Physics Lessons Using Rocketry and Rocketry Simulations

National Association of Rocketry (NAR)

Overview

Model Rocketry is an excellent source of educational material, as well as being an interesting hobby. Along with physics, there are applications of aerodynamics, mathematics, graphs, and pyrotechnics (fire, smoke, and noise). All of this is cleverly hidden by a project that both girls and boys will enjoy doing.

The lab exercises here are designed around selection of a model rocket kit, building the rocket, simulating the first flight, launching and collecting data, and analyzing the results. This can be repeated using different kits and/or rocket motors.

However, not everyone will have the ability to do all of the above steps. There may be restrictions on the actual flight of model rockets (many municipal areas classify them with fireworks), there may be a limited budget, or the climate or weather just will not cooperate. If you have access to a computer running Windows (3.1 or later), then performing the lab exercises with “virtual launches” will work, too.

Resources

Check the Bibliography for books and videos that are available. For a great story about connecting model rocketry with the Space program, the full length movie, ***October Sky***, is an excellent introduction. Teachers – be aware that the PG rating on this movie is for language (minimal but present).

The World Wide Web has several sites that offer excellent coverage:

http://www.nar.org (the NAR's web site)

http://www.rocketryonline.com (all kinds of information)

The above site has links to just about ever known model rocket vendor that operate a business. This is great for locating kits.

Apogee Components offers a full-featured computer program called **Rocksim**. It has the capability to design a rocket from available materials and simulate the launch. Their web site also has an extensive educational section. Take a look:

http://www.apogeerockets.com

The Boy Scouts of America (BSA) has a booklet for the **Space Exploration Merit Badge** which includes model rocketry. There is a web site that covers this merit badge extremely well:

http://www.execpc.com/~culp/space/space.html

Estes (model rocket company) has an education-based web site at:

http://www.esteseducator.com

Materials
Rocketry video, book or other information (from reference materials)

Rocket kit catalog

Rocket kit *

Rocket motor(s) **

Glue, wood (yellow) is best. Hot glue is worst! *

Scissors *

Straight edge

Wadding (fireproof, protects the recovery system) **

NAR safety code

Launch equipment **

Kitchen scale to weigh rockets and motors *

Personal computer (PC) running some version of Windows

Rocket simulation program – wrasp, available at: http://www.wrasp.com

Adult helpers (they may want to participate, too!)

Optional Materials
Stickers, decals, paint (not for the faint-hearted) *

Stopwatch **

NAR tracking station **

Physics textbook

* - only needed if rocket kits are to be built
** - only needed if rockets are to be flown

Lab One – How High Will It Go?

Outline
a. Discussion
b. Build
c. Prep
d. Simulate
e. Fly
f. Compare Data

Discussion

Background – introducing the subject of rocketry can cover a little or a lot of ground. Using available resources, cover topics that would benefit your class the most. Several of the books listed in the bibliography cover these topics in much more detail than what is included here.

History – starting with:

- Chinese invention of gunpowder
- use of rockets in the War of 1812 ("The rocket's red glare" in *The Star Spangled Banner*)
- America's Dr. Robert Goddard (his museum is Roswell, New Mexico)
- German V2 that was developed by Dr. Werner von Braun
- early "space race" between the USA and USSR
- Apollo space program, especially *Apollo 11* and *13* (movie)
- Space Shuttle program
- Other space programs – deep space probes and Mars missions
- International Space Station (and previous stations)

Current events can drive some of the space program discussions. A shuttle launch or transmitted images from a distant satellite could keep the student's interest.

Basic Physics – take a look at Sir Isaac (not Fig) Newton's 3 Laws

1. An object at rest tends to stay at rest and an object in motion tends to stay in motion. Also know as "inertia", good examples are getting a very heavy rock to slide (hard to start but easier once moving), and "coasting" on a bike after you stop pedaling.
2. Force = mass times acceleration (F=ma). An example is that smaller objects (less mass) accelerate faster if the force is the same.
3. Every action has an equal and opposite reaction. This is the main reason that a rocket works, whether in the atmosphere or in a vacuum. A good experiment is to have a student on roller skates (better, ice skates on ice) holding a heavy object like a bowling ball and tossing it forward while stationary (they will move backwards).

