Advanced Manufacturing & Materials

Electric Vehicle: Body Design

Grade Levels: 9^{th} – 12^{th}

Academic Content Areas: Science, Technology, Engineering, & Mathematics

Topics: Physical Science; Science & Technology; Scientific Inquiry; Measurement; Geometry & Spatial Sense; Patterns, Functions & Algebra; Data Analysis

Main Problem/Essential Question

Design the body of a vehicle, taking into consideration the effects of drag on the efficiency of the engine and the distance the vehicle can travel.

Summary

This lesson is designed to be completed independently, consecutively, or concurrently with the Rolling Resistance, Transmission, Electric Power Source, and Electric Motor Lessons for the Electric Vehicle (EV) Unit.

Power efficiency is the goal of all good environmentally conscious designs. As you will see throughout the EV unit, there are many factors that influence this efficiency. The goal of this lesson is to determine the effects of the body design on the vehicle's travel and engine efficiency. Efficiency, practicality, and marketing the product must all be kept in mind when designing the vehicle's body and determining the material the vehicle will be made of. Students will design, test, and create a prototype of their design as well as market their product to industrial customers and consumers by the end of this lesson.

Big Idea / Focus

Drag is a mechanical force generated by the interaction and contact of a solid body with a fluid (liquid or gas). If there is no fluid, there is no drag (such as in a vacuum).

Drag is generated by the difference in velocity between the solid object and the fluid. There must be motion between the object and the fluid. If there is no relative motion, there is no drag.

A falling object will eventually reach a constant velocity known as the terminal velocity due to the force of air resistance (air particle striking the object and trying to slow it down). This force is also referred to as drag.

With downwards vertical motion, there are two forces to consider. We have the force of gravity acting downward and the force of drag acting upward. When these two forces are balanced, the net force on the object is zero, the acceleration of the object is zero, and the object has reached its terminal velocity.

In horizontal motion, the force that causes the forward acceleration of the object is the force of thrust from the engine, (like the force of gravity in vertical motion). The resisting force is still the drag force and still due to air resistance, but this time it is acting horizontally in a direction opposite to the motion of the vehicle. When the thrust force balances the drag force, the acceleration of the vehicle is zero and the vehicle has reached its maximum speed. We call this speed the top speed.

A reminder that speed differs from velocity in that velocity is speed plus direction. For a falling object, the direction of motion is down and the term "terminal velocity" is the maximum speed in the down direction. For a horizontally moving vehicle, the direction (east, west, etc…) is not typically specified and so it is more appropriate to use the term "top speed".

For a falling object, the gravitational force is determined by the mass of the object (its weight). In horizontal motion, the force of thrust is determined by the engine in the vehicle. While building up to top speed, the engine must produce enough thrust to overcome the drag force, which increases as the speed increases (just like it does vertically).

The three factors that have a large effect on the drag of an object are **frontal cross-sectional area**, **body shape**, and the **speed** of the object.

The frontal cross-sectional area of the vehicle will directly affect the drag on the vehicle. The front cross-sectional area is the area of the vehicle perpendicular to the direction of motion. If you could compress the vehicle from front to back until it was as flat as a piece of paper, then the area of the paper would be the front cross-sectional area (assuming none of the vehicle is squeezed out of the sides as it is compressed). Another way to envision the front cross-sectional area is to imagine the vehicle flying through the smallest hole possible so that it just fits through the hole without turning the hole or the vehicle as it flies through. The size of this hole is also the frontal cross-sectional area. The larger the frontal cross-sectional area, the greater the drag force, since more air particles will strike the vehicle as it moves. Since the drag force on the vehicle is a force that opposes the motion of the vehicle, then the frontal area plays a major role in the efficiency of the vehicle.

An object's drag can be calculated measuring aspects of the object's shape. These measurements are used to calculate a quantitative attribute of the shape called the drag coefficient. This drag coefficient gives a measurement of an object's ability to move through a fluid (including air) efficiently, which effects the fuel/engine efficiency.

Prerequisite Knowledge

Ideally students would have some experience with Google SketchUp or the CAD program the instructor wishes to use for this lesson.

Students should be proficient with a graphing calculator.

Students should also be introduced to how the motion detector (CBR) and calculator or software used in the Coffee Filter Experiment will be used.

Standards Connections

Content Area: Science

Physical Sciences Standard
Students demonstrate an understanding of the composition of physical systems and the concepts and principles that describe and predict physical interactions and events in the natural world. This includes demonstrating an understanding of the structure and properties of matter, the properties of materials and objects, chemical reactions and the conservation of matter. In addition, it includes understanding the nature, transfer and conservation of energy; motion and the forces affecting motion; and the nature of waves and interactions of matter and energy. Students demonstrate an understanding of the historical perspectives, scientific approaches and emerging scientific issues associated with the physical sciences.

Grade 9 - Benchmark D: Explain the movement of objects by applying Newton's three laws of motion.	21. Demonstrate that motion is a measurable quantity that depends on the observer's frame of reference and describe the object's motion in terms of position, velocity, acceleration and time. 22. Demonstrate that any object does not accelerate (remains at rest or maintains a constant speed and direction of motion) unless an unbalanced (net) force acts on it. 23. Explain the change in motion (acceleration) of an object. Demonstrate that the acceleration is proportional to the net force acting on the object and inversely proportional to the mass of the object. (F net =ma. Note that weight is the gravitational force on a mass.) 24. Demonstrate that whenever one object exerts a force on another, an equal amount of force is exerted back on the first object. 25. Demonstrate the ways in which frictional forces constrain the motion of objects (e.g., a car traveling around a curve, a block on an inclined plane, a person running, an airplane in flight).
Grade 12 - Benchmark D: Apply principles of forces and motion to mathematically analyze, describe and predict the net effects on objects or systems.	5. Use and apply the laws of motion to analyze, describe and predict the effects of forces on the motions of objects mathematically.

Science and Technology Standard
Students recognize that science and technology are interconnected and that using technology involves assessment of the benefits, risks and costs. Students should build scientific and technological knowledge, as well as the skill required to design and construct devices. In addition, they should develop the processes to solve problems and understand that problems may be solved in several ways.

Grade 9 - Benchmark A: Explain the ways in which the processes of technological design respond to the needs of society.	2. Identify a problem or need, propose designs and choose among alternative solutions for the problem. 3. Explain that when evaluating a design for a device or process, thought should be given to how it will be manufactured, operated, maintained, replaced and disposed of in addition to who will sell, operate and take care of it. Explain how the costs associated with these considerations may introduce additional constraints on the design.
Grade 11 - Benchmark A: Predict how human choices today will determine the quality and quantity of life on Earth.	2. Predict how decisions regarding the implementation of technologies involve the weighing of trade-offs between predicted positive and negative effects on the environment and/or humans.

Scientific Inquiry Standard

Students develop scientific habits of mind as they use the processes of scientific inquiry to ask valid questions and to gather and analyze information. They understand how to develop hypotheses and make predictions. They are able to reflect on scientific practices as they develop plans of action to create and evaluate a variety of conclusions. Students are also able to demonstrate the ability to communicate their findings to others.

Grade 9 - Benchmark A: Participate in and apply the processes of scientific investigation to create models and to design, conduct, evaluate and communicate the results of these investigations.	1. Distinguish between observations and inferences given a scientific situation. 3. Construct, interpret and apply physical and conceptual models that represent or explain systems, objects, events or concepts. 5. Develop oral and written presentations using clear language, accurate data, appropriate graphs, tables, maps and available technology. 6. Draw logical conclusions based on scientific knowledge and evidence from investigations.
Grade 10 - Benchmark A: Participate in and apply the processes of scientific investigation to create models and to design, conduct, evaluate and communicate the results of these investigations.	2. Present scientific findings using clear language, accurate data, appropriate graphs, tables, maps and available technology. 3. Use mathematical models to predict and analyze natural phenomena. 4. Draw conclusions from inquiries based on scientific knowledge and principles, the use of logic and evidence (data) from investigations.
Grade 11 - Benchmark A: Make appropriate choices when designing and participating in scientific investigations by using cognitive and manipulative skills when collecting data and formulating conclusions from the data.	1. Formulate testable hypotheses. Develop and explain the appropriate procedures, controls and variables (dependent and independent) in scientific experimentation. 3. Design and carry out scientific inquiry (investigation), communicate and critique results through peer review.

