Simple Drag Tests for Water Rockets

A Share Lab Project for Rocket Design

This lab is provided for use free of charge by Seeds Software. However, if you make use of this lab, and are satisfied with the results, we request that you submit your test results to rocket@Seeds2Learn.com for tabulation and possible inclusion at our web site (see sample submission form on last page - Appendix C - of document for more directions). Please understand that any information and/or pictures provided, are given to Seeds Software for use free of duty, copyright, or obligation to sender or their associates.

Seeds Software develops exciting quality software packages, comprehensive and complete with lessons and labs. We believe that hands-on activities are an important part of studies because students learn best when they invoke all their senses.

That is why our software always includes innovative labs for students to do along with the software; so that students can experience how science really works and gain valuable insights into their world. We hope this sample lab is useful and that you will come back to our web site for tips, results, updates, and to consider our other exciting products.

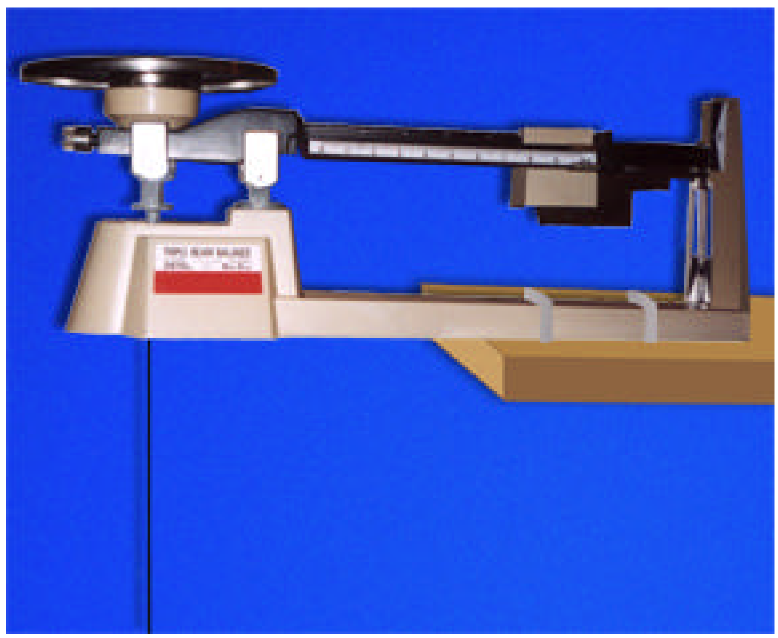
Objective

1) Use a wind tunnel to compare the drag of different design configurations to help determine the optimum aerodynamic shape for your water rocket design.
2) Make an estimate of the coefficient of drag of your rocket designs to use in a computer simulator to assess the performance of your water rockets before you launch.

Materials

a) Water Rockets to Test (including: Nose Cone shapes, Fin sizes - number - shapes)
b) Large Fan (the larger and more powerful, the better -- at least 0.5 meter or 18 inches)
c) Triple Beam Mass Balance Scale or Digital Mass Meter
d) Several meters of Sting to suspend Rockets over the Fan
e) Support Structure to hold the Balance Beam and fan above the ground
g) Digital or Music CD
h) 100 to 120 grams of Clay

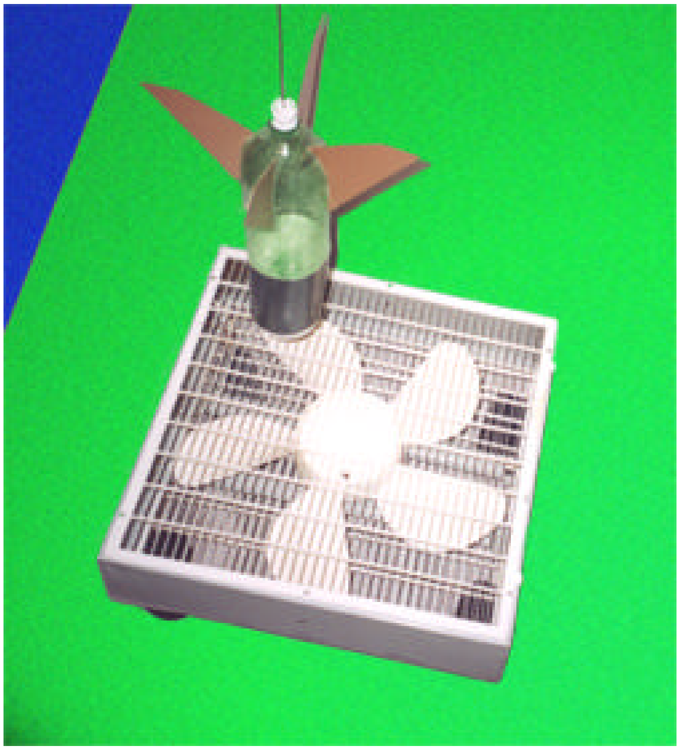
Set Up



The strength of your fan will directly effect how well you can measure and compare different rocket configurations so be sure to use the largest, most powerful, fan you can find. Set up your fan to blow straight up from the ground. Be sure to support the fan a sufficient height above the ground (about 0.3 m) so that the air flow through the fan is unrestricted, especially over the section of the fan you plan to suspend your rocket designs over.

Set up a stand above the fan for a triple beam balance. The balance should be at least 2 rocket lengths above the fan if possible. One possibility is to find a high balcony or deck that you can set your fan up under and have the triple balance beam on the deck. Another possibility is to secure and support the scale on a wood plank cantilevered off a ladder or shelf. If the support will significantly block the air flow above the fan it is best to have the stand a good distance higher. Always be safe with your set up and do not put anyone at risk. Someone will have to be able to actively make use of the triple balance beam scale to take drag measurements. This requires a stable platform that keeps the person reading the scale safe as well as preventing the scale from falling down.

Drill a hole exactly centered in the cap of a soda bottle. Put a knot into one end of a long piece of string and thread the string through the cap hole until it is stopped by the knot. Pull the other



end of the string up to the scale and thread the string around the axle on the bottom end of the vertical post of the scale tray. Screw the cap onto a rocket you wish to test and suspend the rocket by the string above the scale. Adjust the distance the center of the front end of the water bottle (not the tip of a nose cone) hangs above the fan to be about 10 to 15 cm.

Next find out the best part of the fan face to suspend your rockets over to conduct your drag tests. Turn the fan on to maximum speed. Determine the amount of mass required on the scale to balance the rocket hanging below in the air stream. Move the rocket and scale location and/or fan position around and readjust the scale as needed. Establish the position on the fan face that requires the least amount of mass to balance the rocket while providing the greatest stability and consistency in scale readings. This will be the best position to center your rockets at for drag tests. You may also need to do some experimentation to find the best height to position the rocket above the fan. This is because the ideal suspension height will depend on the size and airflow output of your fan, and the actual set up you have. Use a plum to mark this spot on the fan face and record the distance the front end of the bottle is above the fan in case you wish to set up again and do more experiments later. To get consistent results, all your test will need to be conducted with the suspended rockets exactly centered on this same spot and height above the fan face. Be careful not to move the fan or scale out of position until you are completely finished testing or your comparisons may become compromised. Instead, remove the rocket from the cap to do modifications and reattach the rocket to do each test.

You are now ready to conduct some drag tests with your setup. Remember that your results will only be as good as the care you take in conducting the tests. Even then, because the wind tunnel is so primitive, you may have to use some judgment in interpreting your results and what sort of refinements in design you can accurately assess.

Procedure 1 - Determine Air Flow Speed

You can determine the apparent speed of the air flow the fan is generating by measuring the drag that develops when a shape with a known coefficient of drag is placed into the air stream. In this section we will use a CD to estimate the speed of the air flow produced by the fan. A CD is essentially a flat disk that is known to have a coefficient of drag that is 1.17 (C_d = 1.17) when placed perpendicular to the air stream. The velocity of the air flow can be calculated by measuring the drag of the CD in the air stream and using that information in the equation for drag (Eq 1) to solve for the apparent velocity.