If you ask students to recite the above three laws from memory, do not be surprised to get “gravity” or “what goes up must come down” for one of Newton’s Laws. He did, after all, get hit in the head with an apple (or so legend has it).

Basic Aerodynamics – these properties are what drive the physics laws and equations. The main forces affecting the rocket are:

Thrust – the force on the rocket from the motor, making it move
Drag – the friction force caused by movement in air, slowing it down
Gravity – an acceleration that slows the rocket going up and
Speeds up the rocket coming down

By using this data in equations, the behavior of the rocket can be estimated. Note that thrust only is present when the motor is burning and that drag is only present when the rocket is moving. Gravity aids drag coming up and acts as a thrust coming down.

Remembering Newton’s first law, inertia can be an interesting quantity to study. Small, light rockets will appear to just “vanish” off the pad with the proper motor while larger rockets will gather speed slowly. Any videos of the Apollo Saturn V or the Space Shuttle will show the vehicle laboring to get that first inch off the pad under full power but will eventually reach a blistering velocity in the upper atmosphere and in space.

One aerodynamic quantity that is used throughout rocketry is the “coefficient of drag”, or C_D. It is a measure of the air flowing over the surface of the rocket. A very smooth, waxed finish lowers the C_D, as does fins that are rounded. A launch lug adds to the value, as does any additional bumps or seams. The diameter of the nose cone or body tube is not included in this value. However, wider, fatter rockets will have more drag associated with it than a sleeker rocket because the diameter is included in the drag force calculation. All things being equal, the C_D differentiates a fat, ugly unpainted rocket with the same kit that has been sanded, fins shaped, painted, waxed, and finished differently. Sometimes, the determination of the C_D is more an art than a science. There are many, very high level documents that describe what is involved in estimating the C_D.

Model Rocketry – if you are going to build and/or fly rockets, a discussion of what the kids will be doing and what to expect will be important. At the very least, an example of a rocket should be displayed and the various parts explained. Any current or past *Estes* or *Quest* model rocket catalog will have this information. The catalog should also show what happens during the flight of a model rocket and explain the various “phases”:

Ignition (lighting the motor on the launch pad)
Lift-off (beginning of rocket motion)
Boost (the time the motor is burning, including lift-off)

Coast (the time after boost when the rocket is still moving up)
Ejection (the deployment of the recovery system (parachute, etc.)
Recovery (the time the rocket drifts back to earth)

The highest point in the rocket's flight is called "apogee" and, hopefully, occurs at the end of the coast phase when then the rocket has slowed down sufficiently on its own (mainly due to gravity). The perfect place for the ejection charge to go off is here, when the rocket is ready to start downward anyway. Some "bad" places for the ejection charge to go off are during boost (or too soon after), or anytime the rocket is traveling fast.

Of course, there is always a chance that something could go wrong. Sometimes it is a flaw in the rocket construction, the weather, a motor that is old or exposed to a wide range of temperatures, or maybe just no reason at all!

Some terms associated with rocketry mishaps:

Shred – a rocket that ejects at a high rate of speed
Lawn dart – a rocket that does not deploy its recovery system and Impacts the ground at a high velocity (ballistic)
Core sample – a rocket that ejects with such force that the body tube is separated from the nose cone (and recovery system). The body comes in fast (like the lawn dart) but gets dirt/mud crammed into the tube because there is no nose cone. The other half of the rocket is usually "long gone".
CATO – short for "catastrophic failure" – a motor failure that usually trashes the rocket it is in
zipper – a rip down the body tube caused by the shock cord after ejecting at too high a velocity

Model rocketry has been a safe, enjoyable hobby since the late 50's. One of the reasons is the "Model Rocketry Safety Code" which should be studied prior to any launching. Rocket motors are designed to produce thrust and not explode, but they are capable of severe burns if used carelessly. Also, rockets that do not deploy their recovery devices can cause injury if spectators are not kept at a safe distance. The safety code covers all of these areas.

