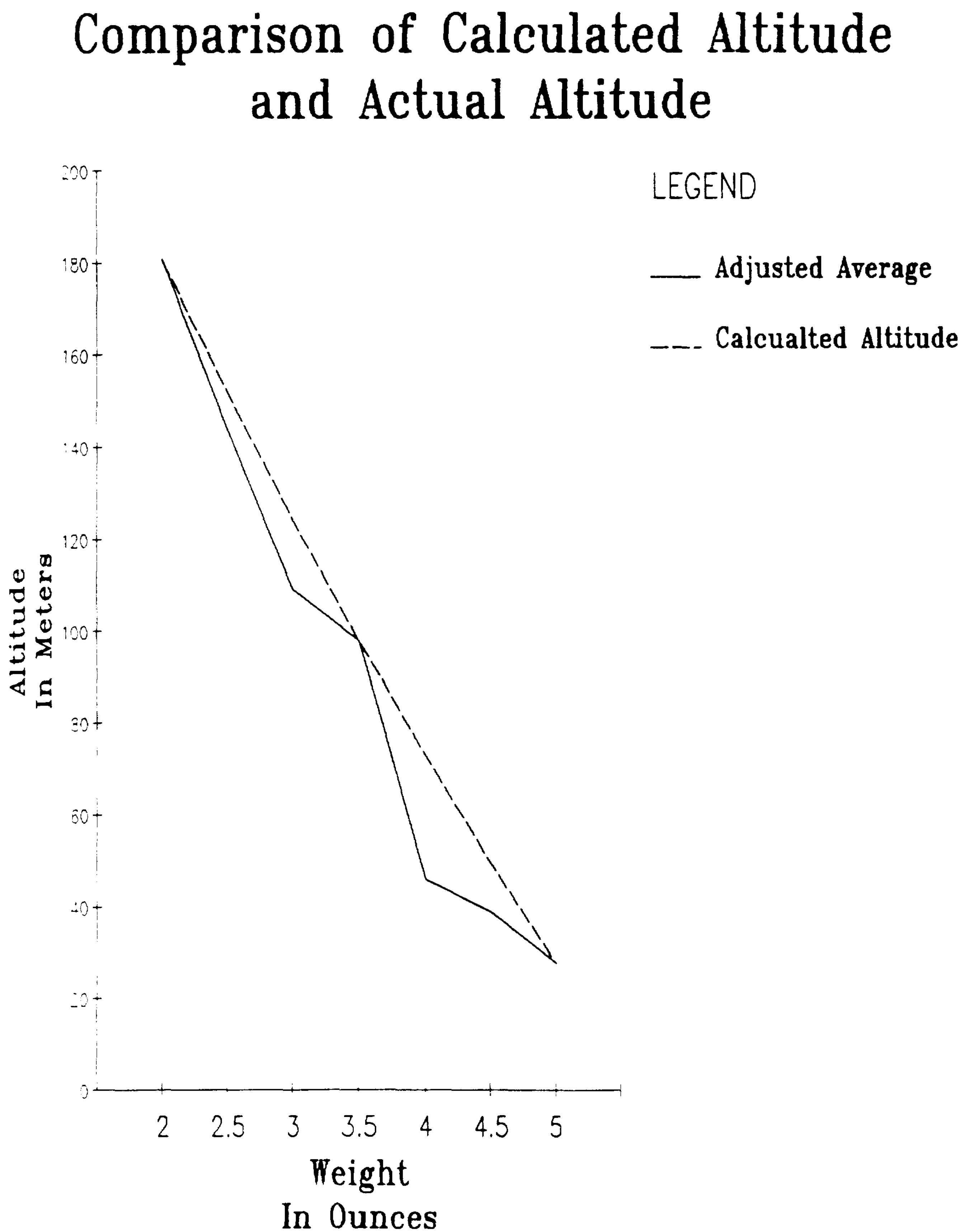


Figure 3



Comparison of Calculated Altitude and Actual Altitude
LEGEND
Adjusted Average
Calcualted Altitude
Altitude In Meters
0
20
40
60
80
100
120
140
160
180
200
2
2.5
3
3.5
4
4.5
5
Weight In Ounces

Figure 4

Comparison of Calculated Altitude and Actual Altitude

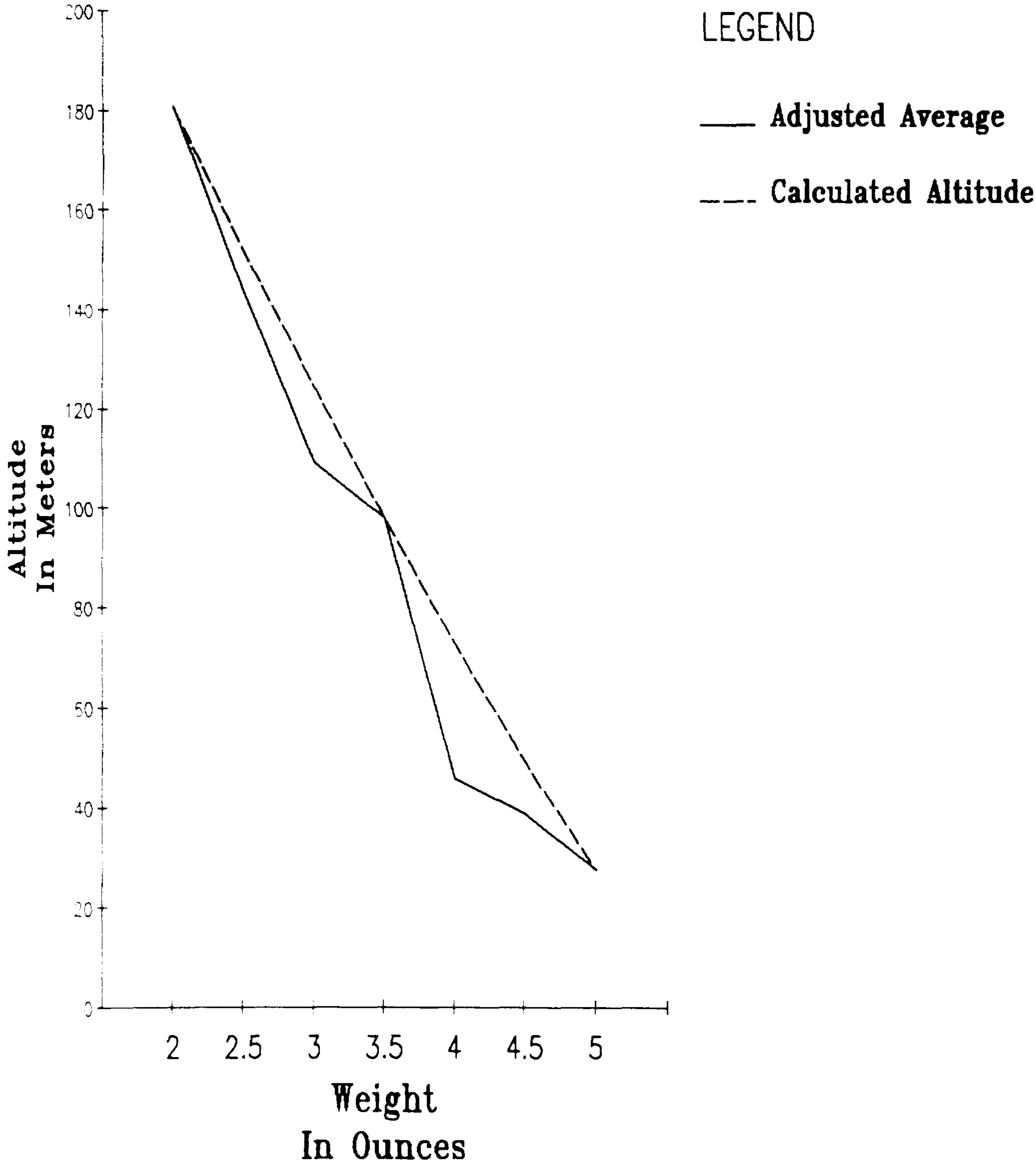


Figure 5

Appendix 3
Materials and Methods

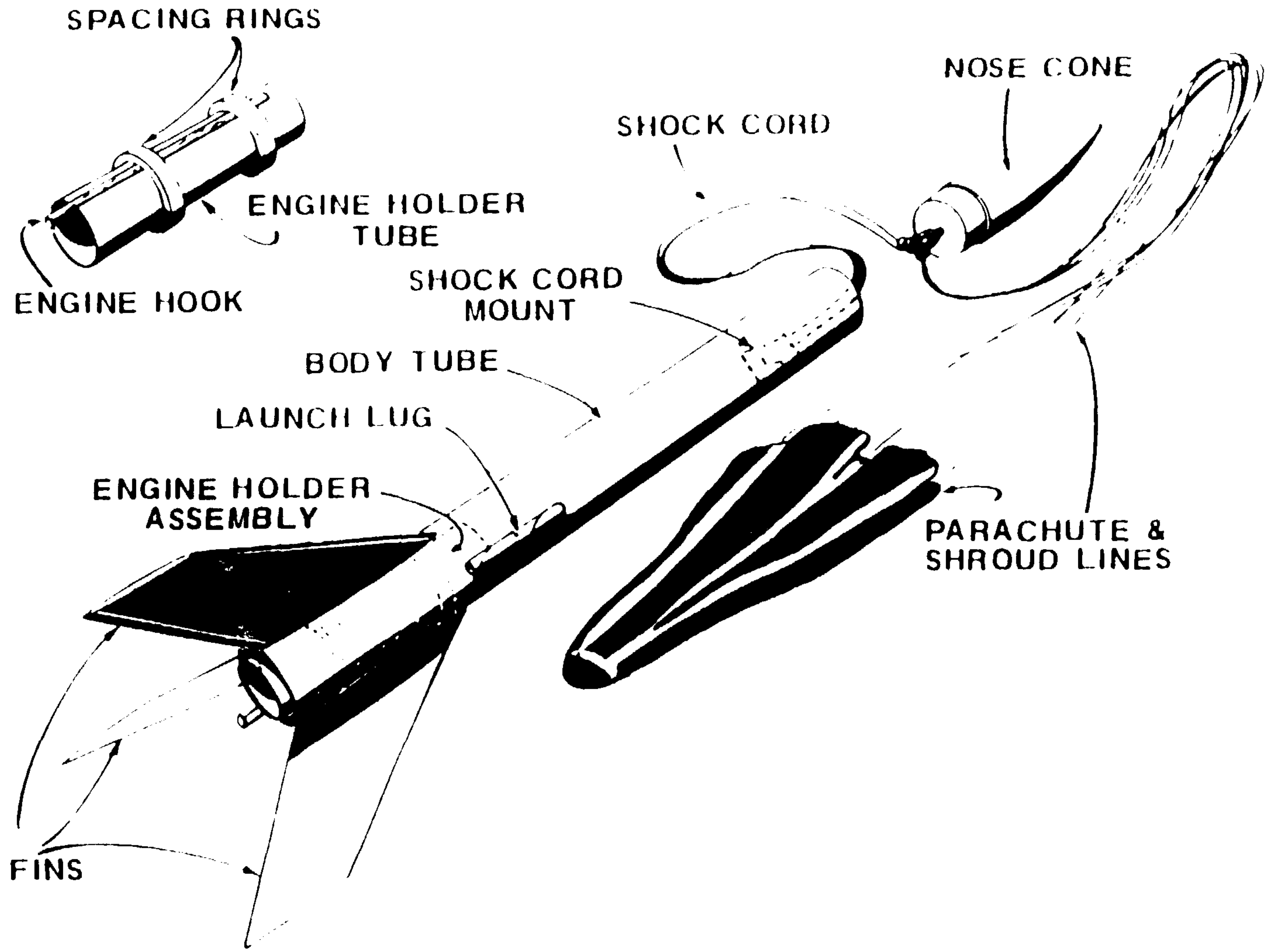
1 Estes <u>Nova Payloader</u> model rocket
1 Estes <u>Altitrak</u> altitude finder
44 Estes B4-4 model rocket engines
2 Estes A8-3 model rocket engines
2 Estes B6-4 model rocket engines
3 packages of Estes model rocket recovery wadding
6 packages of Estes model rocket igniters
1 roll of masking tape
1 scale
1 Estes launch pad
1 Estes model rocket launcher and safety key
75 meters of twine
2 tent pegs
1 level
8 packages of lead fishing sinkers

1. Assemble <u>Nova Payloader</u> model rocket
2. Assemble <u>Altitrak</u> altitude finder
3. Weigh out 6 sets of weights, beginning with 1/2 ounce and continuing to 3 ounces, in 1/2 ounce increments
4. Measure 75 meters of twine, attaching a tent peg to each end
5. Proceed to launch site, Manassas battlefield picnic area
6. Set up launch site:
    a) set launch pad down and check launch rod to be vertical
    b) hammer one tent peg into the ground by the launch pad
    c) stretch twine out until taught and hammer second peg into the ground
    d) station one observer at the far end of the twine with altitraker
    e) prepare launch controller for launching
7. Prepare the rocket for launch
    a) insert 3 crumpled squares of recovery wadding into the rocket
    b) insert and tape an igniter into a rocket engine
    c) insert engine into rocket
    d) roll parachute and insert into body of rocket with shock cord
    e) insert nose cone and payload section into body tube of rocket
8. Determine the best rocket engine for use in experimentation
    a) launch rocket twice with each of the B6-4, B4-4, and A8-3 engines, once with no payload, once with maximum payload
    b) record altitude of each launch
    c) using this information, decide on the best engine to use
9. Conduct experimentation
    a) for each flight, prepare the rocket as in step 7
    b) launch the rocket 3 times with no payload
    c) launch the rocket 3 times with each premeasured payload

d) record the altitude and launch time of each flight
e) record weather conditions every hour while launching rockets

10. Repeat steps 4-7 and 9 at a later date
11. Calculate relationship between altitude and weight

Appendix 4
Other Information



PARTS OF A MODEL ROCKET

ALTITUDE TRACKING GEOMETRY