Grade 12 - Benchmark A: Make appropriate choices when designing and participating in scientific investigations by using cognitive and manipulative skills when collecting data and formulating conclusions from the data.	1. Formulate testable hypotheses. Develop and explain the appropriate procedures, controls and variables (dependent and independent) in scientific experimentation. 2. Derive simple mathematical relationships that have predictive power from experimental data (e.g., derive an equation from a graph and vice versa, determine whether a linear or exponential relationship exists among the data in a table). 4. Create and clarify the method, procedures, controls and variables in complex scientific investigations. 5. Use appropriate summary statistics to analyze and describe data.

Scientific Ways of Knowing Standard

Students realize that the current body of scientific knowledge must be based on evidence, be predictive, logical, subject to modification and limited to the natural world. This includes demonstrating an understanding that scientific knowledge grows and advances as new evidence is discovered to support or modify existing theories, as well as to encourage the development of new theories. Students are able to reflect on ethical scientific practices and demonstrate an understanding of how the current body of scientific knowledge reflects the historical and cultural contributions of women and men who provide us with a more reliable and comprehensive understanding of the natural world.

Grade 9 - Benchmark B: Explain how scientific inquiry is guided by knowledge, observations, ideas and questions.	6. Explain that inquiry fuels observation and experimentation that produce data that are the foundation of scientific disciplines. Theories are explanations of these data.
Grade 10 - Benchmark A: Explain that scientific knowledge must be based on evidence, be predictive, logical, subject to modification and limited to the natural world.	3. Recognize that science is a systematic method of continuing investigation, based on observation, hypothesis testing, measurement, experimentation, and theory building, which leads to more adequate explanations of natural phenomena.
Grade 11 - Benchmark A: Explain how scientific evidence is used to develop and revise scientific predictions, ideas or theories.	3. Demonstrate that scientific explanations adhere to established criteria, for example a proposed explanation must be logically consistent, it must abide by the rules of evidence and it must be open to questions and modifications.
Grade 12 - Benchmark A: Explain how scientific evidence is used to develop and revise scientific predictions, ideas or theories.	4. Analyze a set of data to derive a principle and then apply that principle to a similar phenomenon (e.g., predator-prey relationships and properties of semiconductors).

Content Area: Mathematics

Measurement Standard

Students estimate and measure to a required degree of accuracy and precision by selecting and using appropriate units, tools and technologies.

Grade 9 – Benchmark B: Use formulas to find surface area and volume for specified 3-D objects.	5. Solve problems involving unit conversion for situations involving distances, areas, volumes and rates within the same measurement system.
Grade 11 – Benchmark C: Estimate and compute areas and volume in increasingly complex problem situations.	4. Calculate distances, areas, surface areas and volumes of composite three-dimensional objects to a specified number of significant digits.
Grade 12 – Benchmark D: Solve problem situations involving derived measurements; e.g., density, acceleration.	1. Solve problems involving derived measurements; e.g., acceleration and pressure.

Geometry and Spatial Sense Standard

Students identify, classify, compare and analyze characteristics, properties and relationships of one-, two-, and three-dimensional geometric figures and objects. Students use spatial reasoning, properties of geometric objects and transformations to analyze mathematical situations and solve problems.

Grade 11 – Benchmark A: Use trigonometric relationships to verify and determine solutions in problem situations.	5. Identify, sketch and classify the cross sections of three-dimensional objects.
Grade 12 – Benchmark A: Use trigonometric relationships to verify and determine solutions in problem situations.	4. Recognize and compare specific shapes and properties in multiple geometries; e.g., plane, spherical and hyperbolic.

Patterns, Functions and Algebra Standard

Students use patterns, relations and functions to model, represent and analyze problem situations that involve variable quantities. Students analyze, model and solve problems using various representations such as tables, graphs and equations.

Grade 9 – Benchmark D: Use algebraic representations such as tables, graphs, expressions & inequalities to model and solve problem situations.	3. Describe problem situations (linear, quadratic and exponential) by using tabular, graphical and symbolic representations.
Grade 9 – Benchmark E: Analyze and compare functions and their graphs using attributes such as rates of change, intercepts and zeros.	13. Model and solve problems involving direct and inverse variation using proportional reasoning.

Grade 10 – Benchmark D: Use algebraic representations such as tables, graphs, expressions & inequalities to model and solve problem situations.	3. Solve equations and formulas for a specified variable; e.g., express the base of a triangle in terms of the area and height. 10. Solve real-world problems that can be modeled using linear, quadratic, exponential, or square root functions.
Grade 12 – Benchmark A: Analyze functions by investigating rates of change, intercepts, zeros, asymptotes, and local and global behavior.	6. Make arguments about mathematical properties using mathematical induction.

Data Analysis and Probability Standard

Students pose questions and collect, organize, represent, interpret and analyze data to answer those questions. Students develop and evaluate inferences, predictions and arguments that are based on data.

Grade 9 – Benchmark A: create, interpret, and use graphical displays and statistical measures to describe data.	2. Create a scatterplot for a set of bivariate data, sketch the line of best fit, and interpret the slope of the line of best fit.
Grade 10 – Benchmark A: create, interpret, and use graphical displays and statistical measures to describe data	2. Represent and analyze bivariate data using appropriate graphical displays (scatterplots, parallel box-and-whisker plots, histograms with more than one set of data, tables, charts, spreadsheets) with and without technology. 6. Interpret the relationship between two variables using multiple graphical displays and statistical measures; e.g., scatterplots, parallel box-and-whisker plots, and measures of center and spread.
Grade 11 – Benchmark A: create and analyze tabular and graphical displays of data using appropriate tools including spreadsheets and graphing calculators.	1. Design a statistical experiment, survey or study for a problem; collect data for the problem; and interpret the data with appropriate graphical displays, descriptive statistics, concepts of variability, causation, correlation and standard deviation. 5. Use technology to find the Least Squares Regression Line, the regression coefficient, and the correlation coefficient for bivariate data with a linear trend, and interpret each of these statistics in the context of the problem situation.
Grade 11 – Benchmark B: use descriptive statistics to analyze and summarize data, including measures of center, dispersion, correlation and variability.	4. Create a scatter plot of bivariate data, identify trends, and find a function to model the data. 7. Describe the standard normal curve and its general properties, and answer questions dealing with data assumed to be normal. 8. Analyze and interpret univariate and bivariate data to identify patterns, note trends, draw conclusions, and make predictions.

Preparation for activity

The instructor should make certain the appropriate software has been installed on student computers and should have personal experience with a Computer Aided Design (CAD) program before facilitating this lesson. It is recommended that the instructor also complete a prototype through Sinclair Community college prior to this activity. This may require attending a workshop or having a resource person in your district in case problems occur. Educational versions of these programs are often available through the manufacturer. Examples of CAD programs include Google SketchUp (a freeware program, download at www.google.com/sketchup/download) AutoCAD and Solidworks.

Also, the instructor should have experience with the motion detector and data collection software that will be used in the coffee filter experiment. A program that will record and display a distance versus time graph will be required.

The instructor should schedule two visits by the Wizards of Wright wind tunnel (see Appendix A for contact information). The first visit is for students to explore calculating the drag coefficient of different objects. The second will be to calculate drag coefficient and test the possible designs of their vehicle.

Critical Vocabulary

drag - Drag is a mechanical force generated by the interaction and contact of a solid body with a fluid (liquid or gas) as the solid body moves through the fluid. Drag is a force that opposes the motion of an object and increases with increasing relative velocity between the solid body and the fluid.

drag coefficient - The drag coefficient is a number that is used to model all of the complex dependencies of shape, inclination, and flow conditions on an object's drag.

efficiency (of an engine) - The relationship between the total energy contained in the fuel, and the amount of energy used to perform useful work.

fluid - A substance whose molecules flow freely, so that it has no fixed shape and little resistance to outside stress (e.g. a liquid or a gas).

frontal cross-sectional area - The largest cross-sectional area of the object perpendicular to the direction of motion.

speed - The magnitude of the velocity vector.

terminal velocity - The velocity of a falling object when the downwards force of gravity is balanced by the upwards force of drag. It is also the maximum velocity of a dropped object that remains unchanged in size and shape.

top speed - The speed of a horizontally moving object when the thrust force balances the force of drag.

velocity - The vector measurement of the speed and direction of the motion, or more fundamentally, the vector measurement of the time rate of change of the position, including direction.

Timeframe

Some of the activities during this unit are optional so the timeframe can vary greatly.

Day	Time Allotment	Activities
1	55 min.	Activity I – Experimental data on drag
2	55 min.	Activities II-III – Calculating drag coefficient and correlating to engine efficiency
3	55 min.	Activity IV – Weight and engine efficiency
4	55 min.	Activities V-VI – Body design and wind tunnel tests
5-7	55 min. each day	Activities VII-VIII – Selection of class body and material and entering class body into a CAD program
8	55 min.	Activities IX – Optional – use modeling software for virtual testing (nondestructive testing)
9	Half day	Activity X – Create a prototype (field trip to Sinclair Community College) (preparation and presentation)
10-11	55 min.	Activity XI – Preparation and presentation of results

Materials & Equipment

Coffee Filters
Motion detector and appropriate software/program for data collection
Graphing Calculator
Google SketchUp (freeware), Solidworks (software) or other CAD programs
Block of modeling clay
Clay sculpting tools (for safety, these should be plastic with no sharp edges)
Handouts with questions to be answered throughout activity (maybe guided inquiry packets)

Safety & Disposal

Modeling clay can be used in this lesson. Most modeling clays are reusable. Follow the provided with the modeling clay concerning the proper use and storage for the particular brand/type of modeling used in this lesson. Clay sculpting tools should be chosen that are appropriate for the students. If necessary, the students can shape the modeling clay using just their fingers.

Pre-Activity Discussion

Ideally students would have some experience with Google SketchUp, SolidWorks or the CAD program the instructor wishes to use for this lesson.

Students should also be introduced to how the motion detector and software used in the Coffee Filter Experiment will be used.

Teacher Instructions

I. Coffee Filter Drop Lab

Introduction

When there is no air resistance (such as in a vacuum), the speed of a falling object increases by 9.8 meters per second for every second that the object is in motion. If both a basketball and a coffee filter are dropped at the same time from the same height in a vacuum (where there is no air resistance), both would reach the ground at the same time. An example of free fall can be seen by watching the youtube video of Apollo 15 astronaut David Scott dropping a hammer and a feather on the moon.

However, the same is not true if we dropped a basketball and a coffee filter from the same height in a classroom. As the coffee filter falls through the air, air resistance or the drag force has a much larger effect on its acceleration that does the drag force on the basketball. When the coffee filter is first released, its speed increases from zero, but the air resistance acting on the coffee filter also increases. Eventually, when the air resistance becomes great enough and equals the force of gravity on the object, the coffee filter stops accelerating and falls the rest of the way at a constant rate, known as its terminal velocity. For the basketball, a much larger speed is needed to produce a drag force large enough to balance the force of gravity.

At all times the acceleration of the coffee filter is given by:

Net Acceleration = Acceleration due to gravity - Acceleration from air resistance

The acceleration due to air resistance can be modeled as rV^2, where r is a constant known as the drag parameter and V is the velocity. In this lab we will drop a coffee filter, measure the distance, and use this to determine the terminal velocity of the coffee filter and the drag parameter of the coffee filter.

Equipment and Setup

For this experiment you will need a TI calculator and a CBR (**C**alculator **B**ased **R**anger) unit or a TI calculator with the Vernier PHYSICS program loaded, a CBL (**C**alculator **B**ased **L**aboratory) unit, a motion detector, and a coffee filter.

For experiments without the Vernier systems

Many TI calculators come with a program already installed that is compatible with many CBR's. Check your manual for operation specifics.

For experiments with the Vernier systems

In the home menu choose SET UP PROBES. When asked for the number of probes, enter 1. In the next menu choose MOTION. The screen will display the home menu again. Now select COLLECT DATA, and choose TIME GRAPH. Set the calculator to take 40 measurements 0.05 second apart.

If students have access to a video camera this experiment can be done by gathering information using a video of each drop and stopwatches, although this is not the preferred method.

Procedure

When the calculator is ready to begin taking measurements, place the motion detector flat on the ground facing up while another group member holds the coffee filter directly above the motion detector. Press ENTER on the calculator to begin taking measurements, and release the filter when the motion detector begins clicking. After collecting the data, press ENTER on the calculator to get the graph menu. Select DISTANCE; press ZOOM, select "9: ZoomStat", press ENTER. The calculator will display the graph of the distance of the filter from the motion detector versus time. Note that distance is in meters and time is in seconds.

Data

While viewing the graph of distance versus time, use TRACE to recover the data collected by the CBL unit or CBR unit on your calculator. Record the distances collected by the CBL/CBR unit in the table below. Discard the data points taken before the drop and after the filter hit the floor.

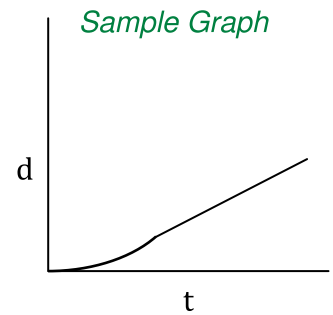
For Vernier users, after recording the data, quit the PHYSICS program by pressing ENTER to get back to the graph menu, then choose RETURN. When asked to repeat select NO, and then in the main menu select QUIT.

Time in seconds	***0.05***	***0.10***	***0.15***	***0.20***	***0.25***	***0.30***	***0.35***	***0.40***	***0.45***	***0.50***
Distance in meters										
Time in seconds	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
Distance in meters										
Time in seconds	1.01	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50
Distance in meters										
Time in seconds	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
Distance in meters										

Analysis

1. Input the data in the table above into your calculator by entering times in L1 and distances in L2. Then enter **only the last five data points** in your table in lists L3 and L4. Using these **last five data points**, find the equation of the regression line for distance D (in meters) as a function of time t (in seconds). (Enter LinReg L3, L4.)
2. Plot **the data from the table above** and **add the regression** line from Question 1 to your graph. Sketch the graph.

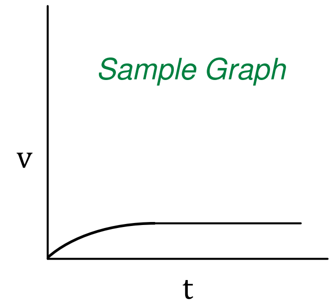
Sample Graph



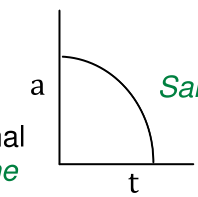
3. Use the graph in Question 2 to help you describe how the velocity of the coffee filter **changes** as it falls. *The velocity begins at zero and speeds up to its terminal velocity, which is a slow speed. It then falls at a constant speed. (The acceleration begins at 9.8 m/s/s and decreases to zero as the filter approaches its terminal velocity.)*
4. Explain why the slope in your formula in Question 1 is the terminal velocity of the coffee filter. *When the distance graph becomes linear, the graph implies that velocity (the*

change in distance divided by the change in time) has become constant. This is the terminal velocity.

5. Use your answers to Questions 2 through 4 to help you carefully sketch a graph of the velocity of the coffee filter. *Students should have the horizontal axis correctly labeled with the times and the vertical axis correctly labeled with the velocity.*



6. Use your graph in Question 5 to help you carefully sketch a graph of the acceleration of the coffee filter. *Students should have the horizontal axis correctly labeled with time and the vertical axis correctly labeled with acceleration. The plot should be a downward curve.*



7. About how long does it take the coffee filter to reach terminal velocity? How did you determine this? *Students will note the time at which the distance-time graph becomes linear (horizontal and flat). Note: It happens rather quickly.*

8. Recall that air resistance or the drag force can be modeled as rV^2, where r is a constant known as the drag parameter and V is the velocity. In this part of the lab we will show one way in which the drag parameter of an object can be experimentally determined. Let A represent the net acceleration of the coffee filter and g the acceleration due to gravity. Then we have the basic equation $A = g - rV^2$ for the net acceleration of the coffee filter during the drop.

   i. What is the net acceleration of the coffee filter once it has reached terminal velocity? *The net acceleration at terminal velocity will be zero.*

   ii. Use the basic equation above to compute the drag parameter of the coffee filter. (Use your answer to Question i above, the terminal velocity you computed earlier in the lab, and the fact that the acceleration due to gravity is about 9.8 meters per second) *Students should use the terminal velocity that they found for the coffee filter (the slope of the line of best fit on the portion of the distance graph that was linear) for the value of V, a value of zero for the acceleration net A, and 9.8 m/sec² for g in the equation* $A = g - rV^2$. *This would produce the equation* $0 = 9.8 - rV^2$ *where V will be known. Students can then solve for r. This will be the drag parameter.*

Note: *The way we have things written here, the drag parameter depends on the density of air, on the frontal cross-sectional area, the mass, and the shape of the falling object. Please do not concern yourself with the proper units, which are* m^{-1}.

Conclusions

Describe how the velocity of a falling feather would differ from the velocity of a falling basketball when dropped from just a few meters above the ground in a classroom. *A feather would fall slower because it has a larger drag parameter.*

At terminal velocity, the acceleration of the object will be zero and can be modeled by the following equation: $0 = 9.8 - rV^2$, where again 9.8 represents gravitational acceleration, r represents the drag parameter of the object, and V is the velocity. In this case V would represent the terminal velocity of the object when the velocity is constant.

Solve the equation $0 = 9.8 - rV^2$ for r. *Solving the equation* $0 = 9.8 - rV^2$ *for r would result in the equation:* $\frac{9.8}{V^2} = r$.

What is the mathematical relationship between r and V at terminal velocity? *Mathematically this implies that the drag parameter (r) is inversely proportional with the square of the terminal velocity (V).*

According to this relationship, in order to increase the terminal velocity of an object what must be done to the drag parameter? *To increase the terminal velocity, the drag parameter must be reduced.*

How could you modify the coffee filter experiment to increase the coffee filters terminal velocity? *If the coffee filters were folded, rolled into a conical shape, or wadded up into a ball, the drag parameter would be reduced and a greater terminal velocity would be achieved.*

When an object is released from rest, it initially experiences no drag force. As it falls, it's speed increases and so does the drag force acting on it. Eventually, the drag force is as large as the force of gravity and then the net force acting on the object is zero. At that point, the speed becomes constant. We call this final speed downwards the **terminal velocity** for the object.

II. Calculating Drag Co-efficients

Drag will also have an important effect on the top speed of a vehicle and the engine power required to maintain highway speeds. This will affect the range of a vehicle. To make a vehicle more efficient it is important to understand how to calculate the drag of different objects.

The fluid component to calculate the drag force of a vehicle will be the same for all designs (since all vehicles will all be driven on the road, in which case, the fluid is air). Therefore, it will only be necessary for the students to compare properties of the body design. Students should solve for the drag coefficient using the equation for drag in the table below.

The two factors of drag that students should examine are the frontal cross-sectional area and the shape of the vehicle.

Frontal Cross-sectional Area

The frontal area of an object is the area of the object that determines its size perpendicular to the direction of motion. It can be thought of as the size of the shadow of the object if there were a light placed in front of it. The other body design aspects of the vehicle will also have an effect on the drag coefficient. Students should find the frontal area of a number of objects (this could be anything). Ideally the objects would be the objects the students will use in the wind tunnel. Students calculate the frontal area and then rank the items by their estimation from most drag to the least drag.

For the Instructor

For examples of common shapes and their drag coefficient, visit http://www.grc.nasa.gov/WWW/K-12/airplane/shaped.html*. This website is NASA's educational page on shape and its effect on drag. Exploring this site will yield a number of helpful items. This should give the instructor ideas for the types of items for which students should test and calculate the frontal area and drag coefficient.*

(Chart from http://craig.backfire.ca/pages/autos/drag#drag *- the bottom equation is commonly used in the study of drag on a car)*

Fluid Properties Component | Object Properties Component

$$F_{drag} = \frac{1}{2}\rho_{fluid} v_{fluid}^2 \; C_d A$$

Using units:

$F_{drag}\left[lbf\right]$

$\rho_{fluid}\left[\frac{lbm}{ft^3}\right]$

$v_{fluid}\left[mph\right]$

$C_d\left[1\right]$

$A\left[ft^2\right]$

$$F_{drag}\left[lbf\right] = \frac{\rho\left[\frac{lbm}{ft^3}\right]\left(v\left[mph\right]\right)^2 C_d A\left[ft^2\right]}{29.91}$$

Drag Coefficient
The drag coefficient is usually determined experimentally. The Wizards of Wright (see Additional Resources for contact information) will schedule time to bring a wind tunnel to your campus. It is suggested that you schedule one visit for this portion of the lesson. The drag coefficient of an object can be calculated if the drag force can be measured and the frontal area is known (assuming again that the fluid component is constant for all designs).

The Wizards of Wright should be able to assist in calculating the experimental drag coefficient since the frontal area and drag of the object can be found and the velocity and density of the air can be calculated.

If it is not possible for you to schedule a visit from the Wizards of Wright, a great alternative is to build your own wind tunnel. This can be done with about $10 if you have a fan. Instructions for building a simple wind tunnel can be found at http://sln.fi.edu/flights/first/makesimple/index.html. To observe the drag of the vehicle through your wind tunnel you can use dry ice if you have access to it, a fog machine, or by attaching a ribbon to the object. The ribbon can be affixed to the object in many places to measure the drag. Although acquiring quantitative data is difficult this way, the ribbon allows for students to test different parts of the objects and allows for the collection of qualitative data. If students are interested in recording quantitative data, the angle of the ribbon in the tunnel can be measured. Based on where the ribbon is attached, the angle measured could imply different conclusions about the drag on the object. Encourage students to study and observe the ribbon and its behavior on different parts of the object's design.

After experimenting with the wind tunnel, students should record the frontal area, drag, and drag coefficient and/or qualitative observations for each of the items they tested. Students should reorder the items they ranked by their drag coefficient and discuss their findings.

III. Connecting the Coffee Filters, the Wind Tunnel, and Vehicle Efficiency
Students should be prompted the following questions:

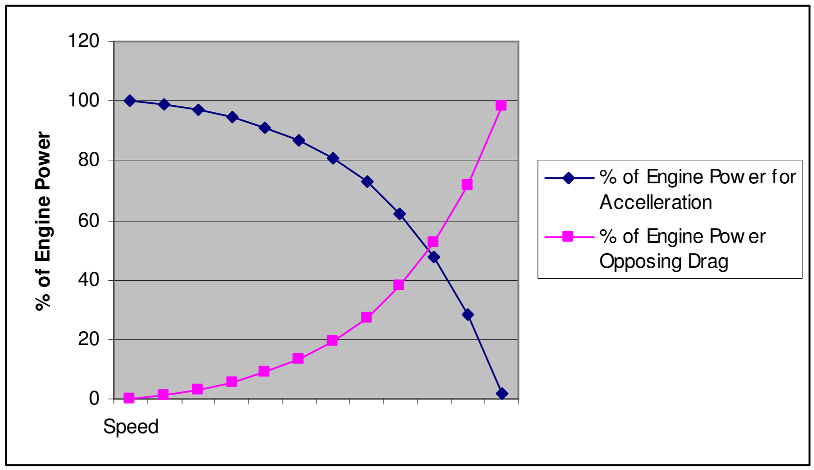
1. What did the coffee filter experiment tell us about acceleration? (What is the acceleration when velocity is constant?) *Falling objects eventually reach a constant terminal velocity, it means that the object will no longer be accelerating.*
2. What kept the coffee filters from continuing to accelerate? What does this tell us about our car? *Eventually the force pulling the coffee filter to the ground (force of gravity)*

was equal to the force opposing its motion to the ground (force of air resistance). For the car, the force of air resistance will eventually reaches the magnitude of the engine thrust. In both cases, when the forces are balanced. The net acceleration will be zero and the object will stop accelerating and travel at a constant speed.

3. How will the power of the engine be affected by the design of the body? As the speed of the car increases what also increases? *As the speed of the car increases so does the amount of drag due to air resistance. The more aerodynamic the car, the less power the engine will have to produce to oppose the drag and a greater maximum speed can be achieved.*

4. Create a line graph with two different colored lines to depict an **estimation** of the percentage of engine power used for acceleration (blue) and the percentage of the engine power used to oppose the drag force (red).

Possible Response to Question 4



5. What two forces affect the top speed of an engine? At top speed, what can be said about these two forces? *The two forces are (1) the force from the engine (thrust) and (2) the drag force (air resistance and friction). At top speed these two forces are equal (balanced).*

Optional: *You may want to have students re-examine the results from their coffee filter experiment or conduct another experiment of their own. One choice may be to repeat the coffee filter experiment by using the same number of coffee filters but reducing the fontal area of the filter by altering the filter in some way without reducing the weight of the filters (refer to conclusions) and comparing these results to their findings in Part I.*

IV. Weight (Connections with other lessons)

A major concern for the engine efficiency will be the weight, or more accurately, the mass of the vehicle. (Be careful here not to confuse weight and mass. Weight is a force, or "F" while mass is "m". The weight of an object is directly proportional to its mass when the object is on the surface of the earth. Weight changes as the object moves away from the surface of the earth, but mass is a physical property of the object and it remains the same regardless of location.) Students should interpret Newton's 2nd Law, F=ma, in terms of the weight or mass of the vehicle and the efficiency of the vehicle.

Students should list the concerns with the weight of the vehicle and how it relates to the overall efficiency of the vehicle in connection to the other lessons. Since it is an option to have different groups within the class working on the other lessons simultaneously, this would be a good opportunity to have a class discussion about the impact of the body design group's decision about the material on the other group's decisions and outcomes. Depending upon the order in which the lessons are done, students could design an experiment with the motor constructed in the Electric Motor lesson to examine the true effects of weight on the engine's efficiency.

Students should compare and contrast different materials that the car can be made from. Sinclair Community College will machine a car model out of aluminum, plastic, and a couple other materials. It is suggested that the instructor contact the industry partner at Sinclair (see Appendix A) for a list of materials currently available for design.

Students should take into consideration production costs and feasibility, durability, environmental impact, safety, etc when deciding on which material to use.

For the instructor: *Students do not need to calculate the actual weight or mass of the vehicle since the design will be the same no matter which material is selected. Simply having samples of the materials that are the same in volume will allow students to create a proportion in the weight of the vehicle made with different materials.*

V. Begin Body Design Using Clay Sculpting

Further research on body designs can de done via the Internet. A good resource for this lesson is http://www.carbodydesign.com/ . This site would be for advanced learners who wish to explore.

Before beginning to sculpt their design, students should create detailed drawings of their designs from different perspectives. Students should keep in mind factors that they have learned about drag and frontal area. Students should also keep in mind other factors about the product they are making like marketability, number of occupants that could ride in the car (if only one person can ride in the car then every driver would need a car – is this efficient?), the speeds that drag really becomes an issue, production costs and feasibility, durability, environmental impact, etc. The objective of the body design lesson is not necessarily to find the design that has the smallest drag coefficient but to **use knowledge of the drag coefficient as another factor in the design** of the electric vehicle.

Students will begin designing their body designs out of clay. Students should try to the best of their ability to be precise with their sculpting. Students should use sculpting tools to accurately create their design.

After creating their design students should estimate the drag coefficient by referring to the results from Part II – Calculating Drag. Also students should calculate the frontal area of their vehicle. This can be done by placing a lamp in front of their design and casting a shadow onto a wall. Students could create a grid on a piece of poster board in which the shadow could be cast. Students could then count the boxes the shadow intersects to determine the frontal area. It would be important that the shadow be cast appropriately onto the poster board. The shadow should be adjusted so that the grid would be approximately proportional to a one-by-one foot square on the vehicle's frontal area. Students should trace the frontal area onto the poster board.

VI. Wind Tunnel (Wizards of Wright)

It is recommended that the second scheduling for the use of the Wizards of Wright wind tunnel would be scheduled here. If the Wizards of Wright could not be scheduled it is possible to construct a wind tunnel for students to experiment (See Activity II Calculating Drag under the Drag Coefficient section). Students would then test their clay models in the wind tunnel. Students should calculate the drag coefficient or make qualitative and quantitative observations (possibly using the ribbon described in Activity II) of each model. Students should then compare and contrast the models with their initial estimates and observations of the drag coefficient.

VII. Selection of Class Body and Material

After gathering information about each design, students should create a presentation outlining the quantitative and qualitative analysis of their designs. The presentation of this material should be left up to the students. Students could create a traditional presentation using a poster or PowerPoint, create a pamphlet about their design, produce a commercial, etc. The students' presentations should include factors that they considered or did not consider in the design of the car and why.

After all designs are presented, the class will select a body design and material that will be used for the class's electric vehicle design. Note: The class could select one group's body design and another group's material based on the information presented by the different groups. This will allow for more discussion, increased opportunities for success, and possibly a better design. Students may even elect to have one group's front end of the body design and the back end design of another group. The class should discuss and select what they feel is the best design.

VIII. Enter Model into Google SketchUp or Other CAD program

Once the class has elected a model, students should enter their design into Google SketchUp, Solidworks, or another CAD program. This could be a difficult task depending upon the instructor's familiarity with the software. It is highly recommended that instructors look into using this software for the following reasons:

1. Students will use technology in a meaningful manner
2. Students will be able to virtually test their product using software that is compatible with most CAD programs.
3. Once the design is entered into a CAD program, students will be able to send the file to Sinclair Community College or possibly another industry partner to have the body machined.

When entering the design of the vehicle into the CAD program, it is suggested that the instructor contact the Sinclair or other industry partner that will be machining the body to determine the maximum dimensions of the design (for example a 4'x4'x8' box).

IX. (Optional) Perform Tests on Model using Fluent or Other Virtual Testing

This activity is optional but gives insight into the nondestructive evaluation process similar to contemporary engineering processes.

Fluent is a flow modeling software that is compatible with many CAD programs, including *Solidworks*. There are other programs with these capabilities. Some CAD programs may come with a test package similar to Fluent for virtual testing. At this stage Fluent or other virtual testing software could be used to further explore the design of the electric vehicle. Fluent offers a number of tests that can be run on a design (e.g. drag, lift, etc.) For more information about Fluent visit their website http://www.fluent.com. This is not absolutely necessary to the lesson but is another opportunity for students to use technology in a meaningful manner and gain experience and knowledge of the materials and manufacturing industry. Many designs are not virtually tested in this manner because of the cost efficiency.

X. Create a Prototype (Sinclair Community College)

Sinclair Community College has agreed to machine one body design from each class. Once the design has been selected by each class, it is suggested that the students visit the Sinclair campus for a small tour of the manufacturing and materials facilities and so that students can witness the manufacturing process of their car design. See Sinclair Community College Contacts for contact information.

XI. Presentation of Results and Justification for Design and Material
Students will present their recommendation for the body design and material to be used on the electric vehicle by creating a presentation that incorporates their findings and the effects of the variables that they tested. Again, students should create a presentation outlining the quantitative and qualitative analysis of their designs. The presentation of this material should be left up to the students. Students could create a traditional presentation using a poster or PowerPoint, create a pamphlet about their design, produce a commercial, etc. It is recommended that students use a different medium than the one they used in the selection process. The students' presentations should include factors that they considered or did not consider in the design of the car and why.

Assignment of Student Roles and Responsibilities

Students will all assume the same role within their group for activities I-IV.

Role Name	Brief Description
Researcher	Students during these activities will be gaining a foundation of knowledge in which to base their decisions. Students should learn through observation, experimentation, and group dialogue.

Students will assume different roles for the activities V-IX

Team	Team Name	Brief Description (12-15 words)
1	Concept Design Team	Conceptualize the design and build out of clay. Will assist in continuing to improve the design during technical process.
2	Technical Design Team	Familiarize them selves with the CAD program. Will generate virtual design.

Student Instructions

I. Coffee Filter Drop Lab

Introduction
When air resistance is ignored, the **speed** of a falling object increases by 9.8 meters per second **for every second** that the object is in motion. So if we dropped a basketball and a coffee filter from the same height in a vacuum (where there is no air resistance), both would reach the ground at the same time. However, as our experience has shown us, we would find that the same is not true if we dropped a basketball and a coffee filter from the same height in our classroom. As the coffee filter moves through the air, air resistance or a drag force tends to slow its motion. When the coffee filter is first released, its speed increases from zero, but the air resistance acting on the coffee filter also increases. Eventually, when the air resistance

becomes great enough, the coffee filter almost stops accelerating and falls the rest of the way nearly at a constant rate, known as its terminal velocity. At all times the net acceleration of the coffee filter is given by:

Net Acceleration = Acceleration due to gravity - Acceleration from air resistance

The acceleration from air resistance can be modeled as rV^2, where r is a constant known as the drag parameter and V is the velocity. In this lab we will drop a coffee filter, measure the distance, and use this to determine the terminal velocity of the coffee filter and the drag parameter of the coffee filter.

Equipment and Setup

For this experiment you will need a TI calculator and a CBR (**C**alculator **B**ased **R**anger) unit or a TI calculator with the Vernier PHYSICS program loaded, a CBL (**C**alculator **B**ased **L**aboratory) unit, a motion detector, and a coffee filter.

In the home menu choose SET UP PROBES. When asked for the number of probes, enter 1. In the next menu choose MOTION. The screen will display the home menu again. Now select COLLECT DATA, and choose TIME GRAPH. Set the calculator to take 40 measurements 0.05 second apart.

Procedure

When the calculator is ready to begin taking measurements, place the motion detector flat on the ground facing facing up while another group member holds the coffee filter directly above the motion detector. Press ENTER on the calculator to begin taking measurements, and release the filter when the motion detector begins clicking. After collecting the data, press ENTER on the calculator to get the graph menu. Select DISTANCE; press ZOOM, select “9: ZoomStat”, press ENTER. The calculator will display the graph of the distance of the filter from the motion detector versus time. Note that distance is in meters and time is in seconds.

Data

While viewing the graph of distance versus time, use TRACE to recover the data collected by the CBL unit or CBR unit on your calculator. Record the distances collected by the CBL/CBR unit in the table below. Discard the data points taken before the drop and after the filter hit the floor.

After recording the data, quit the PHYSICS program by pressing ENTER to get back to the graph menu, then choose RETURN. When asked to repeat select NO, and then in the main menu select QUIT.

Time in seconds	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Distance in meters										
Time in seconds	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
Distance in meters										
Time in seconds	1.01	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50

Distance in meters										
Time in seconds	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
Distance in meters										

Analysis

1. Input the data in the table above into your calculator by entering times in L1 and distances in L2. Then enter **only the last five data points** in your table in lists L3 and L4. Using these **last five data points**, find the equation of the regression line for distance D (in meters) as a function of time t (in seconds). (Enter LinReg L3, L4.)
2. Plot **the data from the table above** and **add the regression** line from Question 1 to your graph. Sketch the graph.
3. Use the graph in Question 2 to help you describe how the velocity of the coffee filter **changes** as it falls.
4. Explain why the slope in your formula in Question 1 is the terminal velocity of the coffee filter.
5. Use your answers to Questions 2 through 4 to help you carefully sketch a graph of the velocity of the coffee filter.
6. Use your graph in Question 5 to help you carefully sketch a graph of the acceleration of the coffee filter.
7. About how long does it take the coffee filter to reach terminal velocity? How did you determine this?
8. Recall that the acceleration due to air resistance or the drag force can be modeled as rV^2, where r is a constant known as the drag parameter and V is the velocity. In this part of the lab we will show one way in which the drag parameter of an object can be experimentally determined. Let A represent the net acceleration of the coffee filter and g the acceleration due to gravity. Then we have the basic equation $A = g - rV^2$ for the net acceleration of the coffee filter during the drop.
   i. What is the net acceleration of the coffee filter once it has reached terminal velocity?
   ii. Use the basic equation above to compute the drag parameter of the coffee filter. (Use your answer to Question i above, the terminal velocity you computed earlier in the lab, and the fact that acceleration due to gravity is about 9.8 meters per second per second.)

Note: *The way we have things written here, the drag parameter depends on the density of air, on the cross-sectional area, the mass, and the shape of the falling object. Do not concern yourself with the proper units.*

Conclusions

Describe how the velocity of a falling feather would differ from the velocity of a falling basketball when dropped from just a few meters above the ground in a classroom.

At terminal velocity, the net acceleration of the object will be zero and can be modeled by the following equation: $0 = 9.8 - rV^2$, where again 9.8 represents gravitational acceleration, r represents the drag parameter of the object, and V is the velocity. In this case V would represent the terminal speed of the object when the velocity is constant.

Solve the equation $0 = 9.8 - rV^2$ for r.

What is the mathematical relationship between r and V at terminal velocity?

According to this relationship, in order to increase the terminal velocity of an object what must be done to the drag parameter?

How could you modify the coffee filter experiment to increase the coffee filters terminal velocity?

When an object is released from rest, it initially experiences no drag force. As it falls, it's speed increases and so does the drag force acting on it. Eventually, the drag force is as large as the force of gravity and then the net force acting on the object is zero. At that point, the speed becomes constant. We call this final speed downwards the **terminal velocity** for the object.

II. Calculating Drag

Drag will also have an important effect on the top speed and the engine power required to maintain faster or highway speeds. This will affect the range of a vehicle. To make a vehicle more efficient it is important to understand how to calculate the drag of different objects.

The fluid component to calculate the drag force will be the same for all designs (since all vehicles will all be driven on the road, in which case, the fluid is air). It will only be necessary to compare the object properties of the body design. Solve for the drag coefficient using the equation for drag in the table below.

	Fluid Properties Component	Object Properties Component
$F_{drag} =$	$\frac{1}{2}\rho_{fluid} v_{fluid}^2$	$C_d A$

Using units:

$F_{drag}\left[\text{lbf}\right]$

$\rho_{fluid}\left[\frac{\text{lbm}}{\text{ft}^3}\right]$

$v_{fluid}\left[\text{mph}\right]$

$C_d\left[1\right]$

$A\left[\text{ft}^2\right]$

$$F_{drag}\left[\text{lbf}\right] = \frac{\rho\left[\frac{\text{lbm}}{\text{ft}^3}\right]\left(v\left[\text{mph}\right]\right)^2 C_d A\left[\text{ft}^2\right]}{29.91}$$

Frontal Area

The frontal area of an object is the area of the object that will come in contact with the flow. It can be thought of as the shadow of the object if the light were in the same direction as the flow. The other body design aspects of the vehicle not in the frontal area will have an effect on the drag coefficient.

Calculate the frontal area of a number of objects (this could be anything). Ideally the objects would be the objects you will use in the wind tunnel. Rank the items from most drag to the least drag.

(Chart from http://craig.backfire.ca/pages/autos/drag#drag - the bottom equation is commonly used in the study of drag on a car)

Drag Coefficient

The drag coefficient is usually determined by experiment. The drag coefficient of an object can be compared if the drag force can be measured and the frontal area is known (assuming again that the fluid component is constant for all designs).

Attach a ribbon to different parts of your object and use the angle of the ribbon in the wind tunnel for quantitative measurements. Based on where the ribbon is attached, the angle measured could imply different conclusions about the drag on the object.

After experimenting with the wind tunnel, record the frontal area, drag, and drag coefficient and/or qualitative observations for each of your objects. Reorder the items you previously ranked by estimating the drag coefficient and discuss your findings.

III. Connecting the Coffee Filters, the Wind Tunnel, and Vehicle Efficiency

1. What did the coffee filter experiment tell us about acceleration? (What is the acceleration when velocity is constant?)
2. What kept the coffee filters from continuing to accelerate? What does this tell us about our car?
3. How will the power of the engine be affected by the design of the body? As the speed of the car increases what also increases?
4. Create a line graph with two different colored lines to depict an **estimation** of the percentage of engine power used for acceleration and the percentage of the engine power used to oppose the drag force.
5. What two forces affect the top speed of an engine? At top speed, what can be said about these two forces?

Repeat the coffee filter experiment by using the same number of coffee filters but reducing the fontal area of the filter by altering the filter in some way without reducing the weight of the filters (refer to conclusions) and comparing these results to your findings in Part I.

IV. Weight

A major concern for the engine efficiency will be the weight, or more accurately, the mass of the vehicle. Interpret Newton's 2nd Law, F=ma, in terms of the mass of the vehicle and the efficiency of the engine.

List concerns with the weight of the vehicle and how it relates to the overall efficiency of the vehicle.

Compare and contrast different materials that the car can be made from. Take into consideration production costs and feasibility, durability, environmental impact, safety, etc.

V. Begin Body Design Using Clay Sculpting

Further research on body designs can de done via the Internet. A good resource for this lesson is http://www.carbodydesign.com/ .

Before beginning to sculpt your design, create detailed drawings of your designs from different perspectives. Keep in mind factors that you have learned about drag and frontal area. Also keep in mind other factors about the product you are making, like marketability, number of people that could ride in the car (if only one person can ride in the car then every driver would need a car – is this efficient?), at what speeds does the drag really become an issue, production costs and feasibility, durability, environmental impact, etc. The objective of the body design lesson is not necessarily to find the design that has the smallest drag coefficient but to **use knowledge of the drag coefficient as another factor in the design** of the electric vehicle.

Begin designing your body designs out of clay. Try to the best of your ability to be precise with your sculpting. Use sculpting tools to accurately create your design.

After creating your design, calculate the frontal area of their vehicle. Then estimate the drag coefficient.

VI. Wind Tunnel
Test you clay models in the wind tunnel.

Calculate the drag coefficient of each model.

Compare and contrast the models with your initial estimates and observations of the drag coefficient.

VII. Selection of Body and Material
Create a presentation outlining the analysis of your designs. The presentation could be a traditional poster or PowerPoint, a pamphlet, a commercial, etc. The presentations should include factors that were and were not considered in the design of the car and why.

VIII. Enter Model into a CAD program
Enter the class design into a CAD program.

You will be able to virtually test the product through this program.

Your instructor will assist you when it is time to send the file to Sinclair Community College to have the vehicle body machined.

IX. Perform Tests on Model using Fluent or Other Virtual Testing
At this stage Fluent or other virtual testing software could be used to further explore the design of the electric vehicle. Fluent offers a number of tests that can be run on a design (e.g. drag, lift, etc.) For more information about Fluent visit their website http://www.fluent.com.

X. Create a Prototype
Sinclair Community College has agreed to machine one body design from each class.

XI. Presentation of Results and Justification for Design and Material
Create a presentation for your recommendations for the body design and material to be used on the electric vehicle by outlining the analysis of your designs and incorporating your findings and the effects of the variables you tested. The presentation could again include a traditional poster or PowerPoint, a pamphlet, a commercial, etc. It is recommended that students use a different medium than the one they used in the selection process. The students' presentations should include factors that were or were not considered in the design of the car and why.

Present your recommendations for the body design and material to be used on the electric vehicle by creating a presentation that incorporates your findings and the effects of the variables you tested.

Formative Assessment

Category	4	3	2	1
Data Collection	All data are reasonable, showing precise work and accurate measurements.	Most data is reasonable, showing precise work and accurate measurements.	Data has been collected, but little attention has been given to accuracy or consistency. Several numbers aren't reasonable for lab situation.	Little data has been collected, and little attention has been given to accuracy or consistency. Numbers aren't reasonable for lab situation.
Calculations	All calculations are shown, organized, and performed correctly, including unit conversions, accurate drawings, formulas, and work.	Most calculations are shown and organized, but one or two steps are missing. One or more calculation has been performed incorrectly.	Data has been used in calculations, but there are 4-8 errors with some organization.	Some calculations are performed, but they are poorly written, poorly organized, or completely inaccurate.
Question / Purpose	The purpose of the lab or the question to be answered during the lab is clearly identified and stated.	The purpose of the lab or the question to be answered during the lab is identified, but is stated in a somewhat unclear manner.	The purpose of the lab or the question to be answered during the lab is partially identified, and is stated in a somewhat unclear manner.	The purpose of the lab or the question to be answered during the lab is erroneous or irrelevant.
Conclusion	Student has explained connection of data to the drag coefficient of design and weight from organized information and accurately solved all sample problems.	Student has found drag coefficients from design and correctly solved some of the sample problems.	Student has found the coefficients from graph but has only correctly solved 1 sample problem.	Student has found the coefficients from graph.
Scientific Concepts	Presentation illustrates an accurate and thorough understanding of scientific concepts underlying the lab.	Presentation illustrates an accurate understanding of most scientific concepts underlying the lab.	Presentation illustrates a limited understanding of scientific concepts underlying the lab.	Presentation illustrates inaccurate understanding of scientific concepts underlying the lab.

Group Cooperation	The student communicated effectively with group members. The student contributed to the discussion. The student was respectful of ideas different from his or her own.	The student communicated effectively with group members for most of the lab. The student contributed to the discussion for most of the lab. The student was respectful of ideas different from his or her own for most of the lab.	The student did not communicate effectively with group members. The student contributed to the discussion for some of the lab. The student was respectful to some ideas different from his or her own.	The student did not communicate effectively with group members. The student did not contribute to the discussion. The student was disrespectful to ideas that were different from his or her own.

Post-Activity Discussion

See Activity Part XI for the post-activity presentation.

To lead in to the next activity in this unit, pose the question:

How will the decisions you make about the tires affect the overall performance of the electric vehicle?

Pre-Test / Post-Test

1) What is aerodynamic drag? *Drag is a mechanical force. It is generated by the interaction and contact of a solid body with a fluid (liquid or gas). It is not generated by a force field, in the sense of a gravitational field or an electromagnetic field, where one object can affect another object without being in physical contact. For drag to be generated, the solid body must be in contact with the fluid. If there is no fluid, there is no drag. For example, drag is the aerodynamic (mechanical) force that opposes an aircraft's (solid body) motion through the air (fluid). Drag is generated by the difference in velocity between the solid object and the fluid. There must be relative motion between the object and the fluid. If there is no relative motion, there is no drag. It makes no difference whether the object moves through a static fluid or whether the fluid moves past a static solid object.*

2) A falling object will eventually reach a constant velocity known as its terminal velocity (assuming it does not change its orientation, size, or shape). Why does this occur? *A falling object will eventually reach a constant velocity due to the increasing force of air resistance (air particles striking the object and slowing it down). This force is also referred to as drag. When an object initially begins falling it accelerates toward the ground due to the force of gravity. In a vacuum (no air particles) the object would continue to accelerate due to the absence of air. If this falling does not occur in a vacuum, the object displaces air as is falls and as the object accelerates the drag on the object increases. Eventually the drag force will equal the force of gravity (balanced forces) causing the object to move at a constant velocity with an acceleration of zero.*

3) Describe the relationship between the terminal velocity of an object in falling vertically and a powered vehicle moving horizontally at top speed. *With vertical motion we have the gravitational force (its weight) acting downward and the force of drag acting upward. When these two forces are balanced, the object has reached its terminal velocity. In horizontal*

motion, the force that causes the forward acceleration of the object is the force of engine thrust from the engine. The resisting force is still the drag force and still due to air resistance, but this time it is acting horizontally. (We could also consider the frictional forces of the tires and the road, but we will ignore that for now.) In both cases, the forces that cause the forward motion are at their maximum: vertically the gravitational force (its weight) is a maximum based on the mass of the object and horizontally the force of engine thrust is a maximum based on the engine in the object. While building up to top speed horizontally, the engine must produce enough thrust to overcome the drag force, which is increasing as the speed increases (just like it does vertically). Once the vehicle reaches top speed, the engine cannot produce any more thrust to accelerate the vehicle, so the acceleration has gradually dropped to zero. It is at this point that the vehicle has reached its terminal velocity

4) What adjustments can be made to the body design to reduce the effects of drag of the vehicle? *The frontal area of the vehicle will directly affect the drag of the vehicle. The larger the area of the vehicle perpendicular to the direction of motion, the more air the vehicle must "push" through. Since the drag on the vehicle is a force that opposes the movement of the vehicle, the frontal area plays a major role in the efficiency of the vehicle. If the frontal area of the vehicle can be reduced, the drag will also be reduced, increasing the efficiency of the engine for movement of the vehicle. Other parts of the body design that can be altered to improve efficiency can be found at* http://www.grc.nasa.gov/WWW/K-12/airplane/shaped.html *(The drag coefficient of the object, the density of the fluid in which the object is traveling, inclination of the profile of the object.)*

5) Describe the relationships between the drag force, the drag coefficient, engine power, terminal velocity, and engine efficiency. *An object's drag can be calculated measuring aspects of the object's shape. These measurements are used to calculate a quantitative attribute of the shape called the drag coefficient. The drag coefficient gives a measurement of an object's ability to move through a fluid (including air) efficiently. At low to moderate velocities, when the drag coefficient of an object is reduced, more of the engine's power will be used to move the object and less of the power will be used to oppose the force of drag. This increases fuel/engine efficiency. All objects outside of a vacuum will eventually achieve terminal velocity but a reduction of the drag coefficient of an object will also will increase the terminal velocity of the object. By adjusting the shape engineers can improve a vehicle's ability to efficiently move and consequently improve engine efficiency.*

Rubric

Question	4	3	2	1
Question 1 - What is drag?	Explanation indicates a clear and accurate understanding of drag, which includes four of the following: (1) it is a force (2) it opposes motion (3) it requires a fluid medium (4) it requires motion (5) the greater the	Explanation indicates an understanding of drag, which includes three of the following: (1) it is a force (2) it opposes motion (3) it requires a fluid medium (4) it requires motion (5) the greater the velocity, the greater	Explanation includes two of the following: (1) it is a force (2) it opposes motion (3) it requires a fluid medium (4) it requires motion (5) the greater the velocity, the greater the drag.	Explanation includes one of the following: (1) it is a force (2) it opposes motion (3) it requires a fluid medium (4) it requires motion (5) the greater the velocity, the greater the drag.

	velocity, the greater the drag.	the drag.		
Question 2 - A falling object will eventually reach a constant velocity (assuming it does not change its orientation). Why does this occur?	Explanation indicates a clear and accurate understanding that the downward force of gravity is balanced by the upward force of air resistance (drag) causing the object to stop accelerating and move at a constant velocity.	Explanation indicates an understanding that the downward force of gravity is balanced by the upward force of air resistance (drag) causing the object to stop accelerating and move at a constant velocity.	Explanation indicates an understanding that the upward force of air resistance (drag) causes the object to stop accelerating and move at a constant velocity.	Explanation includes one of the following: The object will eventually reach a constant velocity because (1) of the upward force of air resistance (drag); (2) balanced forces; or (3) the object stops accelerating.
Question 3 - Describe the relationship between the terminal velocity of a falling object and a powered vehicle moving horizontally at top speed.	Response indicates a clear and accurate understanding that horizontal force that propels the vehicle is analogous to vertical force of gravity; when each of these forces are balanced with the drag force along the same line, the object has reached its terminal velocity. While building up to top speed, the engine must produce enough thrust to overcome the drag force, which is increasing as the speed increases (just like it does vertically).	Response indicates that horizontal force of thrust is analogous to vertical force of gravity; when each of these forces are balanced with the drag force along the same line, the object has reached its terminal velocity. While building up to top speed, the engine must produce enough thrust to overcome the drag force, which is increasing as the speed increases (just like it does vertically).	Response indicates that while building up to top speed, the engine must produce enough thrust to overcome the drag force, which is increasing as the speed increases (just like it does vertically).	Response indicates that the engine must produce enough thrust to overcome the drag force.
Question 4 - What adjustments	Explanation indicates a clear	Explanation indicates an	Explanation indicates an	Explanation indicates an

can be made to the body design to reduce the effects of drag of the vehicle?	and accurate understanding that two things affect the drag on a vehicle, the size of the frontal area and the shape. Explanation includes that reducing the frontal area and/or giving the vehicle a more aerodynamic shape will reduce the drag on the vehicle.	understanding that both the frontal area and the shape of the vehicle will directly affect the drag of the vehicle, but does not explain how these two things affect the drag.	understanding of only one of the two factors of frontal area and shape. For the one given, the explanation describes how to change that parameter to reduce drag.	understanding of only one of the two factors, but does not explain how the parameter might be changed to reduce drag.

Question 5 - Describe the relationships between the drag force, the drag coefficient, top speed and engine efficiency.	Response states in a clear and accurate manner that when the drag coefficient of an object is reduced, the drag force at a given speed is reduced. This allows the vehicle to use less engine power at that speed to oppose drag, which increases the fuel efficiency. The vehicle can also reach a higher top speed before all of the engine power is used to oppose drag.	Response states in a clear and accurate manner that when the drag coefficient of an object is reduced, the drag force at a given speed is reduced. The response then explains the effect that this will have on either the engine efficiency or the top speed, but not both.	Response demonstrates some understanding of the relationship between the drag coefficient and the drag force to both the top speed and the engine efficiency.	Response demonstrates some understanding of the idea of drag to either the top speed or the fuel efficieny.

Technology Connection

The **ADISC** Model of technology created by ITEL

	Integration Model	Application Description
A	Technology that supports students and teachers in **adjusting, adapting, or augmenting** teaching and learning to meet the needs of individual learners or groups of learners	Graphing calculator, motion detector and software, Google SketchUp or other CAD program
D	Technology that supports students and teachers in **dealing effectively with data**, including data management, manipulation, and display	Graphing calculator, motion detector (CBR) and software, Microsoft Excel
I	***Technology that supports students and teachers in conducting*** *inquiry*, ***including the effective use of Internet research methods***	***Graphing calculator, motion detector and software, virtual testing software for CAD designs (i.e. Fluent)***
S	Technology that supports students and teachers in **simulating** real world phenomena including the modeling of physical, social, economic, and mathematical relationships	CAD program, Wind tunnel and/or Wind Tunnel from the Wizards of Wright, prototyping machinery through Sinclair Community College
C	Technology that supports students and teachers in **communicating and collaborating** including the effective use of multimedia tools and online collaboration	Graphing calculator, motion detector and software, CAD program

Interdisciplinary Connection

The presentation at the end of the unit could be incorporated with the students' English class or a multimedia design course.

Home Connection

This multi-day lesson will allow for students to take data and prototypes made from clay home. Students can engage in discussions with parents or other children about their findings.

Differentiated Instruction

Since this lesson can be done independently from the EV unit or simultaneously with the EV unit many opportunities for differentiation can occur.

The EV unit was designed so that a class could be divided into groups where each group participates in only one of the units. The class then collectively constructs the EV with presentations of various types occurring by each group at the end of the lesson.

Each lesson has opportunities for differentiation. For example, this lesson has a design element to it. One or two students could be designated to this responsibility where others can be in a testing group or the clay modeling design.

After the initial stages of the lesson, students can be broken into groups, attacking different aspects of the lesson.

Extension

The intention of this lesson is to couple it with the other lessons in the EV unit. This can be done sequentially or as a team effort with the class as described above. The lessons learned from this unit should be carried through the other lessons or communicated to the other groups throughout the unit.

Career Connection

Aeronautical Engineer

Automotive Engineer

Additional Resources

Resources	Purpose and Application
Sinclair Community College contact Gilah Pomeranz: 937-512-2365	Prototyping Design
Wizards of Wright contact Kathy Schweinfurth - (937) 255-0692	Drag Coefficient and Wind Tunnel
Web Resources	
http://www.grc.nasa.gov/WWW/K-12/airplane/shaped.html	Shape effects on drag
http://sln.fi.edu/flights/first/makesimple/index.html	Building your own wind tunnel
http://craig.backfire.ca/pages/autos/drag#drag	Aerodynamic Drag and its effect on the acceleration and top speed of a vehicle.
www.howstuffworks.com	How Stuff Works
http://www.carbodydesign.com/	Car Body Design

Credits

Adam Ciarlariello – Primary Author

Norma Howell, Todd Smith – Editors

Teacher Reflection

Were students focused and on task throughout the lesson?

If not, what improvements could be made the next time this lesson is used?

Were the students led too much in the lesson or did they need more guidance?

How did students demonstrate that they were actively learning?

Did you find it necessary to make any adjustments during the lesson? What were they?

Did the materials that the students were using affect classroom behavior or management?

What were some of the problems students encountered when using the…?

Are there better items that can be used next time?

Which ones worked particularly well?

Additional Comments