Be sure to include safety in any discussion used to introduce rocketry.

Build
There are three options to consider at this point. Depending on the classroom/neighborhood situation, they are:

1. Arrange to have the kids build rocket kits, either individually or in teams, in preparation of flying them on a "launch day." The kits may be ordered in bulk (all the same), chosen from several acceptable

kits, or each student could supply their own. Also required will be construction supplies, motors, launch equipment, and a safe and legal place to fly. This is the most ambitious option and the teacher(s) should enlist the aid of parents or adult helpers and members of a local rocket club, if possible. Securing permission from the school principal or board, park board, and/or fire department may be necessary. (Sometimes the fire department likes to be notified so they can come watch).

2. Arrange to have the kids build rocket kits with the knowledge that they will become “static” models due to restrictions on flying. The kits can be obtained as in (1) above. Construction supplies will be all that will be needed. The students can do a “virtual” launch as explained below.

3. If it is not possible to even build kits, then the “fantasy flight” version can be used. Collect as many rocket catalogs or data sheets on model rocket kits and motors as possible. These can even be large, expensive, high power rockets – it just depends on individual choice. Hobby shops are a good source of catalogs as are kit manufacturers and sites on the Internet. Students can make a drawing of their rocket, decorated to their taste, as well as a chart of facts about the kit and motor(s) to be used. A Windows computer will be all that is needed since flights will all be simulated. At the very least, a computer could be borrowed for the day.

Depending on the time period allotted for this project, the students may be involved in choosing what kits and motors to purchase. However, it may be less stressful logistically if the teachers just get it done and leave the building decorating to the kids.
Kits can come in several difficulty levels. The teachers should check the kits and get advice (if possible) on recommended kits for their age group. It is best if the teacher builds a kit prior to the students tackling it. At the very least, the instructions should be read by the teacher to answer questions later. Many students will want to improvise on the instructions. (they will also wonder later why their rocket didn’t work correctly.)

The main considerations for a building session are:

Kits available
Instructions available !
Supplies ready
Adequate Work area available
Adult (or experienced rocketeers) on hand
Adequate time to do all or part of the task
Safe place to store unfinished and completed projects

If the class (or individuals) is not building, the following is needed:

Catalogs or data sheets
Drawing materials
Folder or clips to hold each student's work

Prep

Once kits are built and all the hurdles are cleared for a launch, the kits should be "prepped" for flight. This preparation involves adding flame-proof wadding (if needed) and packing the recovery system. This gets the kit into its flight-ready state prior to adding the rocket motor. This "empty" (no motor) condition of the rocket will need to be weighed prior to flight.

This is also a good time for another person (not the builder) to safety check the new rocket. This is usually someone who has done rocketry before and knows some of the pitfalls and "tricks".

Some things to look for:

Fins straight and firmly attached
Launch lug straight and firmly attached
Nose cone: not too tight, not too loose
Shock cord firmly attached at both ends (requires an inside look)
Recovery system attached
Wadding (or other flame-proof recovery protector) included
Motor mount and tube firmly attached
If the climate is humid, some baby powder sprinkled on the 'chute

At this point, the empty rocket should be weighed – the only thing missing should be the motor. This provides the correct "empty weight" value for simulation purposes. The flyer can also verify the length and body tube diameter.

Motor prep is fairly easy – inserting the igniter tip into the motor nozzle and holding it in place by inserting the igniter plug. Igniters are fragile and easily broken. They are the main cause of problems at launches.

Some tips:

For the first launch, the teacher(s) prep all the motors – this helps eliminate handling problems. Second and subsequent launches should require the student to prep the entire rocket.

Keep the paper strip on the igniter – it keeps the wire leads separated

Make sure that the two wire leads are not twisted and/or touching each other. This can cause an electrical "short circuit" which prevents electrical current from reaching the igniter tip, causing the igniter to not work.

