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First-Year Project Experience in Aerospace: Apogee Determination of Model Rockets With Explicit Consideration of Drag Effect

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Dr. Landman is a Professor of Aerospace Engineering at Old Dominion University where he teaches graduate level classes in aerodynamics and statistical based experiment design, and supervises doctoral and masters students. His current research areas include use of statistical process control in long term balance calibration monitoring, use of Design of Experiments(DOE) in wind tunnel check standard testing, and development of in-flight test methods for use with unmanned aerial vehicles. Landman was jointly appointed as Chief Engineer at the Langley Full-Scale Tunnel (LFST) at NASA Langley until its closing in September 2009. During his 13 year tenure at the LFST, Dr. Landman was responsible for designing force measurement systems and supervising wind tunnel tests on a variety of test articles including aerospace and ground vehicles. Dr. Landman has served as an international consultant for training engineers in DOE as applied to aerospace ground testing.

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Dr. Linda Vahala received her B.S..degree from the University of Illinois in 1969, an M.S. degree from the University of Iowa in 1971, and a Ph.D from Old Dominion University in 1983. Her publications include articles in both plasma physics and atomic physics with an emphasis on laser interactions with plasma and with neutral/rare gas collisions. She has presented her work at various international workshops and meetings, both in Europe and in the United States. She is currently Associate Dean and Director of the Engineering Fundamentals Division at ODU. In 1995, she received the Peninsula Engineer of the Year award.

First Year Project Experience in Aerospace Engineering: Apogee Determination of Model Rockets with Explicit Consideration of Drag Effect

Abstract

This paper describes a student team project to learn engineering solution methods for determining the apogee of a model rocket when the drag effect is considered explicitly. Model rocketry is a powerful tool for instructors who wish to incorporate science, engineering, and mathematics into a fun, engaging, and challenging activity for students. In this project, students construct their own rockets and launch them using commercial model rocket engines to determine the apogee of the flight. The apogee can be determined using a number of methods: trigonometry, onboard altimeters, analytical calculations, and simulation. This paper emphasizes numerical and other analytical prediction methods using spreadsheet programming instead of a full analytical solution that requires higher mathematics. Students got a practical introduction to many engineering concepts they will later study. These concepts include thrust, impulse, drag force, payload, ascent and descent (with and without a parachute) times, speed, and acceleration. The importance of the future courses in physics are emphasized. These activities constitute one of two team projects of a 1.5 credit portion of a two-credit course in exploration of engineering and technology at the Old Dominion University in Norfolk, VA. Students learn many skills they need later in their studies and professional practice such as spreadsheet data entry and mathematical operations. Not the least of which is teamwork, a skill that they acquire as they organize into groups with specialized responsibilities for the purpose of launching their rockets, collecting data to be processed, and writing a report. Metric units were used.

Introduction and Educational Goals

Model rocketry is at once miniature astronautics, technological recreation, and an educational tool. A model rocket is a combined miniature version of a real launch vehicle. A model rocket is a very convenient metaphor to illustrate many important engineering concepts and principles in a fun and exciting way. Once a model rocket leaves the launcher, it is a free body in air. Model rockets have been used as student projects for decades. Other similar publications [1, 2, 10, 11, 17, 20, and 21] report engineering projects in the same general area, but this project is unique in the literature. Mathematics and physics aspects of model rocketry are reported in references 3, 5, 12, 14, 16, 18, and 23. Figure 1 shows a cross section of a model rocket. The main educational goal of this project is to study the major methods to estimate the apogee and attempt to confirm the results using extensive field experiments. Student teams performed all analysis, programming, construction, and field work after they were instructed using smaller models. Uncertainty in prediction methods is a lesson well depicted in this project and a life lesson for students.
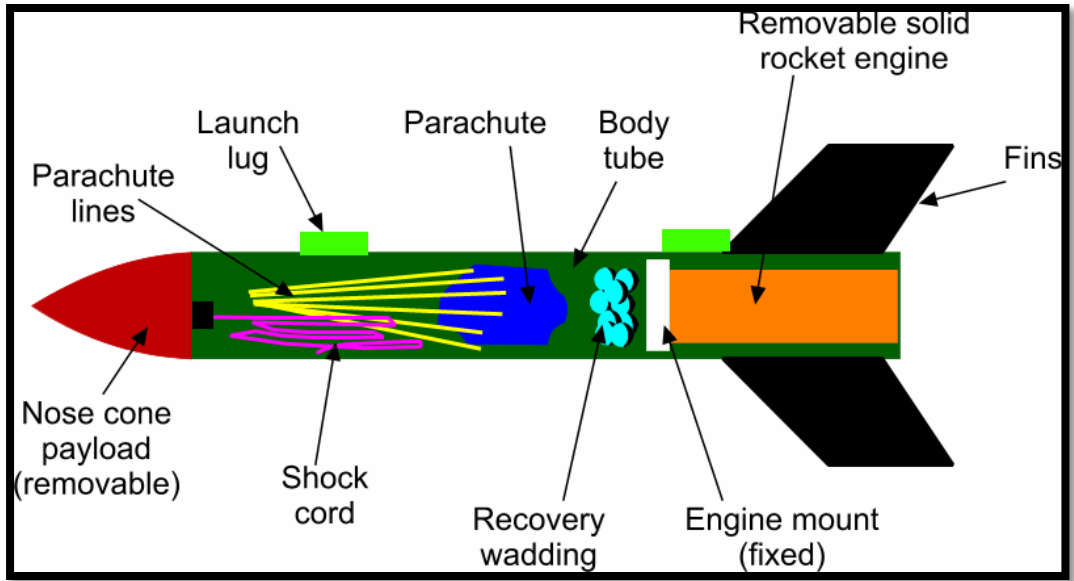
Figure 1. Single stage model rocket with an engine

Model Rocket Flight Details: A model rocket has three flight phases: powered flight, coasting flight, and recovery. Figure 2 shows the three phases of the flight. The rocket is launched by the ignition of the engine.
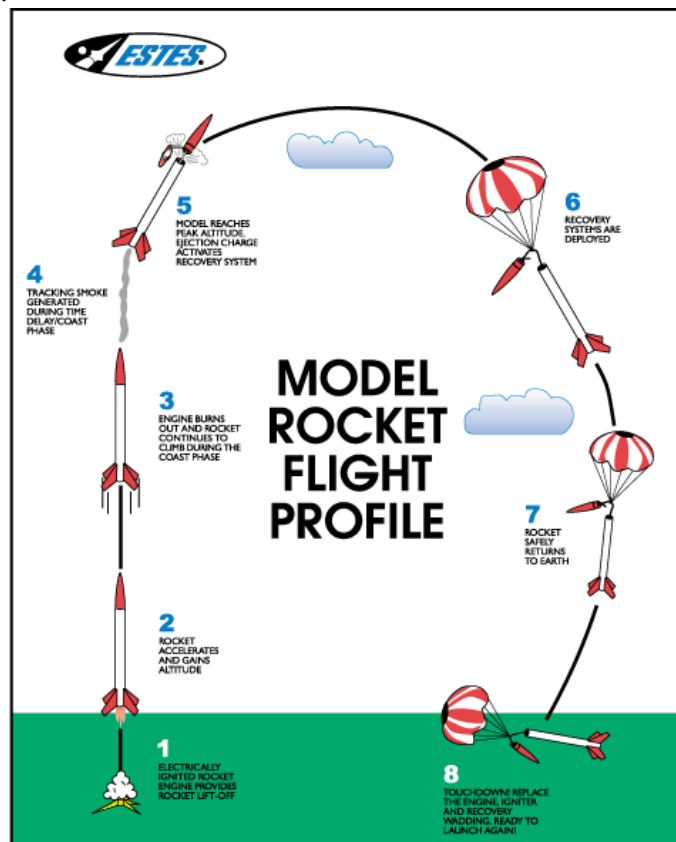

Figure 2. Model rocket flight profile [6].

The powered phase of the flight lasts until the engine has consumed all its propellant. During this phase, the model rocket accelerates and moves in response to the forces of thrust, gravity, drag and lift. In order for this phase of flight to be successful, the rocket must be stable. The fins enable the rocket to correct the flight path when it is momentarily perturbed. When perturbed, an angle develops between the rocket's longitudinal axis and the freestream velocity vector called the angle of attack. At angle of attack, the fins will create a lift force, generated by the relative wind, which causes the rocket to align its longitudinal axis with the relative wind again.

This project utilized Estes D12-5 engines. Model rocket engines consist of a propellant powder pressed into a nonmetallic cylindrical casing. The propellant is black powder made of potassium nitrate, sulfur, and charcoal. The rocket gets its power from a chemical reaction which is a non-stoppable controlled explosion that sends gas out the nozzle at a high speed. The appendix shows the specifications for the engine. It was noted that an impulse of 20 N-sec claimed by the manufacturer is disputed by an independent test carried out by the National Association of Rocketry (NAR). This project also confirmed that D12-5 engine's impulse is less than 20 according to field experiments using an altimeter. The impulse value is random with a mean of 16.84 and a standard deviation of 0.53 N-Sec. Similarly, burn times are also random and longer than 1.60 seconds stated by the manufacturer. The average mass of an engine was 47 grams (vs. 43.1 per manufacturer) in this project. The average mass of a used engine was 18 grams. The majority of the difference of 29 grams is due to lift propellant, but it also includes the chemicals for the tracer smoke and parachute ejection. Hence, the manufacturer's propellant mass value (21 grams) was used in calculations. Figure 3 shows a D12-5 engine on a scale.

Figure 3. Mass determination of a D12-5 engine

An altimeter (AltimeterTwo) was used as a payload. Figure 4 shows the payload. The appendix shows the specifications of the altimeter which worked very well in this project.

Figure 4. Mass determination of the payload

A stable rocket always flies into the relative air flow; the presence of wind blowing across the launch field affects the flight path. The relative wind is the sum of two components -the airflow opposite to the direction of the rocket's motion and aligned with the longitudinal axis and flow with a direction orthogonal to the longitudinal axis. The net result is a relative wind that causes the rocket's flight path to curve away from the pure vertical and into the upwind direction. This effect is called "weathercocking" [6, 22]. The rocket's aerodynamic drag is very important. The drag force is expressed as follows:

$$D = 0.5 \, \rho \, V^2 \, C_d \, A \quad (1)$$

Where ρ is the density of the air. C_d is the coefficient of drag that depends on the shape and surface finish of the rocket. V is the velocity and A is the frontal area of the model. A high thrust engine will cause a rocket to experience more drag than a low thrust engine because the rocket will reach higher velocities, but higher thrust engines will still make the rocket reach a higher apogee. The coasting phase begins when the propellant is exhausted. The delay element is a timing device that controls the deployment of the recovery system. Recovery system deployment occurs near the apogee in most cases. During the coasting phase, the rocket slows down since the engine no longer produces thrust. The smoke that is observed comes from the smoke-tracking and delay element of the engine. The recovery phase starts as soon as the smoke-tracking and delay element is exhausted. Model rockets can be dangerous if not handled safely. Each student turns in a homework early in the semester by handwriting the entire safety code of

the NAR. The students are also asked to find and report a model rocket accident in the same homework.

Commercially Available Model Rockets

Model rockets are available in two common forms: ready to fly (RTF) and to be constructed from a kit. Figure 5 below shows the RTF models used for demonstration and practice calculations. The RTF model rockets in Figure 5, from left to right, are the Fat Jack, the Rattler-7, the MaxTrax, and the Skytrax which comes with its own payload bay. A payload can be an altimeter as in Figure 5 or anything else that is allowable including an insect. The MaxTrax has a built-in altimeter, but it is very unreliable.

Figure 5. RTF model rockets used for practice

The project used QWEST Corporation's Big Dog (B & D) model that had to be constructed. The B&D is a relatively large model, but it does not have a payload bay as in the SkyTrax above. The cone had to be fitted with hooks and wires to hang the altimeter and tiny holes had to be drilled on the upper part of the tube to allow air in for pressure differential detection.   The B & D model has four fins, a length of 82.55 cm and a mass of 198.45 grams according to the manufacturer which also specifies the maximum diameter as 4.80 cm. Measured diameters were larger due to painting and 5.10 cm was used in calculations. In addition, a launch lug with a diameter of 0.635 cm was attached.

Dynamics of Model Rockets

If we assume a vertical flight with zero degree of angle of attack and ignore the lift as a force to simplify calculations, there are three force factors on a model rocket as shown on the right in Figure 6 below.

1) Thrust (T) from the engine acts on the back of the model and makes it accelerate,
2) Weight (W) is a force that slows the model in its vertical flight. This force decreases slightly over time due to propellant consumption and is the product of gravitation acceleration and mass
3) Aerodynamic drag (D) force is a force due to air friction and separated flow which acts to slow the model.
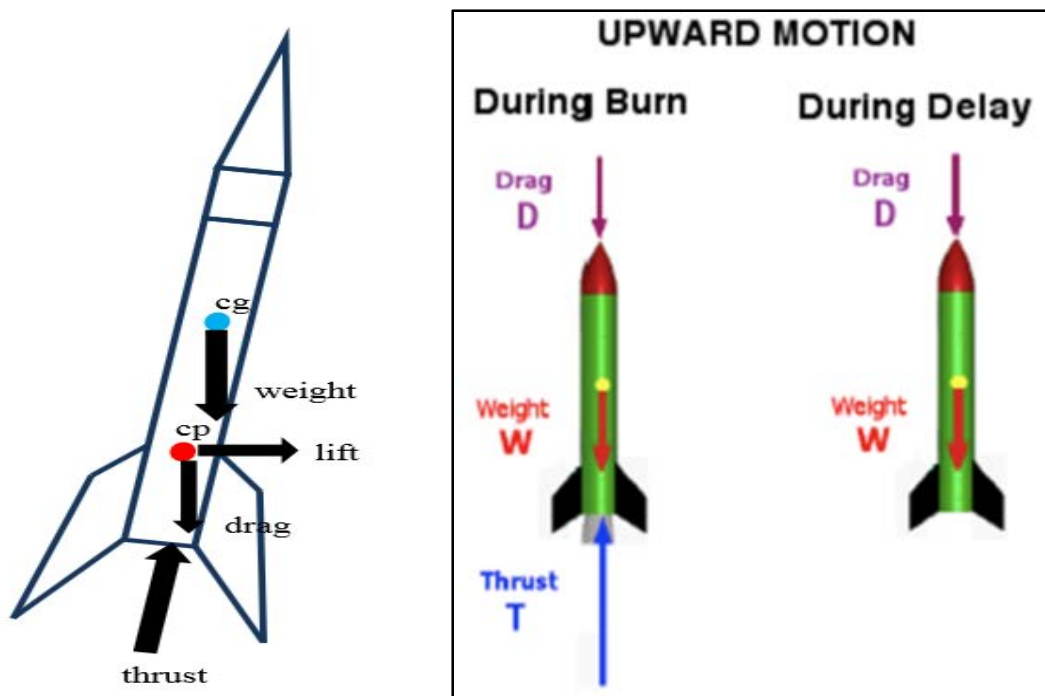
Figure 6. Actual and simplified (right) free body diagrams of a model rocket in Flight [2]

During the powered flight, all three forces act upon the model, but the thrust is zero during the coasting flight. Freshmen are introduced to Newton's three laws of motion or reacquainted as some were exposed to them in high school physics. These laws are stated below:

1. Objects at rest will stay at rest, and objects in motion will stay in motion in a straight line at constant velocity unless acted upon by an unbalanced force,

2. Force is equal to mass times acceleration. $F = m\ a$ (2). This equation applies to launching the rocket off the launch pad. Thrust is a forward propulsive force that moves an object and is produced by the engine.   As the engine ignites and thrust develops, the forces become unbalanced. The rocket then accelerates. Rocket propellant is burned and converted into gas that expands and then

escapes from the rocket. Acceleration is the rate at which the gas escapes. The gas inside the engine accelerates as it leaves the engine. The greater the amount of propellant burned, and the faster the gas produced can escape the engine, the higher the resulting thrust.

3. For every action there is always an opposite and equal reaction. A model rocket will lift off if it expels gas out of its engine. The rocket pushes on the gas and the gas pushes on the rocket. The action, then, is the expulsion of gas out of the engine. In return, the reaction is the departure of the rocket skyward.

Model Construction and Pre-Launch Activities

In fall 2015, 104 students were randomly assigned to groups of 3 to 5 and each group was given a kit to construct the model. Figures 7 through 12 show various stages of model construction and launch preparation.

Figure 7A. Construction of the B&D model mockets by student teams

Figure 7B. Painting
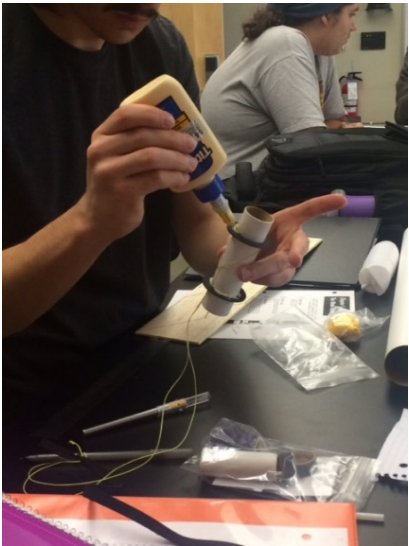
Figure 8A. Engine Mount Insertion and Painting of the Models.

Figure 8B. Holes drilled to allow air for altimeter to work
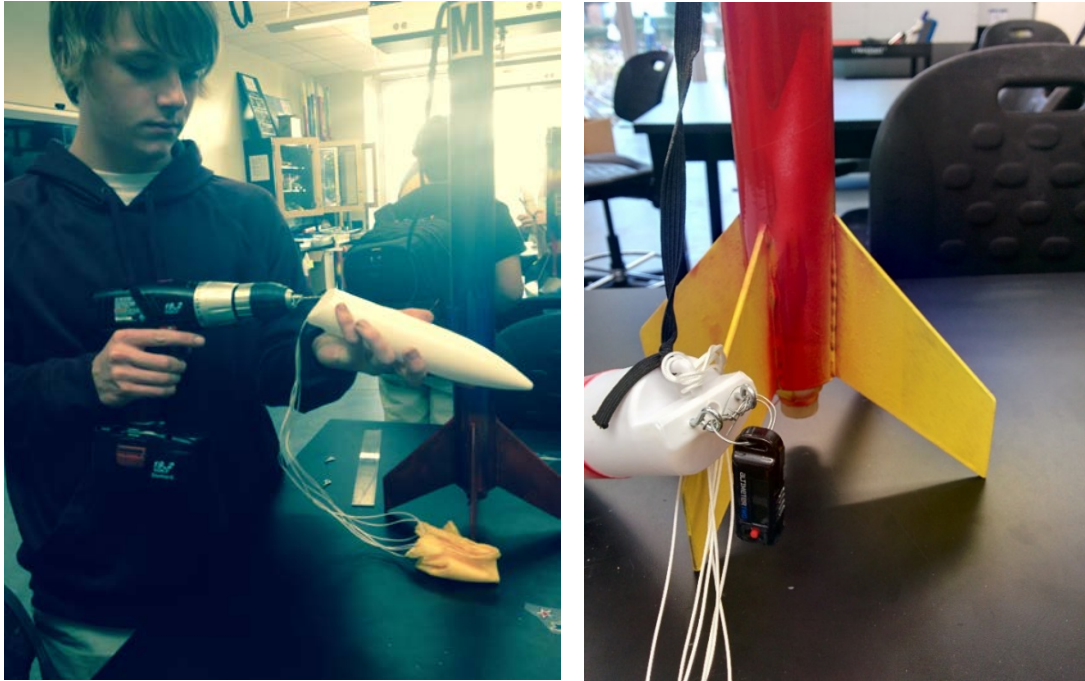
Figure 9. Drill work and wiring for payload (altimeter) insertion

Figure 10. Nose cone with an unattached payload
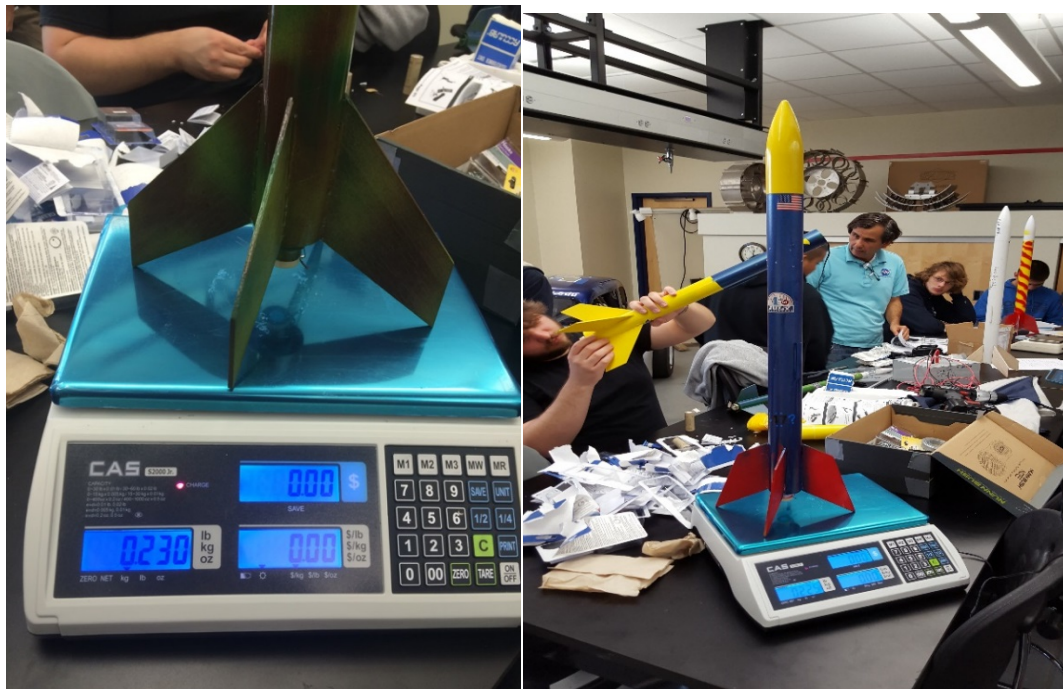
Figure 11A. Determination launch masses excluding the payload and wiring (engine included)
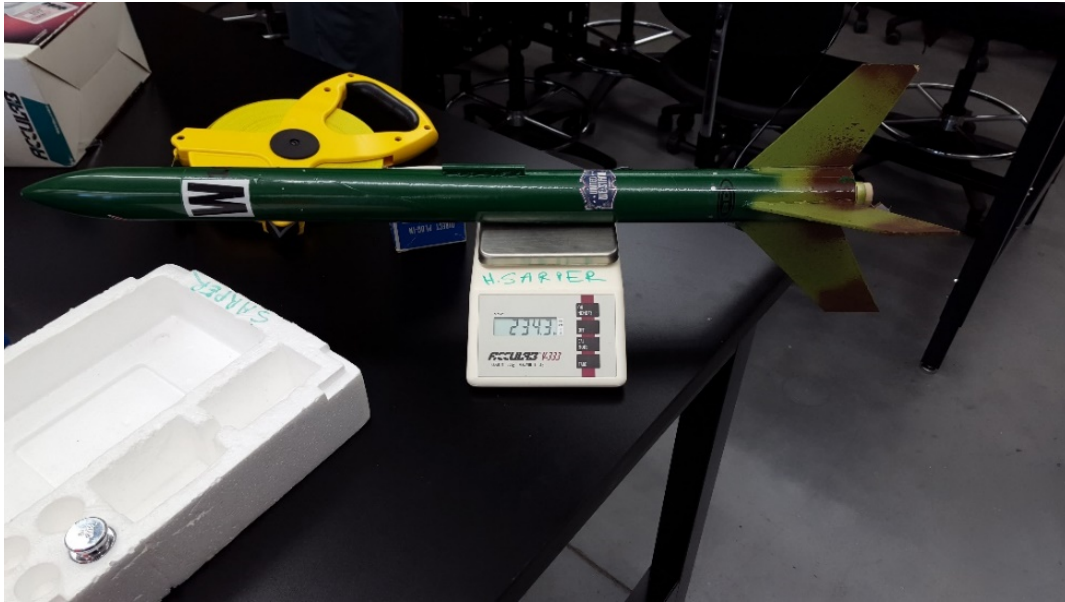
Figure 11B. Determination launch masses excluding the payload and wiring (engine included)
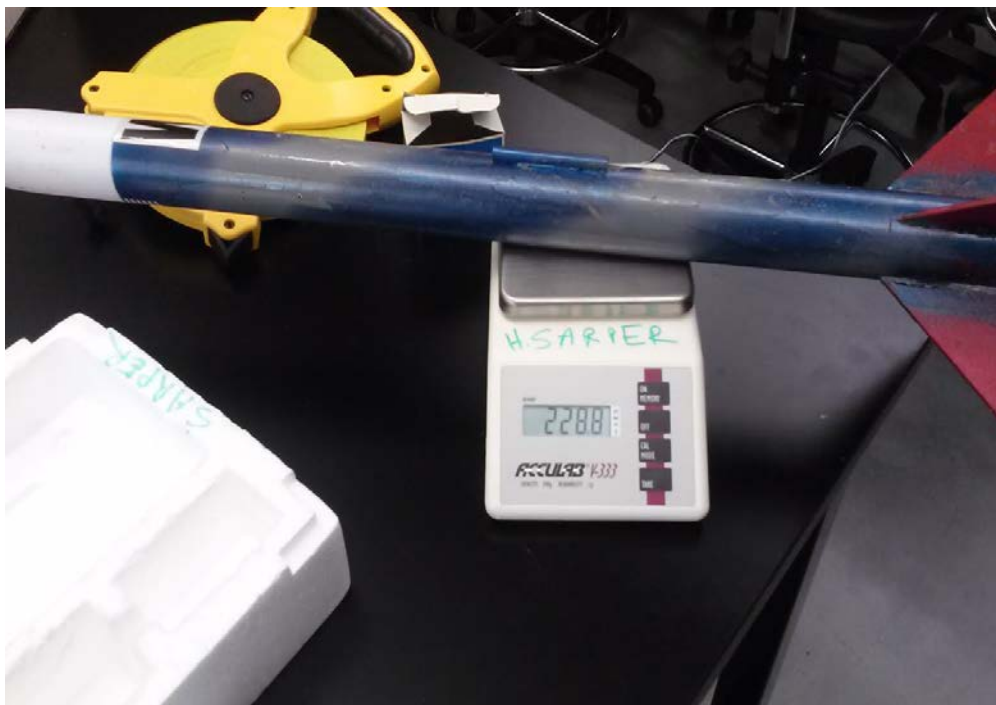
Figure 12. Determination of the launch lass of another model rocket

Figures 13 and 14 show the moments just ahead of marching to a remote parking lot on campus. The university parking service was able to make only one-half of a remote lot available on a Sunday.   This lot is by no means an ideal place, but the urban location of the campus leaves few alternatives. Figure 15 shows the instructor and two teams.

Figure 13. B& D model rockets ready for launch

Figure 14. The main launch event on 10/25/2015

Figure 15. Make up launch event in November 2015

The altimeter was set before each launch as shown below in Figure 16.

Figure 16. Altimeter is set to launch

Figure 17 shows an in-house built launcher as hobby store launchers were not always reliable.

Figure 17. Home built launcher to reduce misfires and provide consistent current

Figures 18 through 21 show various launch and flight scenes. On-board altimeter collects the data shown in Table 1.

Figure 18. The first B&D model rocket descends

Figure 19. A B&D model rocket accelerates and clears the "tower"

Figure 20. Another model rocket takes off

Figure 21. It ascends

Flight Trial Launch Results

Table 1 below shows the data for 27 launches of B&D model rockets in fall 2015. Five rockets with altimeters were lost due to various reasons. Teams with lost rockets were allowed to use another team's data. While this project concentrated on the determination of apogee, a wealth of additional flight data (speed, acceleration, and flight times) were also obtained as shown in Table 1.   The appendix includes two sample raw data collection sheets for fall and spring semesters.

Apogee Prediction Methods

This section provides the variables and the formulas used by the students. Five non-physical apogee determination methods are also explained. Students learn that physical data, as in Table 1 above, should be collected after other methods, analytical and simulation based, are first applied in order to reduce costs and improve physical experiment.

Definition of Variables

m_o = Lift-off mass (kg)
m_p = Propellant mass (kg)
m_b = Burn-out mass (kg)

W_o = Weight before burnout (N)
W_b = Weight after burnout (N)

T = Thrust (N)
D = Drag force (N)

$Vmax_1$ = Maximum speed at burnout (m/sec)
$Vmax_2$ = Maximum speed (MPH)
V_{av} = Average speed (m/sec)

S_b = Burnout occurs (m)
S_t = Total apogee without drag (m)
S_c = Coasting distance
S = Expected apogee with drag (m)

g = Acceleration of gravity (m/sec^2)
d = Drag effect factor
C_d = Drag coefficient

I = Total impulse (N-Sec)

B_t = Thrust duration or burn time (sec)
Δt = Time increment for numerical analysis (sec)

a = Acceleration (m/sec^2)
V = Speed (m/sec)

ρ = Air density (kg/m^3)
A = Area of rocket cross section (m^2)
r = Radius of the rocket (m)

	M4	W8	W10	W6	M1	W5	M9	M13	M2
Launch Sequence	1	2	3	4	5	6	7	8	9
Launch Mass (kg)	?	0.236	0.246	0.236	0.241	0.241	0.241	0.241	0.231
Apogee (m)	103	99	94	98	101	98	82 C	93	98
Parachute Ejection (m)	102	94	85	79	98	56	62	89	75
Maximum Speed (m/sec)	39	37	38	38	38	38	38	37	39
Descent Speed (m/sec)	5	5	5	8	5	3	4	5	7
Thrust Time (sec)	2.70	2.25	2.16	1.94	2.10	2.20	2.50	2.50	1.90
Coast Time (m/sec)	3.30	3.20	3.10	3.20	3.30	3.10	2.70	2.80	3.10
Apogee to Eject Time(sec)	0.60	1.10	1.50	2.20	1.00	n/a	2.50	1.20	2.50
Total Flight Time (sec)	24.30	23.50	22.20	16.70	25.40	23.20	20.40	24.20	18.30
Peak Acceleration (G)	6.0	6.0	6.3	6.3	6.1	8.4	6.5	6.3	6.8
Average Acceleration (G)	2.0	1.7	1.8	2.0	1.8	1.7	1.9	1.7	2.0
Model Rocket ID	M10	W13	M12	M15	M3	M5	W3	M14	W9
Launch Sequence	10	11	12	13	14	15	16	17	18
Launch Mass (kg)	0.236	0.236	0.246	0.236	0.251	0.246	0.236	0.236	0.241
Apogee (m)	111	110	87	87	80	91 S	113	93	91
Parachute Ejection (m)	109	110	78	77	70	81	109	68	76
Maximum Speed (m/sec)	41	40	25	36	35	35	40	37	38
Descent Speed (m/sec)	5	4	13	6	5	6	5	4	6
Thrust Time (sec)	2.18	2.21	1.79	1.92	2.16	2.13	2.17	1.92	1.88
Coast Time (m/sec)	3.40	3.90	2.80	2.90	2.70	3.00	3.30	3.10	3.00
Apogee to Eject Time(sec)	0.70	n/a	1.70	1.70	1.60	1.60	1.10	2.60	2.00
Total Flight Time (sec)	27.50	29.00	11.9 P	19.10	19.20	20.00	27.40	22.40	19.80
Peak Acceleration (G)	7.0	6.8	3.6	6.5	5.7	5.6	6.8	6.7	5.4
Average Acceleration (G)	1.9	1.8	1.5	1.9	1.6	1.7	1.9	2.0	2.1
Model Rocket ID	M7	W12	M8	W10	W10-R	W4	W1	W2	W?
Launch Sequence	19	20	21	22	23	24	25	26	27
Launch Mass (kg)	0.226	0.241	0.251	0.246	0.245	0.237	0.239	0.236	0.235
Apogee (m)	104	94	100	94	99	108	96	112	101
Parachute Ejection (m)	103	87	93	85	96	106	89	108	77
Maximum Speed (m/sec)	39	35	36	36	38	39	37	40	40
Descent Speed (m/sec)	4	5	6	5	4	5	5	9	8
Thrust Time (sec)	2.21	2.15	2.20	2.16	2.15	2.33	2.18	2.19	1.96
Coast Time (m/sec)	3.30	3.10	3.10	3.10	3.00	3.10	3.10	3.40	?
Apogee to Eject Time(sec)	0.40	1.30	1.40	1.50	1.10	0.90	1.30	1.00	2.40
Total Flight Time (sec)	27.60	24.00	21.50	22.20	26.60	25.70	24.70	18.60	17.00
Peak Acceleration (G)	6.6	5	5.6	6.3	6.5	6.1	6	6.8	7
Average Acceleration (G)	1.8	1.7	1.7	1.8	1.8	1.8	1.7	1.9	2.1

Table 1. Fall 2015 Launch Data

1) Simplified Analytical Spreadsheet Model

F in equation 2 is the sum of all applied forces in Figure 6; m is the mass of the model and a is the resulting acceleration. $I = m_b Vmax_1 - m_0 v_0$ **(3)**, v_0 = velocity at lift-off which is zero. Impulse is also equal to force x time. Thrust = total impulse/burn time or $T = (I/B_t)$ **(4).** Using equation 2, the net force ignoring the drag is $T-W = m a$. Then, $T-W = (W/g) (Vmax_1/ B_t)$ **(5)** where $Vmax_1 = a B_t$ and $m = (W/g)$. This yields: $Vmax_1 = [(T/W) - 1] g B_t$ **(6).**

The term $Vmax_1$ is the velocity at the end of the impulse or thrust period and called the burnout velocity. It is also the maximum velocity the model can attain. At lift-off, the propellant to total rocket mass ratio is about 5% for most model rocket and engine combinations. This is contrary to full-scale rockets. This issue is discussed in class by looking up some larger rocket mass ratios on the web. The ratio of the propellant's mass to the model rocket's is very small and during the flight the mass stays fairly constant. As the force is fixed and the mass is almost constant, acceleration can be assumed constant. The velocity is acceleration times the thrust time ($V = a B_t$) where, B_t is the end of the thrust duration. The average velocity during thrusting is the average of initial and maximum velocities or just half of the maximum velocity: $V_{av} = Vmax_1/2$ **(7).**

While thrusting for B_t seconds, the model rocket will climb a distance of $S_b = V_{av} B_t$ **(8).** When the engine stops thrusting, the model rocket starts its coasting flight and climbs up an additional distance of $S_c = [(Vmax_1)^2 / (2 g)]$ **(9).** The apogee is the sum of both distances, $S_t = S_b + S_c$ **(10).**

The discussion so far neglects lift and drag forces. The aerodynamic drag has a big effect on the actual altitude. Stine's text [22] states that aerodynamic drag lowers the computed drag-free maximum altitude of a model rocket by 50 percent (for low-powered models) to as much as 80 percent (for high-powered models). Then, the actual apogee is: $S = S_t * d$ **(11).**

Then, d is the fraction of S_t that is the actual apogee. The value of d ranges from 0.20 to 0.80, but the value of coefficient "d" is never found in the engine specifications of any manufacturer. Steps outlined in equations 3 through 11 constitute the simplified analytical method implemented by each project team before the drag effect is considered explicitly in other methods. A d value of 0.50 seemed to yield the correct apogee value determined later by more advanced methods. The "d" variable is often confused with C_d variable used in other methods.

Figure 22 shows the EXCEL code for the method 1.

2) Numerical Analytical Spreadsheet Model

Thrust: $T = I/B_t$ **(12)**

Weight Force:
$W_0 = - m_o*g$ before burn out **(13)**
$W_b = - m_b*g$ after burn out **(13)**
Drag force:

$D = -0.5 * C_d * \rho * A * V^2$ **(14)**

    Acceleration:

$a = (T + W_0 + D)/m_o$ before burn out **(15)**

$a = (W_b + D)/m_b$ after burn out **(15)**

Speed: $V = V \text{ (before)} + a * \Delta t$ **(16)**

Apogee: $H = H \text{ (before)} + V * \Delta t$ **(17)**

Apogee is reached at an iteration just before the speed becomes negative indicating the model is no longer climbing.   Figures 23 through 26 show various sections of the EXCEL code for this method. Many students with no programming or other EXCEL experience had some difficulty in understanding both methods and the idea of programming in general, but they were very pleased to eventually understand and apply EXCEL to this project.   Reference [19] provides a comprehensive treatment numerical solution approach to model rocket calculations.

Each method was run for two burnout or thrust times: manufacturer's (1.65 seconds) and typical field value (2.16 seconds) as shown in Table 1.   A drag coefficient of 0.95 was used. This value is justified in the appendix.

3) Web Based Calculator: This tool [8] applies Fehskens-Malewicki [15] single stage model rocket equations. This method is an example of another simplified analytical approach. The equations of this method are listed in the appendix, but not used by the students in this project. Figure 33 shows the input and output screen using two burn times.

4) **Web Based Numerical Analytical Model :** A web based "simulator" [7] was also used. Figures 31 and 32 show the application and the output curves.   This tool appears to be a numerical method instead of a simulation as its title implies.

5) RockSim Simulation: Each team constructed the model rocket on a computer using the RockSim model rocket simulation software [19] as shown in Figure 29. Figure 30 shows the output of this simulation software.

6) Trigonometric Method: This method was only applied to the last launch (No. 27). Using hand-held tracking devices, two experienced students measured the apogee angles from two opposite locations each located 200 feet away from the launch pad.

Physical Experiment can be considered as the Method 7.

	A	B	C	D	E	F	G
1	Altitude Prediction Program				ENGN 110		
2	PROGRAMMER NAME: Z. CLARKE						
3	Inputs are in blue						
4	ENGINE DATA			Units			
5	Engine Name	D12-5					
6	Total Impulse	17.00000	N-sec	metric			
7	Thrust Duration	1.65000	Seconds				
8	Delay Time	5.00000	Seconds				
9	Engine Mass	0.04710	kg	metric			
10	Propellant Mass	0.02500	kg	metric			
11	g value in metric	9.81000	m/sec^2				
12	Drag effect factor "d"	0.50000					
13	MODEL DATA						
14	Model Name	Skytrax					
15	Model + Engine + Plugs + Igniter + Paper	0.23500	kg				
16	Wires + Payload	0.01100	kg				
17	Lift-off mass of model (mo)	0.24600	kg				
18	(including the engine & altimeter)						
19	Burnout mass of model (mb)= mo – (mp/2)	Eq 1	0.234	kg			
20	Burnout mass as weight = mass x g	Eq 2	2.291	N			
21	Thrust (T)	Eq 3	10.303	N			
22	Vmax - Max Velocity at Burn out	Eq 4	56.62	m/sec			
23	Vmax in more familiar MPH units	Eq 5	127.39	MPH	Model rockets can		
24	V-average - on the way from ground to the burnout point	Eq 6	28.31	m/sec	go very fast. Be careful !!!		
25							
26	Sb = where the burnout occurs	Eq 7	46.71	m	above ground		
27	(ascend during thrusting in feet)						
28							
29	Sc = Coasting distance above the burn -out point	Eq 8	163.39	m			
30	(ascend during coasting in feet)						
31							
32	St =	Eq 9	210.10	m	if taking off from a place		
33	(total ascend or apogee)				like the moon with no air.		
34	Estimated "d" in equation 10 for DRAG						
35	S =	Eq 10	105.05	m	=		
36	(expected apogee)						

Figure 22. Simplified analytical solution

	B&D	w/ D12-5	Engine					
	5.1 cm DIA							
	Amount	UNITS						
Mass at rest (m)	0.235	kg	Incl. engine		Thrust Force = Impulse/Burn Time (UP or positive)			
Altimeter + wires	0.011	kg	Payload					
Launch Mass	0.246		Incl. Payload					
Propellant	0.021	kg			Weight Force = Mass * Gravity Acceleration (DOWN or Negative)			
Mass after Burnout	0.225				Drag Force= - 0.5 * Drag Coeff * Air Density* Area * Speed^2 (DOWN or Negative)			
Area	0.0020428	m^2						
rho (air density)	1.22	kg/m^3			Acceleration = (Thrust - Weight - Drag)/Mass or NET FORCE/MASS		Max acceleration	Max Speed
Gravity Acceleration	9.81	m/Sec^2					32.072	45.684
C (drag coefficient)	0.95	no unit	.77 + 25%	(lug effect)	Speed(t) = Speed (t-1) + a * Delta t		or	m/sec
weight -(m*g)	-2.41326	Newtons			Height(t) = Height (t-1) + Speed (t) * Delta t		3.269	
Weight after burnout	-2.20725	Newtons					G	
Delta t	0.05	s						
Engine impulse	17	N-s			It is NOT a free fall after apogee.		Apogee:	110.100	meters
Burn time	1.65	s						

Time (sec)	Engine Thrust (N)	Drag Force (N)	Net Force (N)	Acceleration (m/sec^2)	Speed (m/s)	Apogee (meters)	Apogee(Feet)
0.00	10.303	0.000	7.890	32.072	0.000	0.000	0.000
0.05	10.303	0.000	7.890	32.072	1.604	0.080	0.263
0.10	10.303	-0.003	7.887	32.060	3.207	0.241	0.789
0.15	10.303	-0.012	7.878	32.023	4.808	0.481	1.578
0.20	10.303	-0.027	7.862	31.961	6.406	0.801	2.629
0.25	10.303	-0.049	7.841	31.875	8.000	1.201	3.941
0.30	10.303	-0.076	7.814	31.764	9.588	1.681	5.514
0.35	10.303	-0.109	7.781	31.630	11.169	2.239	7.346
0.40	10.303	-0.148	7.742	31.472	12.743	2.876	9.436
0.45	10.303	-0.192	7.698	31.291	14.307	3.592	11.783

Figure 23. The numerical method

	Time		Engine Thrust	Drag Force	Net Force	Acceleration	Speed	Apogee (m)	Apogee(Feet)
	1.35		9.882	-1.708	5.869	24.976	39.987	29.168	95.695
	1.40		9.882	-1.819	5.758	24.500	41.212	31.228	102.455
	1.45		9.882	-1.933	5.644	24.019	42.413	33.349	109.413
	1.50		9.882	-2.047	5.530	23.533	43.590	35.529	116.563
	1.55		9.882	-2.162	5.415	23.043	44.742	37.766	123.903
	1.60		9.882	-2.278	5.299	23.426	45.913	40.061	131.435
	1.65		9.882	-2.399	5.178	22.912	47.059	42.414	139.154
m, w change	1.70	engine stop	0.000	-2.520	-4.619	-21.585	45.980	44.713	146.697
	1.75		0.000	-2.406	-4.505	-21.051	44.927	46.960	154.067
	1.80		0.000	-2.297	-4.396	-20.542	43.900	49.155	161.269
	1.85		0.000	-2.193	-4.292	-20.057	42.897	51.300	168.305
	1.90		0.000	-2.094	-4.193	-19.594	41.918	53.395	175.182
	1.95		0.000	-1.999	-4.099	-19.152	40.960	55.443	181.901
	2.00		0.000	-1.909	-4.008	-18.730	40.023	57.445	188.466
	2.05		0.000	-1.823	-3.922	-18.327	39.107	59.400	194.882
	2.10		0.000	-1.740	-3.840	-17.942	38.210	61.310	201.150
	2.15		0.000	-1.661	-3.761	-17.573	37.331	63.177	207.274
	2.20		0.000	-1.586	-3.685	-17.220	36.470	65.001	213.256

Figure 24. Mass is reduced by the amount of propellant at burn out

Time		Engine Thrust	Drag Force	Net Force	Acceleration	Speed	Apogee (m)	Apogee(Feet)
5.00		0.000	-0.005	-2.212	-9.833	1.591	109.491	359.223
5.05		0.000	-0.003	-2.210	-9.823	1.100	109.546	359.403
5.10		0.000	-0.001	-2.209	-9.816	0.609	109.577	359.503
5.15		0.000	0.000	-2.208	-9.812	0.119	109.583	359.523
5.20		0.000	0.000	-2.207	-9.810	-0.372	109.564	359.462
5.25		0.000	0.000	-2.207	-9.811	-0.862	109.521	359.320
5.30		0.000	-0.001	-2.208	-9.814	-1.353	109.453	359.098

Figure 25. The Apogee is 110 meters as the speed becomes negative (1.65 sec burnout)

Time		Engine Thrust	Drag Force	Net Force	Acceleration	Speed	Apogee (m)	Apogee(Feet)
5.35		0.000	-0.002	-2.209	-9.817	0.664	106.197	348.416
5.40		0.000	-0.001	-2.208	-9.812	0.173	106.206	348.444
5.45		0.000	0.000	-2.207	-9.810	-0.317	106.190	348.392
5.50		0.000	0.000	-2.207	-9.811	-0.808	106.149	348.259
5.55		0.000	-0.001	-2.208	-9.813	-1.299	106.085	348.046
5.60		0.000	-0.002	-2.209	-9.819	-1.790	105.995	347.753

Figure 26. The Apogee is 106 meters as the speed becomes negative (2.16 sec burnout)

Figures 27 and 28 show the altitude and speed as a function of time for the numerical method using a burn time of 1.65 seconds. The maximum speed is reached around 5 seconds which is the sum of the most thrust and the coast times for the field or the physical experiment data in Table 1.
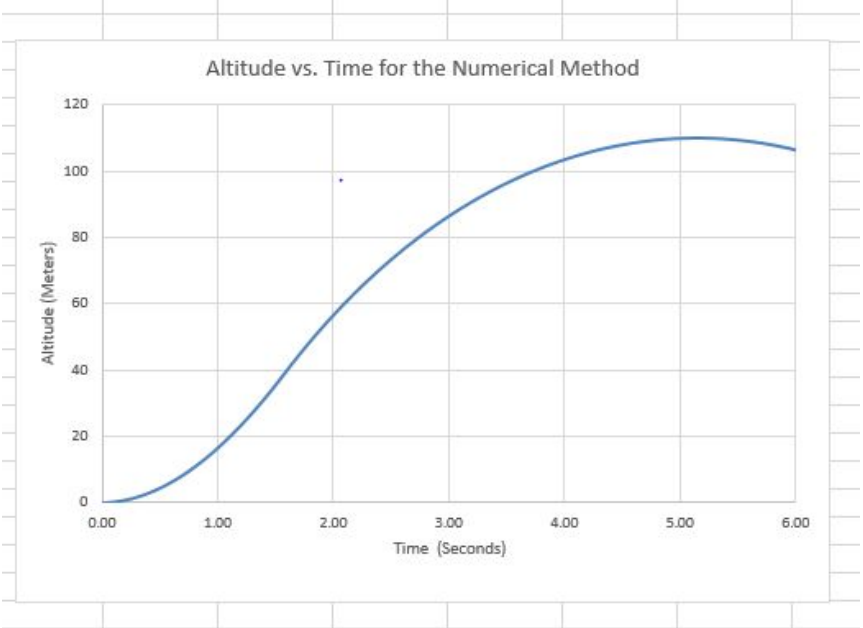

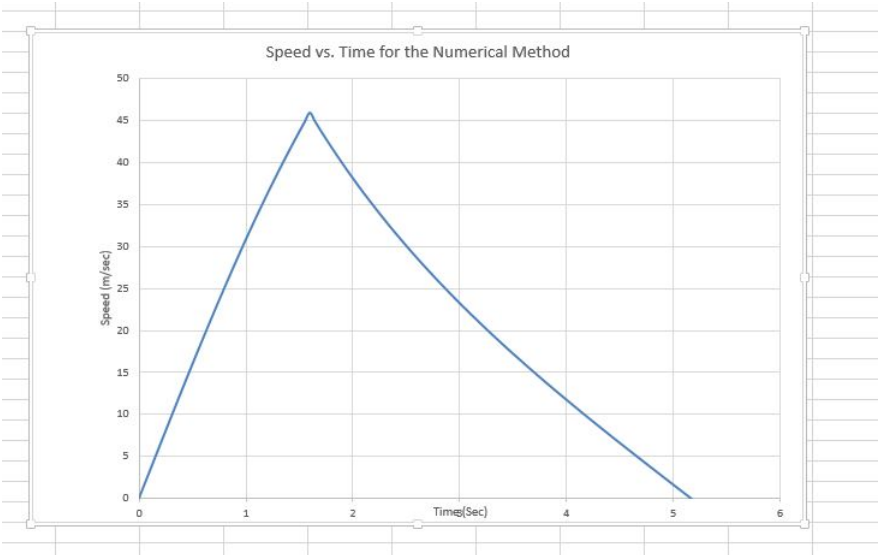Figure 27. Altitude vs. time plot for the numerical method

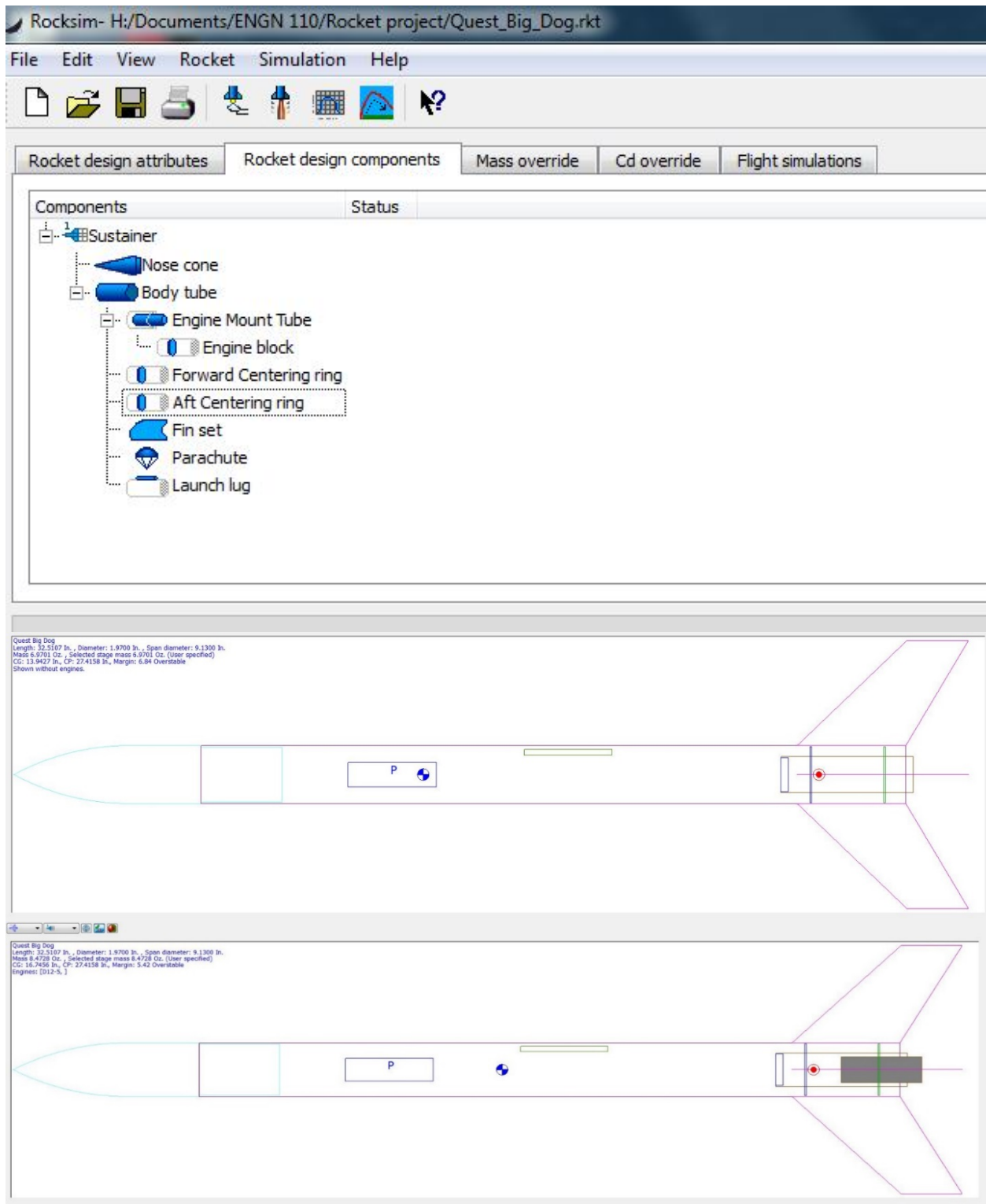Figure 28. Speed vs. time plot for the numerical method

Figure 29. Model rocket ronfiguration and input for the RockSim simulation software of reference 19.

Quest Big Dog - Simulation results

Engine selection

[D12-5]

Simulation control parameters

Flight resolution: 800.000000 samples/second
Descent resolution: 1.000000 samples/second
Method: Explicit Euler
End the simulation when the rocket reaches the ground.

Launch conditions

Altitude: 0.00000 Ft.
Relative humidity: 50.000 %
Temperature: 59.000 Deg. F
Pressure: 29.9139 In.

Wind speed model: Calm (0-2 MPH)

Low wind speed: 0.0000 MPH
High wind speed: 2.0000 MPH

Wind turbulence: Fairly constant speed (0.01)

Frequency: 0.010000 rad/second
Wind starts at altitude: 0.00000 Ft.
Launch guide angle: 0.000 Deg.
Latitude: 0.000 Degrees

Launch guide data:

Launch guide length: 60.0000 In.
Velocity at launch guide departure: 53.9730 ft/s
The launch guide was cleared at : 0.317 Seconds
User specified minimum velocity for stable flight: 43.9993 ft/s
Minimum velocity for stable flight reached at: 41.3987 In.

Max data values:

Maximum acceleration:Vertical (y): 378.069 Ft./s/sHorizontal (x): 1.643 Ft./s/sMagnitude: 378.069 Ft./s/s
Maximum velocity:Vertical (y): 159.4399 ft/s, Horizontal (x): 2.1433 ft/s, Magnitude: 159.5749 ft/s
Maximum range from launch site: 26.29281 Ft.
Maximum altitude: 414.71016 Ft.

Engine ejection charge data:

Using a delay time of : 5.000 Seconds
Velocity: 39.8422 ft/s
Altitude: 388.80045 Ft.

Recovery system data

P: Parachute Deployed at : 6.651 Seconds
Velocity at deployment: 39.8422 ft/s
Altitude at deployment: 388.80045 Ft.
Range at deployment: -26.29281 Ft.

Figure 30. The output of the RockSim simulation software of reference 19.

Model Rocketry Simulator

Rocket Details and Simulation Constants:	
Rocket Name:	B&D
Date:	02-01-2016 22:10:44
Rocket Mass (dry):	0.245
Engine Type:	31
Mass of Engine Casing:	0.0241
Propellant Mass:	0.0211
Thrust:	10.21
Impulse:	17
Rocket Diameter:	0.051
Air Density:	1.22
Drag Coefficient:	0.95
Parachute/sheet Diameter:	0.30
Time Increment:	0.05
Mass Decrement:	0.012672411764706
Gravitational Constant:	9.8
Area of Rocket:	0.0020428206229968
Parachute/sheet Area:	0.07068583470577
Burn Time:	1.6650342801175
Eject Time:	5

Time	Drag Force	Thrust	Net Force	Mass	Acceleration	Velocity	Altitude	Area	Velocity (mph)	Air Density
t	Fd	Ft	F	M	Acc	V	Y	Area	mph	rho
0	0.00000	10.21	7.36604	0.29020	25.38263	1.26913	0.09518	0.00204	2.83905	1.22000
0.05	0.00191	10.21	7.37034	0.28957	25.45303	2.54178	0.25409	0.00204	5.68597	1.21999
0.10	0.00765	10.21	7.37081	0.28893	25.51047	3.81731	0.47684	0.00204	8.53932	1.21997
0.15	0.01725	10.21	7.36742	0.28830	25.55477	5.09505	0.76354	0.00204	11.39762	1.21994
0.20	0.03073	10.21	7.36015	0.28767	25.58579	6.37433	1.11424	0.00204	14.25939	1.21990
0.25	0.04810	10.21	7.34899	0.28703	25.60340	7.65450	1.52897	0.00204	17.12313	1.21986
0.30	0.06935	10.21	7.33395	0.28640	25.60751	8.93488	2.00772	0.00204	19.98733	1.21980
0.35	0.09449	10.21	7.31502	0.28576	25.59806	10.21478	2.55046	0.00204	22.85047	1.21974

Time	Drag Force	Thrust	Net Force	Mass	Acceleration	Velocity	Altitude	Area	Velocity (mph)	Air Density
4.80	0.01364	0.00	-2.65082	0.26910	-9.85070	2.92022	100.04671	0.00204	6.53253	1.20722
4.85	0.00999	0.00	-2.64717	0.26910	-9.83712	2.42836	100.15583	0.00204	5.43225	1.20721
4.90	0.00691	0.00	-2.64409	0.26910	-9.82567	1.93708	100.24040	0.00204	4.33325	1.20719
4.95	0.00440	0.00	-2.64158	0.26910	-9.81633	1.44626	100.30045	0.00204	3.23529	1.20718
5.00	0.00245	0.00	-2.63963	0.26910	-9.80910	0.95581	100.33598	0.00204	2.13814	1.20718
5.05	0.00107	0.00	-2.63825	0.26910	-9.80398	0.46561	100.34700	0.00204	1.04157	1.20717
5.10	0.00025	0.00	-2.63743	0.26910	-9.80094	-0.02444	100.33353	0.00204	-0.05467	1.20717
5.15	-0.00000	0.00	-2.63718	0.26910	-9.80000	-0.51444	100.29556	0.00204	-1.15080	1.20717
5.20	-0.00031	0.00	-2.63687	0.26910	-9.79885	-1.00438	100.23309	0.00204	-2.24680	1.20718
5.25	-0.00118	0.00	-2.63600	0.26910	-9.79561	-1.49416	100.14614	0.00204	-3.34244	1.20718
5.30	-0.00262	0.00	-2.63456	0.26910	-9.79028	-1.98368	100.03471	0.00204	-4.43748	1.20719
5.35	-0.00461	0.00	-2.63257	0.26910	-9.78287	-2.47282	99.89885	0.00204	-5.53170	1.20721

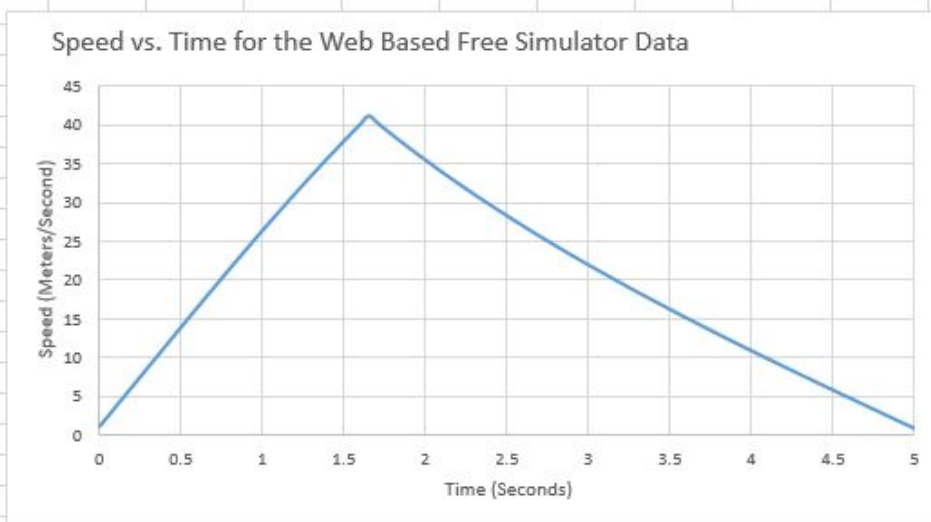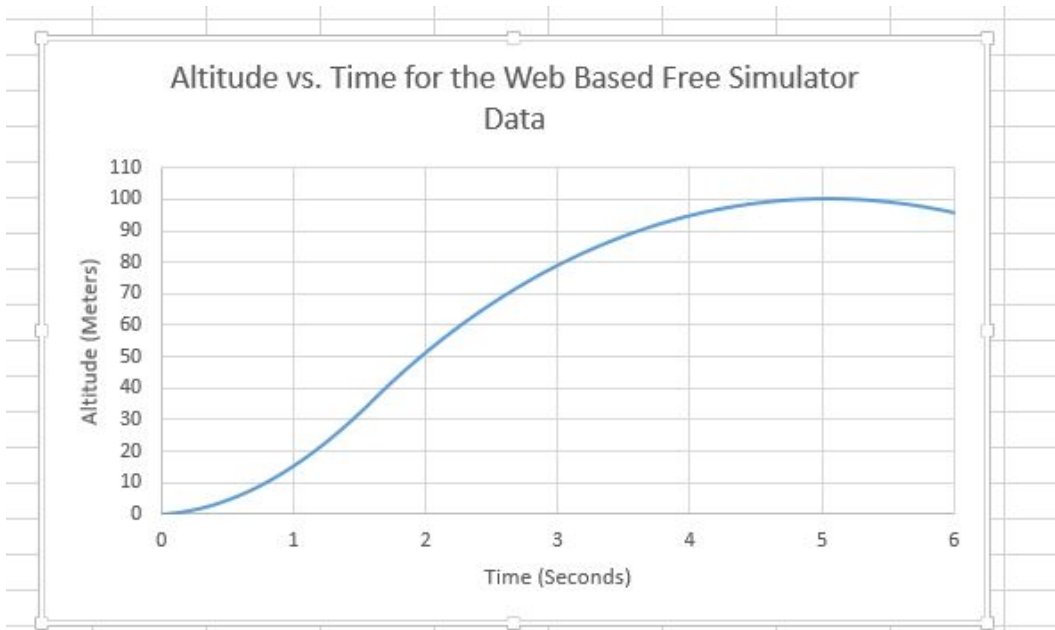Figure 31. Input and output screens for the web based numerical tool [7].

Figure 32. Altitude and speed as functions of time using the web based numerical tool [7]

Rocket Altitude Calculator (Flash ver. 0.9)

Help

Rocket Mass: 198   grams   oz. → g / lb. → g

Drag Coefficient: 0.95   (typically 0.75)

Calculate Single Stage or Booster

Calculate Upper Stage

Calculate Optimum Mass

Body Tube: customized   **Select Tube**

Diameter: 5.1   cm

Frontal Area: 20.428   cm²

Peak Altitude: 122.2 meters

Peak Altitude: 400.9 feet

Coast Time: 3.7 seconds

Motor: D12   **Select Motor**

Total Impulse (N-sec): 17

Burn Time (sec): 1.65

Motor Mass (grams): 47.1

Propellant Mass (grams): 21.1

Number of Motors in Cluster: 1

Burnout Vel: 48.99 m/sec

Burnout Alt: 43.26 meters

Site Elevation: 0   meters ft. → m

Temperature: 21   °C   °F → °C

Air Density: 1.2 kg/m³

Rocket Altitude Calculator (Flash ver. 0.9)

Help

Rocket Mass: 198   grams   oz. → g / lb. → g

Drag Coefficient: 0.95   (typically 0.75)

Calculate Single Stage or Booster

Calculate Upper Stage

Calculate Optimum Mass

Body Tube: customized   **Select Tube**

Diameter: 5.1   cm

Frontal Area: 20.428   cm²

Peak Altitude: 118 meters

Peak Altitude: 387 feet

Coast Time: 3.5 seconds

Motor: D12   **Select Motor**

Total Impulse (N-sec): 17

Burn Time (sec): 2.16

Motor Mass (grams): 47.1

Propellant Mass (grams): 21.1

Number of Motors in Cluster: 1

Burnout Vel: 43.58 m/sec

Burnout Alt: 50.96 meters

Site Elevation: 0   meters ft. → m

Temperature: 21   °C   °F → °C

Air Density: 1.2 kg/m³

Figure 33. Input and output screens of the web based calculator [8]

Physical Experimental vs. Other Results

Table 1 shows that the actual burn times were usually more than the manufacturer's specified value of 1.65 seconds for engine D12-5. Table 2 shows the apogee values for two burn times: 1.65 and 2.16 seconds for each of the five non-physical methods using a launch mass of 0.246 kg that includes the engine, payload, and attachments.   The apogee values in field data have a mean of 98 meters with a standard deviation of 9 meters. The burn times have a mean of 2.0 seconds and a standard deviation of 0.2 seconds.   Physical experiments generally agree with the results shown in Table 2.

Method No.	Method	Burn Time: 2.16 Sec.	Burn Time: 1.65 Sec.
1	Simple Analytical	96	105
2	Numerical Analytical	106	110
3	Web Based Calculator	118	122
4	Web Based Numerical	N/A	100
5	RockSim Simulator	N/A	126

Table 2. Apogee Comparison of the Five Methods Used by Student Teams

The methods 1 and 2 (programmed by each student team) and the method 4 are in good agreement with the field or the physical experiment results while the methods 3 and 5 are within statistical agreement.   It should be noted the actual launch masses varied as shown in Table 1, but there was no clear correlation between the launch mass and the apogee as measured by the altimeter.   The method 5 assumes ideal conditions and results in the highest apogee value. The top three altimeter values were 113 (Table 1) and 125 and 119 meters observed in spring 2016.

Conclusions

The outcomes include an understanding of how each of the apogee prediction methods works, a realization that engineering results are sometimes inconsistent, and appreciation for teamwork. Other outcomes include gaining a firm belief that engineering data is often resource intensive, facility dependent, and it must be carefully recorded and saved for future use.   All launch results are entered into a spreadsheet and posted on a web-based educational management program, for all teams to share. Documentation of lessons learned is a major outcome also. Just as in the real practice, model rocket launches are subject to many unexpected and surprising problems including loss of a vehicle with costly altimeter or other sensors onboard. Each team carefully notes and reports the problem encountered and remedy, if any, to the instructor who enters the information to the master flight log spreadsheet.   Practice activities use RTF rockets with progressively bigger engines and higher average thrusts. Students get a practical introduction to many engineering concepts they will encounter later on in their studies and can decide if engineering excites them based on experience, rather than just textbook learning.

This paper has discussed a major group project using model rockets in a two-hour per week laboratory that is a part of a two-credit course in exploration of engineering and technology. The paper presented experiences with the rocket project with particular focus on comparing and

contrasting several approaches to apogee prediction.   As an aside, students also learned that the metric units were easier to use in aerospace work. The other main lab team project (metal cutting and manufacturing), however, uses the U.S. standard units to provide a balanced engineering unit instruction.

There were several educational goals expected of this project: 1) develop team work skills, 2) gain appreciation for future coursework in physics, statics, dynamics, aerodynamics, flight dynamics, and thermodynamics, 3) get an early understanding on the role of experimental (physical and simulated) and analytical approaches to solve engineering problems, 4) gain practice in writing technical team reports, 5) experience a "real life," hands-on engineering project from start to finish, 6) learn about rockets in general, 7) excite students about engineering and space exploration and improve the overall retention rate.   These educational goals were either accomplished or it is too soon to tell, as in the case of goal 7 that seeks to improve retention. Team reports show that goals 1, 3, 4, and 5 were accomplished at various levels that ranged from fair to excellent. Teams were required to meet with the instructor and/or the graduate assistant to review draft versions of reports. An anonymous exit survey taken on the last day of classes indicate that a majority (70%) of the students felt this project was a very good learning experience for all the stated goals. In addition, substantial anecdotal evidence suggests that this project had a positive impact on student learning and retention. Positive student comments about the project were not just limited to student exit survey and course evaluations.

Recommendations

The urban location of the campus made it difficult to find as much open space as desired to conduct better experiments. The maximum distance from the launch pad was 65 to 100 meters depending on the direction from the launch area. This distance was not long enough for good triangulation. This project would work much better and be more exciting if more open space were available. Limited area made it impossible to use E engines that could send the models to 250 meters instead of around 110 meters feet as is the case now. E engines with twice the impulse were used in spring 2015, but too many rockets were lost due to the inability to track them in the urban environment. An altimeter should be used as a gold standard if there is a high probability that it can be recovered. This probability can be increased by simply adding additional weight as payload to cause more powerful engines to provide a lower apogee. More paint and/or an additional payload can be added to increase weight. This project was repeated in spring 2016. A key chain was used to hang the altimeter to the cone instead of wire used in fall 2015. This change allowed much faster removal and re-installation of the altimeters between successive launches on different rockets. Metal wires used in the fall semester to attach the payload took too long to tie and then cut open them. Table 1 shows that launch masses varied by up to 20 grams among the 27 rockets. All launch masses should be equal.   This will make the results more consistent and easier to compare with the methods summarized in Table 2. It also became clear that engine loading and other prep work should be done before the launch day as the combined fall semester activity took over 8 hours. This was too long for many students who had other commitments. Finally, more angular data should be taken to further confirm altimeter data using trigonometry.

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Appendix

Fehskens-Malewicki Equations of the Method 3

For those of you who enjoy a good equation (and who doesn't?) here are the Fehskens-Malewicki equations for a single-stage rocket:

Single Stage Fehskens-Malewicki Equations:

burnout velocity:

$$v_b = \sqrt{\frac{F - mg}{k}} \ \tanh\left[\frac{t_b}{m}\sqrt{k(F - mg)}\right]$$

burnout altitude:

$$y_b = \frac{m}{k} \ \ln\left\{\cosh\left[\frac{t_b}{m}\sqrt{k(F - mg)}\right]\right\}$$

coast altitude:

$$y_c = \frac{m_b}{2k} \ \ln\left[\frac{k v_b^2}{m_b g} + 1\right]$$

coast time:

$$t_c = \sqrt{\frac{m_b}{g k}} \ \tan^{-1}\left[v_b\sqrt{\frac{k}{g m_b}}\right]$$

Where:

$k = \frac{1}{2}\rho C_D A$

ρ = atmospheric density

C_D = drag coefficient

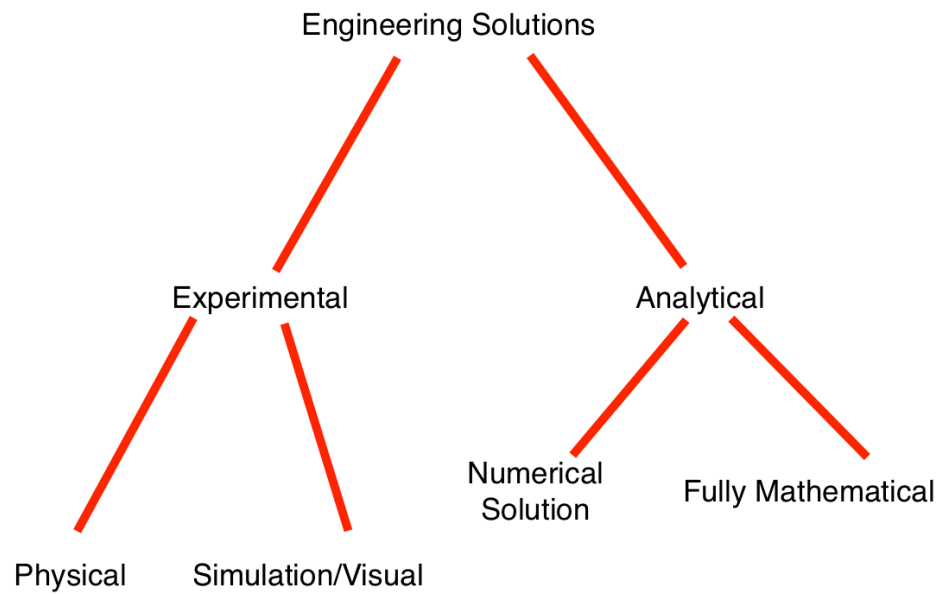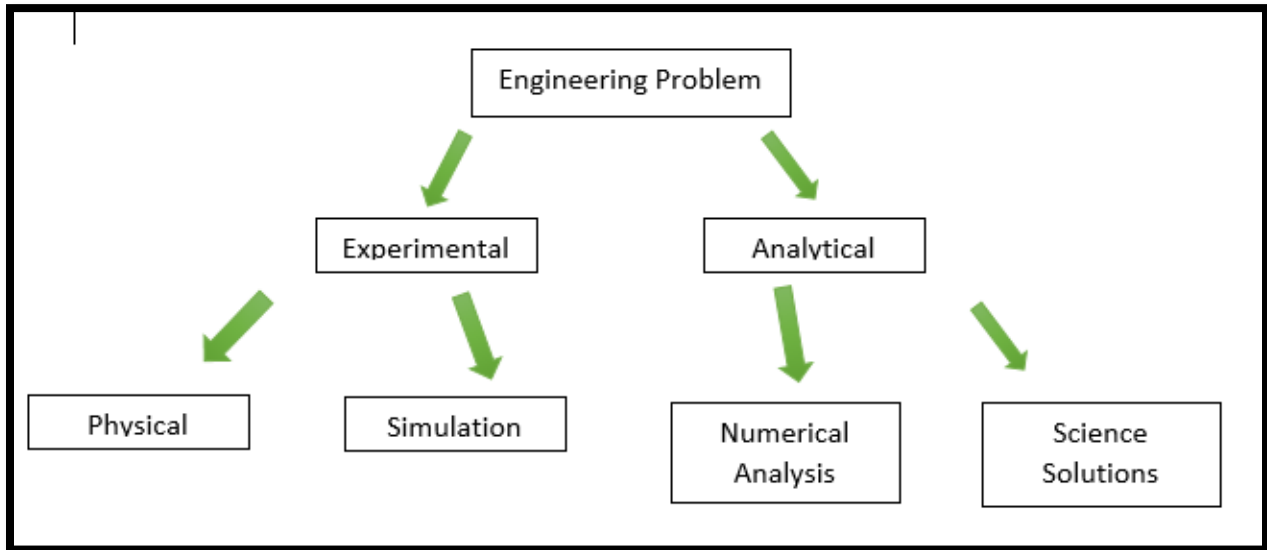A = frontal area

t_b = burn time

F = average thrust

m = average thrusting mass

m_b = burnout mass

g = acceleration due to gravity

Solution Methods Studied in this Project as Depicted by Students

Engineering Problem

Experimental

Analytical

Physical

Simulation

Numerical Analysis

Science Solutions

Engineering Solutions

Experimental

Analytical

Physical

Simulation/Visual

Numerical Solution

Fully Mathematical

Engine Data from the Manufacturer and the NAR.