Simple Drag Tests

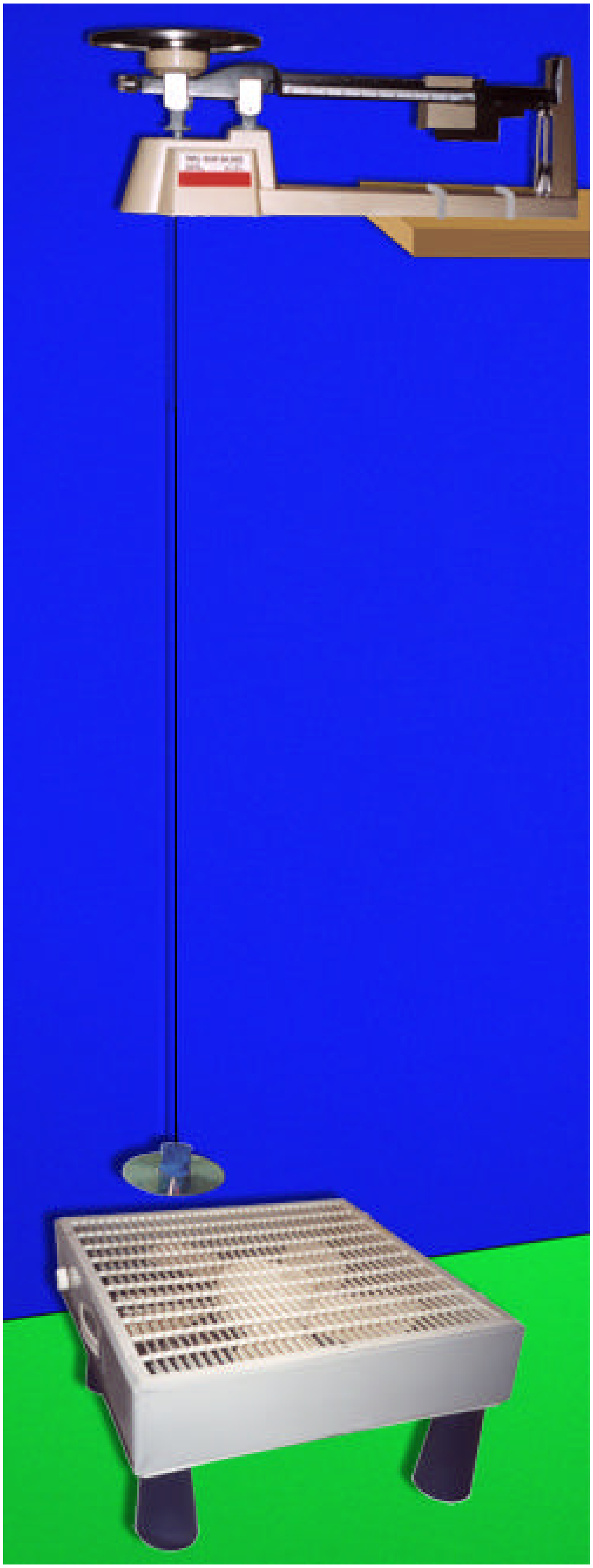
Given:

A = Projected Frontal Area (m^2)
V = Velocity (m/s)
ρ = Air Density (1.22 Kg/m^3)
C_d = Coefficient of Drag
D = Drag Force (N)

Eq(1): $D = (1/2)\rho AV^2C_d$

Follow the Steps Below to Find the Velocity of the Fan Air Flow :

1) Measure out enough clay (80g to 120g) to place on top of a CD to approximate the mass of your typical rocket design to be tested (help stabilize the CD and normalize results).
2) Place that clay against the CD in the center quarter of the disk -- away from the edges.
3) Push the cap with the knotted string into the clay centered so that the CD can be suspended above the fan level.
4) Adjust the sting length so that the CD will hang at the same position above the fan as the front end of a water bottle does suspended above the fan.
5) Make adjustments to the mounting of the CD onto the string to get the CD to hang perfectly level and perpendicular to the air flow -- the CD needs to be level to get accurate results.
6) Measure and record the initial scale mass required to balance the CD.
7) Turn the fan on high and rebalance the scale. Record the new mass measurement.
8) Calculate the difference in mass(Kg) between the initial mass and final mass measurement.
9) Multiply the mass difference by the acceleration of gravity (9.81 m/s^2) to get the drag force acting on the CD in Newtons. Calculate the face area (A) of the CD in meters^2.



Solve the drag equation (Eq 1) for velocity to obtain (Eq 2). Use the calculated drag force, known drag coefficient (C_d =1.17), and CD area in Eq 2 to get an apparent air velocity V(m/s^2)**

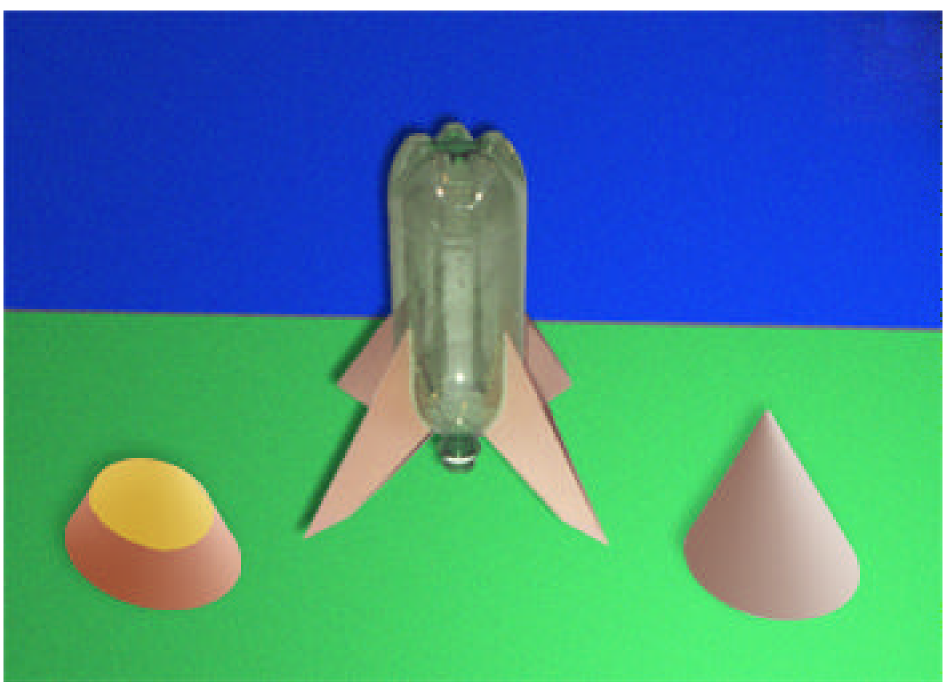
Eq (2): V_t = sqrt (2D / (1.22*A*C_d)) = sqrt (2D / (1.427*A))

** Note: To conduct drag investigations and comparisons that will help you streamline your rockets (Procedure 2) you need to be using a fan that can produce an air flow rate of at least 4 (m/s). Otherwise it becomes difficult to compare the drag between different rocket configurations because the differences in drag measured between configurations gets to be too small to readily distinguish from the turbulence in the air flow. If your test results show that the fan is not powerful enough to provide a fast air flow, consider finding a more powerful fan before proceeding to testing your rocket configurations for drag.

Procedure 2 - Rocket Configurations

Using a fan as a wind tunnel is a pretty primitive setup so don't expect to get impeccable results. Instead, look for the tests to give you a much better feel of the influence drag has on the performance of your rockets. By directly comparing the drag values you measure for different designs you can gain some understanding of how the shape and size of rocket components effect the amount of drag that develops and hence how well a given rocket performs. Try to use your fan testing to help you find a shape that streamlines and optimizes the aerodynamic efficiency of your designs, just as aerodynamists do with wind tunnels.

Start out by creating a matrix of the shapes and configurations you wish to test. You may wish to investigate different nose cone shapes, different fin shapes, and different parachute release mechanisms. Do tests on the basic differences that nose cones make in the drag characteristics of rockets first. And then work towards investigating more refined details such as the changes in drag that occur with different fin shapes. How much refinement in details you can measure and accurately compare will depend a lot on your measurement and craftsmanship skills, and how powerful the fan is that you are using to conduct the tests.



Sample Test Matrix for 2 Liter Bottle Design

Measured Mass (g)

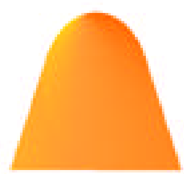
Test	Fan Off	Fan On	Drag
2 Liter Bottle + Extra Mass	______	______	______
Bottle + Nose 1	______	______	______
Bottle + Nose 2	______	______	______
Bottle + Nose 3	______	______	______
Bottle + Best Nose + 4 Fin A	______	______	______
Bottle + Best Nose + 4 Fin B	______	______	______
Bottle + Best Nose + 4 Fin C	______	______	______

Fin A

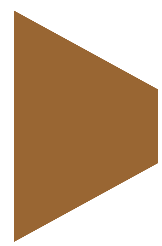
Fin B

Nose 1

Nose 2



Nose 3



Fin C

Once you have decided on what tests to conduct, follow the procedures and guidelines below to run each test.

1) Add (water or clay) to your rocket as needed to keep all your tests at about the same mass
2) Suspend your rocket above the fan face on the triple beam scale and check the location and height above the fan to make sure the rocket is properly positioned.
3) Measure and record the scale mass required to hold the rocket in balance with the fan off.
4) Turn the fan on to full speed.
5) Measure and record the amount of scale mass to balance the rocket with the fan on. *
6) Calculate and record the apparent mass difference between measurements with the fan off and the fan on. This mass difference is caused by the drag action as the air from the fan flows past the rocket model. The drag force acts against gravity, reducing the mass required to balance the rocket with the scale.
7) You can calculate the drag force as D= mg -- with gravity being 9.81 (m/s^2) and force (N)

Eq (3): $D_{(N)} = 9.81_{(m/s2)} * \text{ mass change}_{(g)} * 0.001_{(g / Kg)}$

* Note that as you get close to massing out the rocket in each test, you are likely to find the scale becomes unsteady and more difficult to appraise scale adjustments and progress towards

balance; even so you should be able to closely estimate the mass that "on average" centers the scale. You may wish to lightly constrain the string laterally right above the rocket for an instant to steady the rocket, then release and check the scale again to verify your estimation before you record your results. If you find that the rocket is spinning with the fan on it is likely that some of your fins are slightly off true from up and down and are developing slight lateral forces.

Procedure 3 - Estimation of Drag Coefficient for Apogee Calculations

Use the equations below (Eq 4 & 5) to estimate the actual drag coefficients of your rockets during a launch. Use eq(4) to calculate the apparent drag coefficient at the velocity of your tests. Then use eq(5) to adjust the drag coefficient to the actual speeds your rocket will obtain in a launch.

Equation 5 is a factor that accounts for the transitional nature of drag, from viscous to pressure dominated actions, as the air flow velocities are increased from that of your tests results to those of real launches. It is a semi-empirical approximation based on theory and expectations and it should not be presumed to be precise, but rather a rough cursory estimate from modest tests results.

Given

V_t = Velocity of Air in Wind Tunnel Tests (m/s)

V_r = Velocity of Rocket Launch (m/s) -- use 2/3 maximum velocity to approximate full range

D_r = Dia of Rocket Body (m)

D = Measured Drag Force from Tests (N)

ρ = Air Density (1.22 Kg/m^3)

η = 2 (factor based on the ratio of wetted surface area to projected frontal area of the rocket with a value of 2 being nominal for a typical 2 liter water rocket)

Find the drag coefficient for your rocket at the apparent test velocity (V_t):

Eq (4): $C_{dt} = 8D / (\pi \rho D_r^2 V_t^2)$

Then calculate a velocity adjusted drag coefficient to use in rocket launch apogee simulations:

Eq (5):

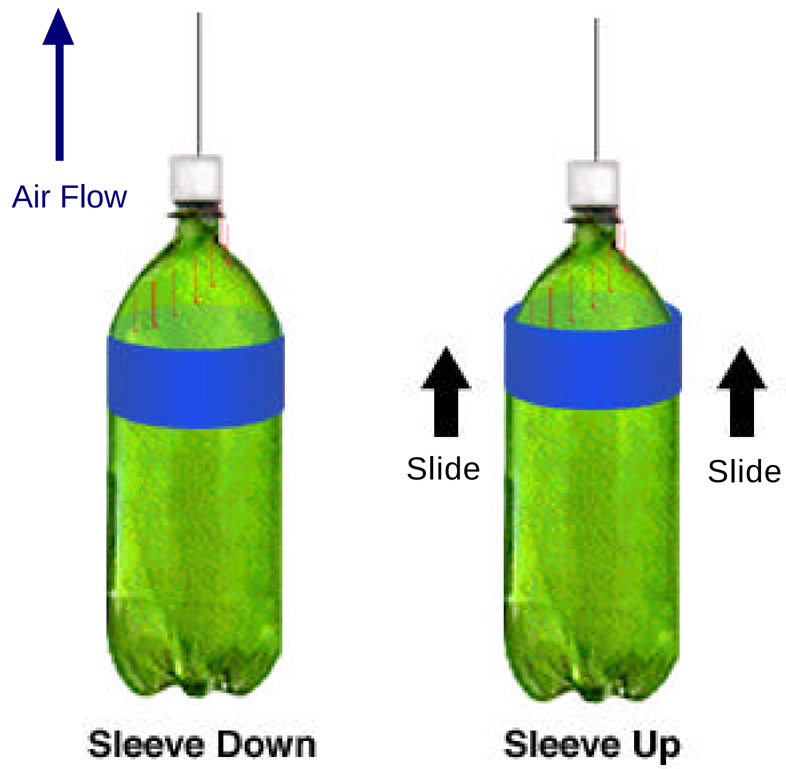
$$C_{dr} = C_{dt}\left[1 - \frac{1 - \text{sqrt}(V_t / V_r)}{\eta\,(1 + (C_{dt} / 1.17))}\right]$$

See Appendix A - Background for more information about drag and the need for adjustment.

Procedure 4 - Experimentation

Using some ingenuity, and careful lab skills, it is possible to investigate various aerodynamic characteristics of your rocket designs with your fan setup. One very important aspect of aerodynamic streamlining is to encourage the air to flow smoothly around your design. If the shape transitions too abruptly at the ends, the air gets plowed (the air flow separates from the body) instead, causing a pressure drop behind it. The separation will increase the drag acting against the motion of your rocket because any pressure drop at the aft end results in the pressure at the front, that remains higher, pushing against your rocket with a greater net force. The drag characteristics of your rocket body essentially become more bluff with flow separation.

You can test to see if your rocket design is streamlined enough to keep the air flow attached around the aft end of your rocket with your fan set up.



Additional Materials:

a) Strip of Poster Board or Heavy Stock Paper (6 cm x 36 cm)
b) Light Weight Thread cut into 8 to 10 sections of about 4 cm length
c) Clay mass and/ or nose cone
d) Clear Tape

Set Up:

1) Wrap the strip of paper snugly around the bottle to form a flush sleeve and lightly tape it to the bottle on the cylindrical portion of the bottle just forward of the aft end.
2) Use small pieces of tape to attach the thread sections to your bottle in a spiral pattern to use the thread as air streamers or tufts (as shown on the bottle in red).

Procedures:

Follow section 2 procedures to compare the results between having the sleeve positioned on the cylindrical portion of the bottle, and slid up about 1 to 2 cm off the tangent point so that the sleeve forms a lip or dam that prevents the air flow from following the bottle contour around the aft end -- it separates the air flow. If your bottle is streamlined you will be able to measure the change in drag between having the sleeve down or up. Also notice the difference in the behavior of the thread tufts attached to the aft end. The free ends of the tufts will point aft if the air is streamlined for the sleeve down case, and bend around somewhat to point downward when the air flow separates from the bottle -- causing a turbulent wake -- for the sleeve up case.

Appendix A - Background

Most everyone who launches water rockets wants to design their rocket to go as high as possible (highest apogee). You might consider using trial and error to try to find the best design. But this requires doing many repeated test launches, each with some minor change, to observe the results. And such an approach takes a lot of time, is often difficult to assess, and may not lead you to the best design. It is usually better to take a more scientific approach. The apogee your rocket obtains will depend on a number of factors of design. There are simulators available, like Water Rocket Fun, that you can use to determine the performance to expect from your rocket based on the mass, gas pressure, amount of water, and the drag characteristics of your rockets. The simulators can be used to determine the optimum mass and water volume to use for your rockets to get the highest apogee. Unfortunately the drag of your rocket , which is one of the key parameters in the analysis, is not readily known and is difficult to calculate by analytical means. Many get around this short coming by resorting back to trial launches to measure apogee and back out the drag characteristics of their rocket and then use the simulation to determine the amount of water and mass to use in the rocket to optimize its performance. To be more effective, you need to use some method of assessing and determining the drag characteristics of your rockets as well.

Drag is the resistance to motion that is exerted by a fluid such as air as it flows around a solid body. Drag takes energy away from a body, slowing it down, by converting motion energy into heat. The more drag there is against flow around a body, the faster energy is lost over time. A rocket that has a lot of drag will not accomplish nearly as high an apogee as a rocket with the same amount of launch energy that has much less drag. So it is important to try to minimize the drag that occurs when you launch your rocket.

The amount of drag that occurs with flow is often characterized by a value called the coefficient of drag (Cd). The Cd of a body is a function of the body shape and the properties of the fluid flowing around the body. Once a coefficient of drag is established for a body one can use the coefficient in equation (1) below to calculate the drag force a fluid is exerting on a body at a given speed. Simulations that predict the apogee of water rockets often use this equation to account for the effects of drag on the performance of the rocket.

Given: A = Projected Frontal Area of Rocket (m^2), V = Velocity (m/s)
ρ = Air Density (1.22 Kg/m^3), C_d = Coefficient of Drag, D = Drag Force (N)

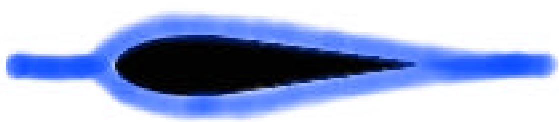
Eq(1): $D = (1/2)\rho A V^2 C_d$

Objects that are shaped to minimize the amount of drag that develops moving through a fluid are considered aerodynamically streamlined. Typically finding the best aerodynamic shape is an exercise in compromise. This is because the vehicle designs are almost always limited somewhat in form to shapes that allow the vehicle to perform its functions effectively as well as being fashioned to minimize drag. For water rockets the challenge is to come up with the most aerodynamic shape that can also hold compressed air, provide an efficient nozzle for thrust, and possibly enclose a parachute that ejects at apogee. Even more restrictive for your water rocket designs is that often you start off your design with a preexisting body such as a soda bottle which you modify as best you can to achieve your objectives.

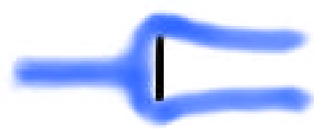
Aerodynamists toil over what the drag characteristics of rockets and aircraft are too because the amount of drag that develops can be so critical to how well their designs will perform. In the early days of flight aerodynamists depended on testing designs in wind tunnels that they could use to provide a controlled air flow and measure the drag that developed. Through testing and comparison of results, the aerodynamist could check their designs and optimize their shape to minimize the drag. In modern times aerodynamists include computer computational fluid models (CFM's) to idealize and predict the drag of fluid flow around a body. With CFM's they can better understand and interpret the flow around the vehicle, to get a better handle on how to optimize their designs. However they usually still use wind tunnel testing along with their models to fine tune, and verify their model results. These tools provide assessments that help them shape the vehicle to achieve the best drag characteristics before they build their designs. Unfortunately getting meaningful answers with CFM's takes a lot of experience, and a deep understanding of the advanced theory and results these models provide. Luckily wind tunnel testing is not so difficult and is something you can easily do to help you configure your rockets to get the best performance.

Wind tunnels are designed to provide a controlled streamlined flow of air that is both steady and free of turbulence. This allows aerodynamists to make very precise measurements of the flow around a body and the lift and drag forces that result. Fortunately drag is not as sensitive of a test to do as determining the lift characteristics of a body -- the flow does not have to be as streamlined. It is possible to do simple useful comparisons of different rocket design configurations for drag using nothing more than a powerful household box fan. Such a tests can help you identify the most efficient aerodynamic shape for your rocket design. Furthermore, it is possible to roughly estimate the coefficient of drag from your test results to use in a water rocket simulator to predict the apogee performance of your designs.

There are two aspects of fluid flow that cause drag, the friction the body experiences as the fluid slides past a body (typical of an airfoil at slow speeds), and the pressure imbalance caused by the drop in pressure that develops behind an obstructing body as the fluid flows around (typical of a blunt object) as shown below.