If you plan to use more than one type of motor, there may be different sizes of igniter plugs. They are color coded and using the wrong one will either not fit or not hold the igniter inside the motor nozzle. Some common Estes motors and matching igniter plugs:

A8, B4 – yellow plug
B6,C6 – magenta plug
C5 – blue plug
Mini-motors – orange and green plugs (smaller motors)
D12 – white plug (larger motor)

Be careful when inserting the motor into the motor mount – rotate it so that the igniter leads away from the launch lug. This makes the rocket much easier to load onto the launch pad.

Make sure that the motor is secure in the motor mount. Many rockets have clips so that the motor "snaps in" and will not move much forward or backward. The thrust ring inside the motor mount prevents the motor from sliding forward toward the nose cone. The clip prevents the motor from sliding out the back. It is **important** to keep the motor in the rocket! (some very small kits are exceptions) The student or teacher may need to add masking tape to "friction fit" the motor inside the motor tube. It should not easily slide back out.

Simulate

There are several computer-based rocket flight simulation programs available. They range from free-ware (no cost at all), share-ware (minimal cost), and commercial products (more money but more comprehensive). This exercise is based on the free-ware **R**ocket **A**ltitude **S**imulation **P**rogram for **W**indows (wRASP) but there are several that could be used. This lab focuses on the use of a simple mathematical flight model to predict what altitude a rocket kit and motor combination will obtain.

The wRASP program includes a database of rocket kits and motors. However, the data needed to represent a rocket kit is usually available in the catalog or on the kit packaging material. The following data is needed to calculate a basic predicted altitude:

Rocket empty weight, in ounces
Maximum diameter of the body tube, in inches
An initial guesstimate of the coefficient of drag, like 0.7
Motor type

wRASP also can take into account the following environment data:

elevation of the launch area above mean sea level (MSL), in feet
atmospheric pressure at sea level, in degrees Fahrenheit
atmospheric pressure at sea level, in inches of Mercury
whether the above data is for a hot day, cold day, or "standard" day

To simulate a flight, the above data is collected (see the Rocket Flight Record included here), and plugged into the program using the “Data” screens:

Rocket – data pertaining to the whole rocket like weight and C_D
Stage – motor selection data (also used for multi-stage rockets)
Environment – data pertaining to launch conditions (the basic RASP does not use the temperature, pressure, and elevation)

Once the data is entered, the “Launch” button is selected. The graph will show the altitude as a function of time while the rocket flies. For most motors, several ejection delay times are available, and these are marked along the flight path. This can be used to select which delay is closest to apogee and whether it will eject before the apogee or after. This may be important in trying to time the flight from lift-off to apogee – if the selected delay fires the ejection prior to the rocket reaching apogee, it will be hard to time the flight correctly.

The flight should be printed out for the student. If possible, fly once using the “basic” environment and then fly again using predicted for the actual launch day (field elevation, atmospheric temperature and pressure). The “basic” just assumes that the flight is from sea level on a very “standard” day. This may differ widely from the planned launch in Hartsel, Colorado, on January 15th (cold day profile, 8800 feet base altitude, 20º temperature and 30.0 inches pressure).

Keep the simulation results to compare with the actual flights. If you aren’t going to fly, try different runs at different locations and environmental conditions. Discuss why there are differences in the results. Some research into what ranges of temperature and pressure are reasonable may be required.

Fly

Everyone looks forward to this part! Unless you have a small group and an equal number of launch pads, students will have to wait their turn, watching the others fly their rockets. There needs to be some organization here – too much chaos can result in someone getting hurt.

Some things to consider during the launch:

Allow just the rocket owner/builder to chase and retrieve their rocket
Keep the crowd away from the launch control box
Have students wait for the rocket to land before taking off after it
Have a trash can or bag for used motors and igniters

Don’t forget to collect data points! This can easily get lost in the excitement of each student watching their rocket take off. Tracking rockets is in a more advanced exercise but timing a rocket’s flight from lift-off to apogee can be done with an inexpensive stop watch. Many times these can be borrowed from a school’s athletic department. The time value is used to better estimate the rocket’s coefficient of drag (C_D) for simulation purposes. Any notes about the launch can help later when everyone's memory is confused by a multitude of flights. Some examples:

Igniter trouble
Corkscrew flight path
Parachute failed to open
Windy – rocket flight was about 20º from the vertical
Etc.