ESTES D12

CERTIFIED VALUES

Total Impulse: 17.00 newton-seconds
Delays: 0, 3, 5, 7 seconds

Propellant Type: Black Powder
Propellant Mass: 21.1 grams

Casing Dimensions: 24 mm × 70 mm

Certification Date: Continuing
Contest Use Date: Continuing

Certification Type: Model Rocket

STATIC TEST DATA

Date Tested: 94-September-17

Total Impulse: 16.84 newton-seconds (σ 0.53)
Peak Thrust: 29.73 newtons (σ 4.59)
Burn Time: 1.65 seconds (σ 0.30)
Average Thrust: 10.21 newtons

Mass After Firing: 16.0 grams

Delay Time	Average Measured Delay	Initial Mass	Mfg Recommended Max Liftoff Weight
0	0.00	39.2 g	396.2 g
3	2.39	41.4 g	396.2 g
5	4.25	45.2 g	283.0 g
7	5.75	44.9 g	226.4 g

TYPICAL THRUST-TIME CURVE
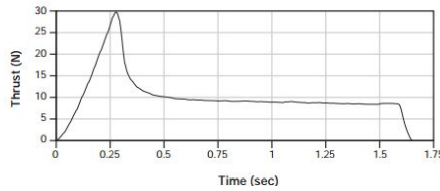
Estes D12-5 Rocket Engine Specifications:

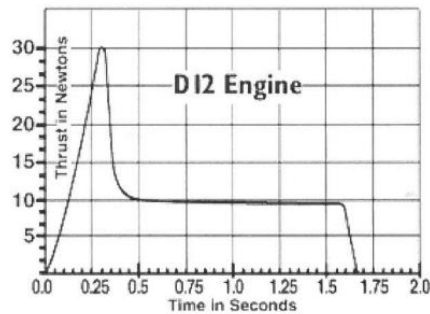|	
Engine Type:	D12-5
Total Impulse - N-sec:	20.0
Time Delay - Sec.:	5
Maximum Lift Mass - g:	283
Maximum Thrust - Newtons:	32.9
Thrust Duration - Sec.:	1.6
Initial Mass - g:	43.1
Propellant Weight - g:	24.93

Note that the average thrust is 12 N and this results the engine labeled as "12"

The engine has a max lift mass of 283 grams. We could load up about 40 grams more.

Jolly Logic AltimeterTwo

Jolly Logic's AltimeterTwo is a rechargeable digital altimeter for model rockets. The AltimeterTwo analyzes and reports flight altitude, acceleration, top speed, flight duration and six other important flight statistics. The AltimeterTwo retains the rugged design, easily-readable LCD, small size, and rechargeability of the AltimeterOne. With the addition of a three-axis accelerometer and a 4X speed increase in processing speed, it can provide a full suite of important flight statistics that can help you analyze and improve your rocket's performance.   The Jolly Logic AltimeterTwo has been approved by the National Association of Rocketry for use in rocketry competitions.

- 3-axis, 24g accelerometer can detect launch, acceleration, speed, ejection, and landing
- Accurate 19-bit barometric pressure sensor sensitive to altitude changes of less than one foot
- Daylight-readable LCD display clearly displays all flight statistics-no computer needed
- Rechargeable Lithium Polymer battery lasts for hundreds of launches, no batteries to buy
- Recharges in less than 2 hours from any standard USB port (no cable necessary)
- Samples pressure over 30 times/second, and acceleration over 200 times/second
- Power button turns device ON/OFF and RESETs the display between flights
- Automatically powers down to conserve power
- Handy tether point allows secure attachment
- Rugged fiberglass and ABS construction to survive crashes
- Approved for use in official contests
- Displays results in either English or metric units

Specifications:

- Size: 0.57" x 0.71" x 1.93" (14.5mm x 18mm x 49mm)
- Weight: 0.36 ounces (9.9 grams)
- Max Altitude (above sea level): 29,500 feet (9000 meters)
- Max Acceleration: 23G to 40G (depending on mounting)
- Altitude Precision: Nearest foot below 10,000; Nearest 10 feet above 10,000 feet; Nearest meter
- Acceleration Precision: Nearest 0.1G
- Speed Precision: Nearest MPH; Nearest m/s
- Timing Precision: Nearest 0.1 second

Sample Data Collected in Fall 2015

LOCATION _____ ODU Campus
                            Norfolk, VA

ENGN _110_ Lab   MON WED 10 12 2   DATE 10/25/2015

MODEL ROCKET PROJECT LAUNCH RECORD by H. SARPER

Team Members who are present _____ Ben _____

Model Name: _BO_   Rocket No. ,

Payload: _Altimeter Two_   Mass: _0.0099_ (kg)

Engine : _D12-5_   Mass: _____ (kg)

Propellant mass. _0.025_ kg per mfg.   Used Engine Mass : _____ (kg)

Impulse : _20_ Newton-sec   Thrust duration or burn-time : _1.6_ (seconds)

Launch Mass: _0.224_ (kg)   including plugs, igniter, engine, fire retardant, and the payload

Launch No. 1 :

Apogee : _101_ (meters)   Ejection at : _77_ (meters)

Top speed : _40_ m/sec   Descent speed _8_ m/sec

Apogee to ejection time _2.4_ sec.   Thrust time: _1.96_ sec

Coast to Apogee Time _____ sec.   Total flight time _25_ sec.   _17.0_

Peak Acceleration _70_ G   Average Acceleration: _2.1_ G   where G = 9.81 m/sec²

Angles at _200_ feet : _59:55;_ _51:49_ : ____ , Average Angle: ____ degrees

Angle based apogee calculation: Tangent( ) x _____ x 0.3048 m/ft = ____ meters

Launch No. 2:

Apogee : . (meters)   Ejection at : _____ (meters)

Top speed : _____ m/sec   Descent speed _____ m/sec

Apogee to ejection time _____ sec.   Thrust time: _____ sec.

Coast to Apogee Time _____ sec.   Total flight time _____ sec.

Peak Acceleration: _____ G   Average Acceleration: ___ G   where G = 9.81 m/sec²

Angles at _____ feet : __;__;__. Average Angle: ____ degrees

Angle based apogee calculation: Tangent( ) x _____ x 0.3048 m/ft = _____ meters

OBSERVATIONS: (weather, unusual events, etc..)

ATTACH THIS SHEET IN THE APPENDIX SECTION OF THE TEAM REPORT.

[handwritten margin notes:] Angles 59 & 55, 51 49 ; Av: 53.50°; 270.3 ft; Tan 59 x 200 rate = 101.5 met; = Ava (03:43); 04 01/04/2016

Sample Data Collected in Spring 2016

ENGN 110   MON WED 10 12 2   DATE :   April/4/2016   17°

MODEL ROCKET PROJECT LAUNCH RECORD at OLD DOMINION UNIVERSITY- Norfolk, VA

NAMES : Chris / Walker   ROCKET NO: M10

Model Name B 8 D

Payload: Altimeter2 ;   Mass: 0.0099 kg

Engine :   D12-5   Average Mass: 0.047 (kg)

Propellant mass : 0.0245 kg per mfg   Average used engine mass : 0.0177 (kg)

Impulse : 20 Newton-sec per mfg   Thrust time or burn –time : 1.6 seconds per mfg.

The NAR certified: impulse is 17 ; Thrust duration is 1.65 ; Propellant mass is 0.0211

++

Launch Mass: _0.220_ (kg) including plugs, igniter, engine, ring, screws, fire retardant, and tapes.
Excludes payload.

Launch No. 1 OBSERVATIONS: (weather, unusual events, etc..) : _____   _____

Apozee at : 103 (meters)   Ejection at : 91 (meters)

Top speed : 39 m/sec   Descent speed 5 m/sec

Apogee to ejection time 1.4 seconds.   Thrust time: 2.10 seconds.

Coast to Apogee Time 3.5 seconds.   Total flight time 22.7 seconds

Peak Acceleration: 6.9 G ; Average Acceleration: 1.7 G   where G = 9.81 m/sec^2

Angles at 200 feet : _._ __._ __._   __._ ____.   Average Angle: _____ degrees.   } Not done

Angle based apogee calculation: Tangent( )× 200 × 0.3048 m/ft = _____ meters

Launch No. 2: OBSERVATIONS: (weather, unusual events, etc..) : _____   _____ .

Apogee : 108 (meters)   Ejection at : 103 (meters)

Top speed : 43 m/sec   Descent speed 5 m/sec

Apogee to ejection time 1.0 seconds.   Thrust time: 2.8 seconds.

Coast to Apogee Time 3.4 seconds.   Total flight time 24.2 seconds

Peak Acceleration: 72 G ; Average Acceleration: 2.1 G   where G = 9.81 m/sec^2

Angles at 200 feet : __._ __._ __._   __._ ____.   Average Angle: ___ degrees   } Not done

Angle based apogee calculation: Tangent( )× 200 × 0.3048 m/ft = _____ meters

Determination of the Drag Coefficient for the B&D Model Rocket Using Reference 4

From the technical report by
J. S. Demar (1997). See our reference list.

Appendix B: Test Model Drawings and Measured Drag Coefficients

This project is in metric although This page has the standard units.

NOTES:

1) All models are finished with average smoothness, primed and sprayed with Krylon, unless noted.
2) All models have no launch lug unless noted.
3) All dimensions are in inches. Dimension X is 0.75 unless noted.

Model #	C_d
1 (X=0.55)	n/a
2	0.68
3 (X=1.0)	0.73
4 (unfinished)	0.77
5 (polished)	0.61
6	n/a
7	n/a
8	0.88
9	0.80
2A	0.68
2B	0.80
2C	0.75
2D	0.68
2E	1.49

→ w/o launch a lug!

→ with a launch lug.

I find several Air Density values from 1.20 to 1.30 kg/m3 at sea level Let's use 1.25

For project report, C_d = will be at least 0.88 and possibly more.

DIA = 1.0"

Note that model 8 resembles our B&D model, but ours has a diameter of almost 2 inches. With launch lug of 1/8" dia & 2" length, the $C_D = 0.88$ for this smaller model. Our launch lugs are 1/4" dia and 3" long. With a length of 30.5" our project model is twice the size of model 8 ...

Some Pictures from Spring 2016 Projects