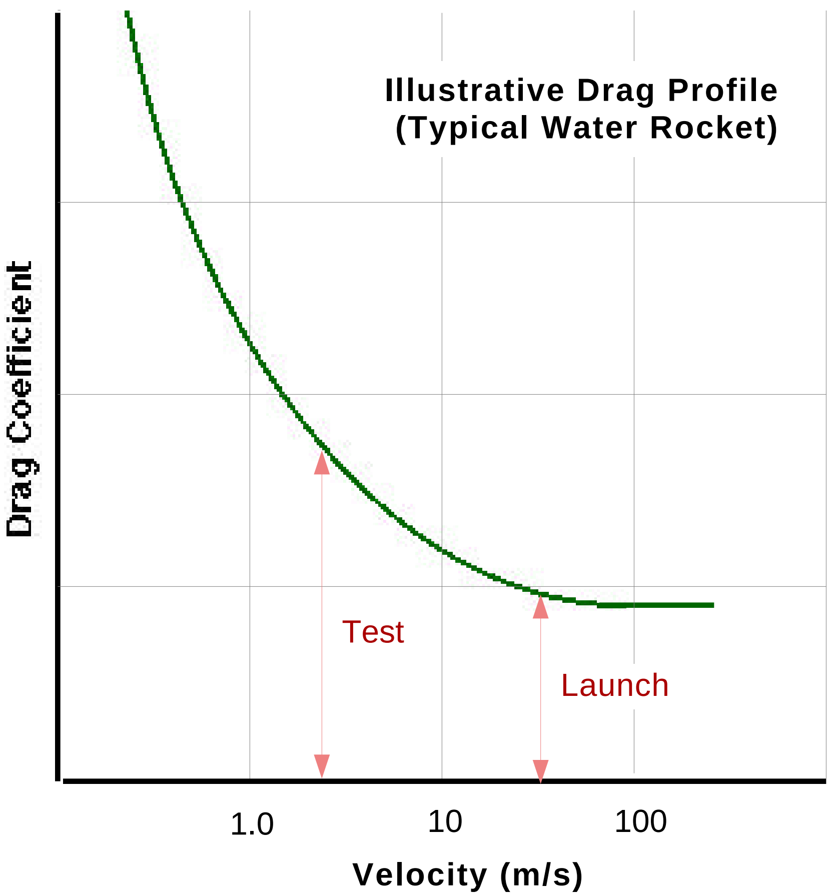


Streamlined Frictional Drag



Blunt Pressure Drag

The propensity for frictional (viscous) and pressure drag to develop when fluid flows around a body depends on the body's shape, size, and surface characteristics. The actual magnitude of the drag will depend on the speed of fluid flow, and the properties of the fluid. The predominance of frictional or pressure effects will vary as the speed of the flow changes (a value called Reynolds Number provides a measure of what type of drag behavior to expect for a given body and fluid). At low speeds of fluid flow frictional (viscous) drag plays the biggest role on the resistance a body experiences moving through a fluid. As the flow speed of the fluid increases the pressure drag becomes more influential, becoming a greater and greater factor. Eventually, as the speed continues to increase, pressure becomes the most dominate aspect of drag. In the flow speed ranges where frictional resistance dominates, the coefficient of drag changes with flow speed but can be calculated using equations derived by theory. And at much higher flow rates, where pressure is dominate, the body is said to be "bluff", with a coefficient of drag that more or less becomes a constant value with speed (a range that full size airplanes and rockets more typically operate at). Unfortunately because of their size and rate of climb, water rockets tend to operate in the transitional region of flow where both aspects of frictional drag and pressure resistance are important influences.



To make matters worse, your rocket will most likely experience considerably faster speeds in a real launch than what you can test with a fan or home constructed wing tunnel (the fan likely develops an air flow speed of around 4 m/s to 6 m/s while an actual rocket may reach up to 60 m/s or faster). Hence, if you directly use equation 2 to estimate the coefficient of drag for your rockets from your test results you will end up with a drag coefficient that is significantly too high. This is because, at the lower air flow speeds of your fan tests, the rocket develops a larger proportion of frictional (viscous) drag effects than the rocket will develop at the faster speeds of an actual launch.

Aerodynamists often test models at slower speeds in wind tunnels too; but they adjust the size of their test models, and the properties of the air or fluid they use, so that they will get the correct flow influences around the test model. Then they use dimensional analysis of the results they obtain to scale the results to the actual vehicle. Unfortunately it would require a lot of work and skill to build accurate scale models and do the dimensional analysis correctly. And unless you build a much more refined wind tunnel, building the scaled model is probably not worth the extra effort. Fortunately there is enough test data and theory around to have a rough idea on just how to adjust the drag as it transitions with increases in the rate of airflow around a body.

Equation 5 is derived to adjust the drag value from the test speed to launch speed. It is a semi-empirical approximation based on theory and expectations and it should not be presumed to be precise, but rather a rough cursory estimate from modest tests results and specific assumptions.

V_t = Velocity of Air in Wind Tunnel Tests (m/s)

V_r = Velocity of Rocket Launch (m/s) -- use 2/3 maximum velocity to approximate full range

C_{dt} = Apparent Drag Coefficient from Test Results

ρ = Air Density (1.22 Kg/m^3)

η = 2 (factor based on the ratio of wetted surface area to projected frontal area of the rocket with a value of 2 being nominal for a typical 2 liter water rocket)

Eq (5):

$$C_{dr} = C_{dt}\left[1 - \frac{1 - \mathrm{sqrt}\,(V_t / V_r)}{\eta\,(1 + (C_{dt} / 1.17))}\right]$$

The astute reader may notice that you will need to know something about how fast your rocket climbs (V_r) in actual launches before you can use equation 5. An analytical means of obtaining this information is to use an apogee simulation program like Water Rocket Fun to iterate and converge towards a drag coefficient that is consistent with the results the simulation calculates. To do this, start out using the apparent drag coefficient (C_{dt}) in your rocket apogee program to find an initial estimate of the maximum velocity (V_r) and use it in equation 5 to determine a more consistent drag coefficient (C_{dr}). Then put the calculated (C_{dr}) back into the simulator program as a better estimate of the drag coefficient and again get a new prediction of the maximum velocity (V_r) of your rocket launch. In this manner continue to iterate and improve your estimate of maximum launch velocity (Vr) and drag coefficient (C_{dr}) until the results of Vr and C_{dr} are satisfactorily consistent (in most cases one iteration will be sufficient).

You may wish to verify your drag calculations with an actual launch before you try to optimize the fluid and mass of your rocket to obtain the highest apogee. You can use the method outlined in the info section of the Water Rocket Fun program to track your launch from two separate positions and triangulate the results to determine the apogee of a test launch. Another quick approximate way to find the apogee of your launches is based on the time your rocket remains in the air. A good equation to use for time was developed by Dean Wheeler and can be found at: http://www.cchem.berkeley.edu/~jsngrp/dean/benchtop/motion.htm. Once you know how high your rocket goes, you can use the Water Rocket Fun program to back out what drag value must be used to get an apogee consistent with the initial conditions of your launch.

When you are satisfied with your estimation of the drag coefficient for your rocket, you can work the Water Rocket Fun program, or other simulator, to determine the optimum amount of water and mass to use to achieve the highest apogees.

Appendix B - Limitations

Limitations of the lab and methodology:

- The theory, drag profile, and simplifications used to derive equation 5 limit its validity to those of your basic 1 to 3 liter soda bottle water rocket launches (the basis is a 2 liter bottle being tested at 4.5 m/s over a fan). Pyro rockets and water rockets made from long tubes, that achieve a higher rate of climb, are likely to operate within a different Reynold's number range, and may approach a drag coefficient of constant value.

- The value for V_r should not be taken to be more than approximately 70 m/s which is about the speed -- depending on the size of the rocket -- that the influence of friction has become minimal. The drag that develops above this speed is likely to be a pressure dominated action due to the high momentum of the air and hence more or less constant.

- The stability of the rocket is also an important factor in the apogee performance of your rocket. You should use the Barrowman equations and/or do a spin test to help you design and check the stability of your rockets. Additional drag is induced by the fins as they work to keep the flight of the rocket straight and true. The more efficient the fins are at keeping the rocket stable, the less drag they will create in doing so. The turbulence in the flow of your fan set-up forces the fins to act, to some extent, to stabilize the rocket and hence in a crude sense include the drag they induce stabilizing your rocket. But the accuracy of this influence is unknown and should not be considered a substitute for doing stability checks -- the accuracy of the methodology depends on assuming the rocket will fly stable.

- The actual drag coefficient of a water rocket launch is typically not a constant as the velocity of the rocket changes and most likely is never moving fast enough to become a constant . Sophisticated wind tunnel testing would be required to precisely account for how the drag coefficient changes with velocity. Since this information is so difficult to acquire and include, most simulators instead assume a constant drag coefficient for the drag profile. Hence the drag coefficient provided for the simulator usually needs to be a nominal average value that approximates the effects of the full range of the drag profile.

- The air flow above the fan is not very consistent. It tends to vary by location and height above the fan. Even where you stand relative to the fan can have an influence on the results you measure. There are many improvements you can make to build a better wind tunnel. Adding walls to the sides and a grate to the fan face may make the flow more consistent. However, be careful assuming these modifications bring about better results. Walls that are too close will influence the flow inside and around the rocket while adding additional grating may make the flow too slow to get meaningful results. Judicious testing is needed to assess whether any changes are in fact an improvement. If you are really ambitious there are a number of plans around for wind tunnels that you can build yourself. As long as any of these tunnels are big enough for the rocket, they are almost certain to be superior to doing things with a fan. With a more refined wind tunnel many of the tests suggested to do in this lab could be done more concisely and probably would give more definitive results.

Appendix C - Submission Information to Provide

Name or Group: ____

School or Institution: ____

Address

Street: ____
Street: ____
City: ________________ State: __________ Zip: ________ Country: _________

Distance of CD above Fan Face: ______ (m) **Apparent Fan Velocity:** ____ (m/s)

Sample Test Matrix for Bottle Design (Procedure 2)

Test	Fan Off	Fan On	Drag	C_r (estimate)
	Measured Mass (g)			
2 Liter Bottle + Extra Mass	______	______	______	
Bottle + Nose 1	______	______	______	
Bottle + Nose 2	______	______	______	
Bottle + Nose 3	______	______	______	
Bottle + Best Nose + 4 Fin A	______	______	______	______
Bottle + Best Nose + 4 Fin B	______	______	______	______
Bottle + Best Nose + 4 Fin C	______	______	______	______

Provide Dimensions, Materials, and Pictures or Illustrations of Components:

Nose Cones Fins Tail Modifications

Any Additional Comments and/or Tests Results

Send to:

email: rockets@Seeds2Learn.com
snail mail: Seeds Software, PO Box 30157, Seattle, WA 98103, USA

Thank You for your Consideration!

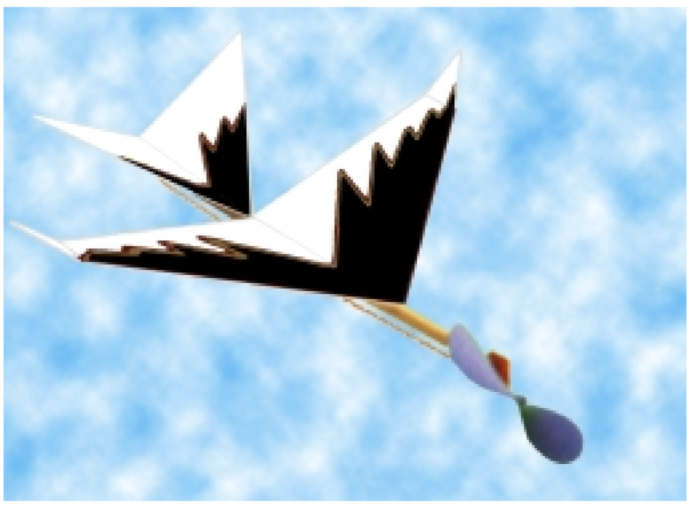
Introduction to Airplane Design

A Theme for Math and Science With Hands-On Lessons

By: Seeds Software

About the Software

Introduction to Airplane Design is a fun software package to learn math and science. It provides an exciting challenge that covers many principles and stimulates thinking. You can use technology wisely to improve your student's learning and understanding with interactive simulations and design tools. Have your students analyze and design their own performance gliders on the computer and then build and test their designs. As they learn more, they can advance to powered flight by including a rubber band motor and propeller in their designs. Your students can explore science with flight!



Climb into our software and take your class soaring to new levels of excitement and learning!

This software package provides much more than game fun, it teaches science with challenge, inquiry, and accountability, yet it is easy to implement and use, and classroom tested. The in-depth content of this package can provide 1 to 8 weeks of classroom curriculum that nicely fits learning standards, or can be a comprehensive resource. For grades 7 -12.

The package includes lessons and numerous activities and plans for labs which keeps the students actively involved with the software, gives the students the opportunity to test aerodynamic principles by flying aircraft, and helps them to understand how to design their own aircraft that fly well. These lessons will free up more time for you to teach!

Science of Software

Science Principles Include:

Balance of Forces
Centrifugal Action
Energy
Force
Geometric Change
Newton's Laws
Power
Supersonic
Bernoulli's Principle
Density
Fluid
Friction
Line of Action
Moment or Torque
Pressure
Velocity

Important Aerodynamic Concepts:

Gravity
Thrust
Stability
Lift
Drag
Control

Important Design Principles:

Airfoil Shape
Wing Configuration
Control Surfaces
Dihedral
Wing Shape
Tail Requirements
Balance and Trim
Propulsion

Aircraft Design Computer:

Easy input of dimensions
3-D visual of the aircraft design
In-depth analysis of performance
Detection and explanations of design problems
Simulation of glide performance

Software Content:

27 computer simulations
58 detailed explanations of principles
22 colorful and illustrative diagrams
7 graphs of aerodynamic trends

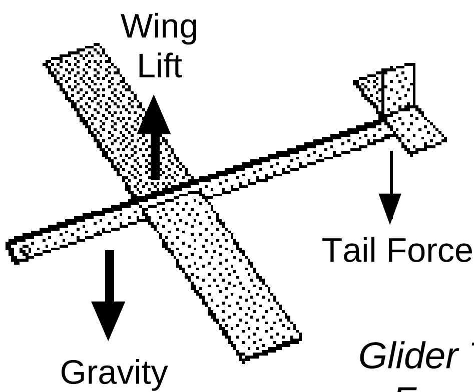
Optional Activities and Labs:

16 classroom activity lessons with objectives
10 hands-on lab plans with material lists
Detailed design and build guides
Answers, teachers notes, and 5 quizzes

Connect Technology to the Real World

The Hands-On Advantage

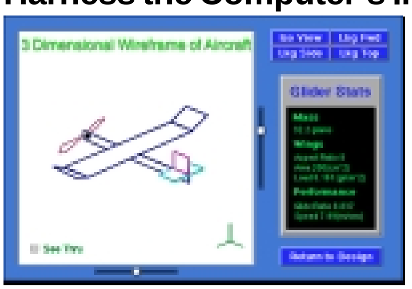
Do you know why and how to design a tail to balance (trim) an airplane or glider? Use the software and hands-on activities provided to clearly explain and develop an understanding of aerodynamic concepts like this while making use of and synthesizing many physics principles.



Glider Trim Forces

The labs in the lessons activities and labs folders provide students with the opportunity to actually test out many principles and exercise careful use of scientific methods in testing and examining results. The labs can be used to help them understand aerodynamic concepts and experiment with how configuration effects flight performance. They provide additional learning styles and help students assimilate and apply what they are studying.

Harness the Computer's Impressive Power



Use the computer to help you design your aircraft

Challenge students to make use of their understanding of principles and concepts and come up with their own aircraft designs. Give them the experience and insight on how the computational power of computers is used to find solutions in the real world. Empower students with the science and technology that enables them to design and build their own aircraft that fly well. Learning will soar!

System Requirements

At least a 256 color monitor

Hybrid (CD-ROM):
Macintosh PowerPC or
Windows95/98/NT/2000/XP
At least 4xCD-ROM Drive

Macintosh (Network CD Image):
Macintosh System 8.0 to OS X
10 MB of available RAM
3.5 MB of Disk Space

Windows (Network CD Image):
Windows 95/98/NT/2000/XP
10 to 20 MB of RAM (depending on OS)
3.0 MB of Disk Space

Software Prices

Single Computer License $ 137.00
Multi-Computer License Discounts Available

Seeds Software

For Growing Knowledge and Understanding

email: Airplane@Seeds2Learn.com
Ph: 206.782.0914
Fax: 206.782.0918

For New Software Titles, Glider Designs and Tips, and Software Updates:

http://www.Seeds2Learn.com

To contact us by mail:

Seeds Software
8446A Summerdale Rd
San Diego, CA 92126

The Bungee Egg Challenge

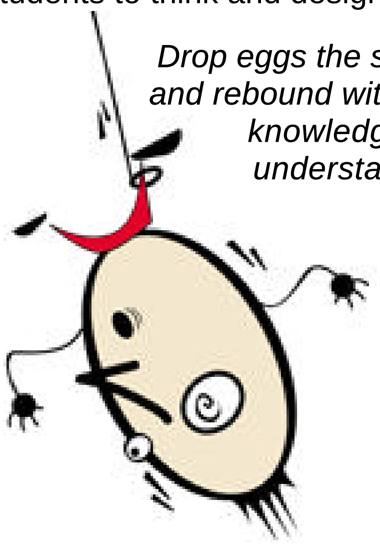
A Theme for Math & Science With Hands-On Lessons

By: Seeds Software

About the Software

The Bungee Egg Challenge is a software package to learn math and science. Most egg drop projects are big on fun but lacking in science, being trial and error. With the Bungee Egg Challenge, students can experience the thrill and fulfillment of using science to achieve success as well! You can use technology wisely to get students to think and design.

Drop eggs the scientific way and rebound with a wealth of knowledge and understanding



This software package provides much more than game fun, it teaches science with challenge, inquiry, and accountability, yet it is easy to implement and use, and classroom tested. Students must do experimental science and make use of realistic design processes to successfully protect their egg from a reasonable drop height. The software nicely fits many learning standards.

Additional Egg Activities and Lab write-ups provide numerous lessons to keep the students actively involved. It includes plans for labs which have the students perform careful experiments to determine the stretch properties of candidate chord materials. The students must decide which chord materials to use to suspend their egg inside a container and input the properties into the computer to predict what happens to the egg when dropped.

Science of Software

Science Principles Include:

Damping	Elasticity
Forces	Gravity
Impact	Kinetic & Potential Energy

Important Design Considerations:

Energy Absorption
Energy Dissipation
Harmonic Motion
Statistical Design Allowable
Stiffness and Displacements

Egg Drop Computer Simulation:

Easy input of dimensions and properties
Visual view of the egg container design
Simulation of the drop event
In-depth analysis of the impact dynamics
Detection and simulation of failures
Time plots of egg motion energy & acting forces

Software Content:

8 detailed explanations of physics principles
10 computer simulations
17 physical science formulas explained
10 interactive graphs of physics trends

Additional Activities and Labs Disk:

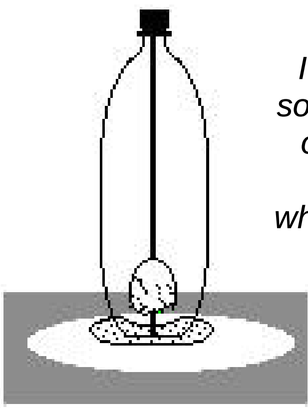
11 classroom activity lessons with objectives
5 hands-on lab plans with material lists & notes
Answers and teachers notes

Experimental Testing in Labs:

Stretch characteristics of chords
Internal friction in stretching chords
Strength of eggs
Dynamic impact drop event

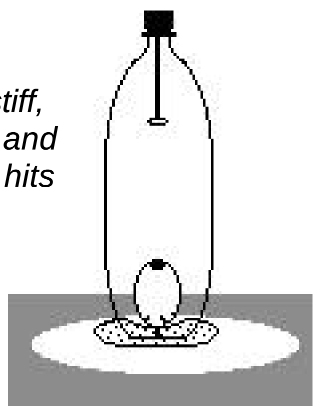
The Hands-On Advantage

How do you determine if an egg will survive a given drop height suspended inside a bottle? Do you know what forces develop, where the best place to position the egg is inside the bottle, how much the chords will stretch, how fast energy is dissipated? With this package you can show students how science principles can be used to answer these questions. You can simplify a very exciting but advanced problem down into understandable concepts. Students can assemble and assimilate science and technology to do realistic designs using an elegant but easy to run computer solution.



If the chords are too soft, the egg will crash or slingshot into the bottle and SPLAT! when the bottle hits the ground

If the chords are too stiff, the egg will pull apart and break when the bottle hits the ground



The labs available in the Lessons folders show students how to conduct tests to determine the stretching and internal friction characteristics present in likely chord suspension materials. The tests give the students an appreciation of how important it is to take careful scientific measurements and how these measurements can be used; test results are used as properties by the software to calculate what happens to the egg inside the container when it impacts the ground.

Software Prices

Single License $ 97.00

Multi-Computer Licenses Also Available

System Requirements

At least a 256 color monitor

Hybrid (CD-ROM):
Macintosh PowerPC or
Windows95/98/NT/2000/XP
At least 4xCD-ROM Drive

Macintosh (Network CD Image):
Macintosh System 8.0 to OS X
10 MB of available RAM
3.0 MB of Disk Space

Windows (Network CD Image):
Windows95/98/NT/2000/XP
8 to 16 MB of RAM (depending of OS)
3.0 MB of Disk Space

Contacting Seeds Software

email: Science@Seeds2Learn.com
Phone: 206.782.0914
Fax: 206.782.0918

For New Software Titles, Glider Designs and Tips, and Software Updates:

http://www.Seeds2Learn.com

By Mail:

Seeds Software
8446A Summerdale Rd
San Diego, CA 92126

Science Methods: Searching for Solutions Experimentally

A Theme for Math & Science With Hands-On Lessons

By: Seeds Software

About the Software

Science Methods: Searching for Solutions Experimentally is a software package to teach students how math and science can be used to find experimental solutions; it introduces students to the important ideas and methods of Experimental Design.

A simple theme of color mixing and matching is used as a model example of many real world problems that embody several inputs which combine to form a result. The problem is to find how much of each input is needed to get the results that you want. For color mixing, students have fun trying to find the amounts of the colors red, green, and blue required to match a specimen color of unknown formulation.

Illuminate Science with Colors!

The natural tendency is to try to solve these problems using trial and error. With this package students will discover how ineffective guessing is and learn to make use of math and science methods to efficiently converge to desired solutions. The software is structured to work over a wide range of abilities and can be used to support many learning standards. The package is classroom tested and is recommended for grades 5-12.

Science of Software

Color Theory:

Introduce students to color theory and how monitors use primary colors to generate a wide spectrum of hues while having fun and doing challenging activities.

Science Methods Include:

- Pattern Recognition
- Information Modeling
- Accuracy and Error Measurement
- Systematic Problem Solving
- Solution Convergence

Solution Strategies:

- Guess
- Error Measurement
- Bisection
- Ratio
- Gradient

Software Content:

- Five Computer Simulations of Color Mixing & Problem Solving Methods
- 3 Dimensional Information Modeling
- Simulation of Experimental Design Scenarios

Activities and Labs:

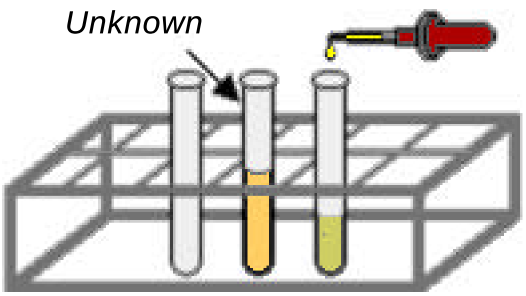
- 6 classroom activity lessons with objectives
- 2 hands-on lab plans with material lists, notes
- Answers and explanations

Applicable Science Curriculum

- Astronomy
- Biology
- Chemistry
- Other Physical Sciences

The Real World Connection

How do you match the color, to repaint a car that has been damaged, when the original color of the car has faded? How do you mix several color dyes together for an accessory when you wish to match the color of a dress? How does an astronomer determine the abundance of a certain heavy metal in the photoshere of a star when the observed spectrum is effected by the temperature, density, and pressure of the star? Experimental Design problems abound in all aspects of life; the question asked often is how much of several known inputs is needed to get the results desired.



Adding Colors to Find a Match

This package includes lab lessons to ask this question. Students perform experiments mixing food coloring dyes, trying to match a color of unknown formulation. These labs help the students grasp the issues and develop an awareness of the difficulties in arriving at an experimental solution. Direct links between computer technology and the lab experiments are established by simulating the same type of experiments on the computer.

By doing the same color mixing experiments on the computer, students will discover how much more rapidly they can: do the color mixing tests, investigate solution strategies, and develop pattern recognition. They will experience how computers are used as a tool to study real world problems and learn solution strategies.

The package also includes lessons that help the students understand the solution strategies that are presented and keep the students actively involved with the software.

Software Prices

Single Computer $ 40.00

Multi-Computer License Discounts Available

System Requirements

At least a 256 color monitor

Hybrid (CD-ROM):
Macintosh PowerPC or
Windows95/98/NT/2000/XP
At least 4xCD-ROM Drive

Macintosh (Network CD Image):
Macintosh System 8.0 to OS X
10 MB of available RAM
3.0 MB of Disk Space

Windows (Network CD Image):
Windows95/98/NT/2000/XP
8 to 16 MB of RAM (depending of OS)
3.0 MB of Disk Space

Contacting Seeds Software

email: Science@Seeds2Learn.com
Phone: 206.782.0914
Fax: 206.782.0918

For New Software Titles, Glider Designs and Tips, and Software Updates:

http://www.Seeds2Learn.com

By Mail:

Seeds Software
8446A Summerdale Rd
San Diego, CA 92126

Global Warming: Understanding Greenhouse Gases

A Theme for Math and Science With Hands-On Lessons

By: Seeds Software

About the Software

Global warming is an incredibly rich theme to teach your students science while investigating a very important environmental issue. With this package you can provide students with an understanding of the science behind global warming instead of just having them look at the data of predictions. The package includes an authentic global climate model to use to find answers and take ownership of predictions.

This software package provides much more than game fun, it teaches science with challenge, inquiry, and accountability, yet it is easy to implement and use, and classroom tested. The in-depth content of this package can provide 1 to 8 weeks of classroom curriculum that nicely fits many learning standards, or can be a comprehensive resource. For grades 8-12.

Included in the package are write-ups of lessons and numerous hands-on labs in a modifiable format. These lessons and labs keep the students actively involved with the software, give the students the opportunity to test scientific principles, and help them to get an intuitive feel of the principles. The lessons will free up more time for you to teach!

Science of Software

Science Principles Include:

Absorptance	Beer -Lambert Law
Blackbodies	Emittance
Energy Equilibrium	Heat Capacity
Inverse Sq. Law	Kirchoff's Law
Photons	Planck's Law
Planet Atmospheres	Radiance
Radiation Spectrum	Resonance
Specific Heat	Stefan-Boltzmann Law
Transmittance	Waves

Supporting Material:

The content on global warming, and the global climate model, are based extensively on the final reports of the Intergovernmental Panel on Climate Change (IPCC 1990-97). These recent reports include the preparation, workings, and review of hundreds of leading scientists from 25 counties. The reports represent an information source of the finest quality and authority.

Simulations & Global Climate Model:

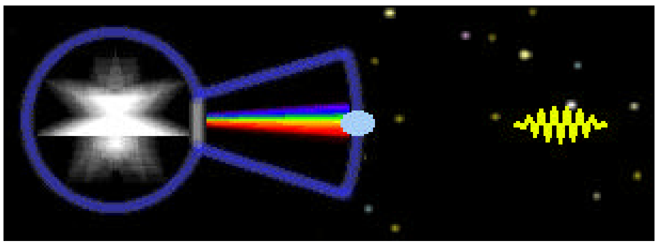
The software provides simulations of many of the important concepts needed to understand global warming. These simulations make the concepts much more accessible and meaningful to students than they are in text books. The global climate model included has a simple elegance. It is easy to use with clear understandable results; yet it unleashes the incredible computational power of computers and uses many advanced methods to deliver compelling inferences on the future of the Earth.

Activities and Labs:

9 classroom activity lessons with objectives
9 hands-on lab plans with material lists
Answers and teachers notes

The Hands-On Advantage

Everyone has read something about global warming and how our emissions and activities may be causing climate changes. But how many individuals really understand the science behind the information? Consider how much more meaningful and comprehensible this important information can be with a working knowledge of the processes that are causing change.



Computer Simulations:

The concepts of global warming are more than publications of predictions and observation of data, it involves an astonishing amount of science that is extremely challenging for scientists. By using computer simulations and hands-on labs many of the fundamentals are made accessible and understandable to students, abstractions and advanced formulas become animated and intuitive. Students can use the software to learn why climate change is a very real environmental issue.

Turn your students onto technology. Give them the experience and insight on how the computational power of computers and technology are used to study the real world. Empower students with the science and technology that enables them to understand their environment. Students can do more than play games or look at data. Don't be surprised to find your students far more interested and intrigued doing real science with powerful science tools. With our authentic global climate model you can give them ownership of global warming issues and the many science principles involved.

Software Prices

Single Computer License $ 137.00

multi-computer licenses also available

System Requirements

At least a 256 color monitor

Hybrid (CD-ROM):
Macintosh PowerPC or
Windows95/98/NT/2000/XP
At least 4xCD-ROM Drive

Macintosh (Network CD Image):
PowerPC
10 MB of available RAM
3.0 MB of Disk Space

Windows (Network CD Image):
Windows 95/98/NT/2000/XP
8 to 16 MB of RAM (depending of OS)
3.0 MB of Disk Space

Contacting Seeds Software

email: Science@Seeds2Learn.com
Phone: 206.782.0914
Fax: 206.782.0918

For New Software Titles, Glider Designs and Tips, and Software Updates:

http://www.Seeds2Learn.com

By Mail:

Seeds Software
8446A Summerdale Rd
San Deigo, CA 92126

Seeds Software Order Form

Web:www.Seeds2Learn.com

Email: Science@Seeds2Learn.com **Phone:** 206.782.0914 **Fax:** 206.782.0918

Title: Software & Lessons	Single (1) License	√	Lab (5)~ License	√	Lab (15)~ License	√	Site (30)~ License	√	Selection Prices
Introduction to Airplane Design	$137.00 Hybrid CD		$285.50 NW $357.00 CD		$397.00 NW $507.00 CD		$536.00 NW $697.00 CD		
The Bungee Egg Challenge	$97.00 Hybrid CD		$151.50 NW $189.50 CD		$269.00 NW $344.50 CD		$374.00 NW $487.00 CD		
Science Methods: Searching for Solutions	$40.00 Hybrid CD		$95.50 NW $119.50 CD		$215.00 NW $274.50 CD		$321.00 NW $417.00 CD		
Global Warming: Greenhouse Gases	$137.00 Hybrid CD		$309.50 NW $387.00 CD		$443.50 NW $567.00 CD		$613.00 NW $797.00 CD		
Science by Design	$279.00		Sgl CD only		Sgl CD only		Sgl CD only		

Notes:(#)max. number of computers ~**NW** is for multi-install CD, **CD** is for multiple Hybrid CD's in license

Name: ______________________________ **Phone:** __________________

Address: ____

____

____

Subtotal	
Tax **	
S&H (USA)	$8.00
Total	

__ Purchase Order # (US schools only) ______________________

__ VISA/MasterCard Card #: ______________________________

Card Holder's Name: _________________________ Exp. Date: ________

P.O. or Card Holder's Signature: ______________________________

Choose Medium √	
Mac NW*	Win NW*
Hybrid Mac/Win CD-ROM	
	~

***Notes:** Mac or Win NW are program images on a CD to install onto computer network hard drives. Hybrid CD's load into memory and run off the CD without installation on either Macintosh or Windows

Ordering: Check options wanted in table above and calculate prices, subtotal, and total
(** CA State (residents only) x subtotal by 0.086 for sales tax).
Provide required payment and mailing information.
Be sure to specify computer medium choices.

Mail: Seeds Software, 8446A Summerdale Rd, San Diego, CA 92126 **Fax To:** 206.782.0918

Warranty: Send complete package back to Seeds Software by verifiable means within 30 days for your money back if not satisfied.