If the student has used the "Rocket Flight Record" in this packet (or something similar) all during this exercise, then comments and data can be collected in one place. Some of these comments can be used to explain why an actual flight differs from the simulated one.

Compare Results

Once all the data is collected, a discussion about the results is planned. Here are some questions that may help open it up:

What problems were encountered during the launch?

Was the selection of delay time adequate? Too short? Too long?

How do flights with the same kit/motor combination compare between different flyers?

Did the rockets that flew straighter fly higher? Did the wind affect the flights?

Could you tell which rockets might have higher drag than others?

Do you think that there might be variation between motors of the same type? That is, did two flights using the same kit on similar motors produce different results?

How does the simulated altitude and flight profile compare with what was seen? Does the C_D seem too high or too low?

If you still have the personal computer, allow the students to re-enter their flight data (or re-call it, if saved). If they were able to time the lift-off to apogee time, switch to "DigiTrak" mode (Options menu), run the flight again (the altitude might be slightly different than the "wRASP" mode). Now, enter the "ascent time" and select "temporal back-tracking" (time-based). The program should calculate a new value for C_D. Compare this is the original value. How did the new value affect the altitude for the flight? Does this seem reasonable?

To get the best results, more flights need to be performed and the C_D values averaged and evaluated. The new C_D should be used for this particular rocket whenever a simulation is to be run.

If rockets were not actually flown, the students can still tinker with the simulation program and see what can change. To try backtracking, choose an ascent time that is close but not exactly the same as what the graphs show. Then see what the resultant altitude and C_D turn out to be.

There are other ways to measure the altitude. This first lab looks at the most basic flight data collection. Without some proper measuring tool, we are using the simulation results to estimate the flight altitude. In the next exercise, additional methods will be investigated.

If time permits, wrap up the exercise by having several students summarize the results of the simulation and flight data. The lab is a success if everyone had fun and somehow learned a little something along with it.

<u>Future Installments</u>

Lab Two – What Will This Motor Do?

Lab Three – Fantasy Flights

Lab Four – Coefficient of Drag (C_D)

Lab Five – NAR Competition Tracking (Trigonometry)

Bibliography

Movies
Apollo 13, Universal City Studios, 1995, VHS and DVD

October Sky, Universal City Studios, 1999, DVD

Books
Basics of Model Rocketry, Douglas R. Pratt, Kalmbach, 1981

Handbook of Model Rocketry, G. Harry Stine, John Wiley & Sons, 1994

Model Rocket Design and Construction, Second Edition, Timothy S. Van Milligan, Apogee Components, 2000

69 Simple Science Fair Projects with Model Rockets, Timothy S. Van Milligan, Apogee Components, 1996

Pamphlets
Space Exploration Merit Badge, Boy Scouts of America

Web Sites
(see resources section)

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Rocket Flight Record

Rocketeer(s)________________ ________________
________________ ________________
________________ ________________

Rocket **Kit** Data:
Manufacturer: ________________ model: ________________
Date built: ________________
Length: ________________ inches
Body tube diameter:________________ inches
Empty weight: ________________ ounces
Recovery system: ________________

Rocket **Motor** Data:
Manufacturer: ________________
Type: ________________
Total impulse: ________________

N

sec

Thrust Curve

Flying **Field** Data:
Name: ________________
Elevation: ________________ feet above mean sea level (MSL)
Temperature:________________ ºF
Pressure: ________________ inches Hg (mercury)

Simulation Data: **Input** **Results**
Empty wt: ________________ ounces max altitude: ________ ft
Body diam: ________________ inches time to max: ________ sec
Motor: ________________ best motor delay: ___ sec
C_D used: ________________
Environmental: none / standard / hot / cold
Field elevation: ________________ ft MSL
Temperature: ________________ ºF
Pressure: ________________ in Hg

Flight Data: **Post-Flight**
Date: ________________ backtracked
Temperature: ________________ ºF C_D: _______
Pressure: ________________ in Hg Optimal
Time to apogee: ________________ sec mass: _____ oz
Tracking altitude: ________________ ft (optional) Results:
Comments: