This is Rocket Science

A Teacher’s Guide to Teaching Physics with Model Rockets

By

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Introduction

This curriculum originated in a McMurry University General Education course entitled *Leadership in Science and Mathematics*. One of the core activities in the class was to involve the students in research on a science or math-based problem that affected an outside community and to develop and implement a solution to that problem. The faculty teaching the course had chosen to work with the science teachers at a nearby rural high school. The teachers there indicated that they wished to have help getting their students to pass the science portion of the 11th grade TAKS test, a state-mandated exam required for graduation. Specifically, the students involved had not passed the 10th-grade science TAKS test the previous year, and so the pressure was on them to pass the 11th-grade exam.

This curriculum grew out of our work with the teachers and students at the high school. The McMurry students first determined what science concepts the students had had the most trouble with on the 10th-grade exam. Then they explored a variety of ideas which would give the high school students hands-on experience with the physics concepts which were most problematic. They chose to use rocketry to focus on energy and Newton’s laws of motion. The students then designed and wrote the curriculum.

This teacher’s guide represents the final product of this course, and involves hands-on activities building, testing, and launching Estes model rockets, as well as math-intensive worksheets relating to the rockets. For a more basic approach to rocketry in the classroom, please see the teacher’s guide provided by Estes Industries at [http://www.esteseducator.com](http://www.esteseducator.com).

The material presented here is suitable for use in regular and AP-B high school physics courses, as well as high school science remediation courses in which the students have already been exposed to physics. Suggestions are given throughout for modification of the material for use in middle school science or physics AP-C courses. The classes with which the McMurry students worked ranged from 10 to 15 students in size.

A note about rocket supplies

The rocket kits do not include various finishing supplies such as glue. The rocket motor packs DO include igniters and recovery wadding. The Alpha-III starter kit includes all necessary launch equipment plus two A8-3 rocket motors. Other starter kits may not include any rocket motors, but should still have the necessary launch equipment. Launch pads are available separately but typically cost more than the starter kits. The PASCO equipment is only needed if doing a live bench test, but the Xplorer GLX and force sensor have many other laboratory uses and many other sensors are available.
Budget

The following supplies are recommended for this project. Of course, each situation is different and some schools may already have some of these items; however, this list should serve as a basic initial guide to the cost of the project.

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Estimated Cost:</th>
<th>Recommended Source:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estes Generic E2X Rocket Kit</td>
<td>$73 per pack</td>
<td>Megahobby via Amazon.com</td>
</tr>
<tr>
<td>Bulk Pack – 1764 12 rocket kits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A8-3 Educator Bulk Pack 24 Rocket Motors</td>
<td>$50 per pack</td>
<td>Hobby Strickland via Amazon.com</td>
</tr>
<tr>
<td>Estes Alpha-III Starter Kit (for launch pad)</td>
<td>$21</td>
<td>Hobby Lobby or other hobby retailer</td>
</tr>
<tr>
<td>4 AA batteries for launch controller</td>
<td>$4</td>
<td>anywhere</td>
</tr>
<tr>
<td>PASCO Xplorer GLX PS-2002</td>
<td>$329</td>
<td>pasco.com</td>
</tr>
<tr>
<td>PASPORT Force Sensor PS-2104</td>
<td>$110</td>
<td>pasco.com</td>
</tr>
<tr>
<td>Rocket Engine Test Bracket ME-6617</td>
<td>$39</td>
<td>pasco.com</td>
</tr>
</tbody>
</table>

Additional Materials Used:
- Protractor
- String
- Nuts (metal) for mass at end of string
- Tape
- Straw
- Glue
- Scissors
- Calculators
Day 1

Overview:
The project is introduced with the story line, followed by a general discussion of rockets and forces.

Supplies:
- Example model rocket
- Two balloons and a twist tie
- Preliminary Design Review handouts

Outline of Activities:
(45 minute class period)

<table>
<thead>
<tr>
<th>Time allotted</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 min</td>
<td>Introduce project with storyline</td>
</tr>
<tr>
<td></td>
<td>Hand out “Preliminary Design Review”</td>
</tr>
<tr>
<td>10 min</td>
<td>Show model rocket</td>
</tr>
<tr>
<td></td>
<td>-discuss uses, shape, parts</td>
</tr>
<tr>
<td></td>
<td>-students record notes on hand out</td>
</tr>
<tr>
<td>15-20 min</td>
<td>Show deflated balloon</td>
</tr>
<tr>
<td></td>
<td>-similarities to rocket? (Record notes)</td>
</tr>
<tr>
<td></td>
<td>Inflate the balloon, tie tightly with twist tie</td>
</tr>
<tr>
<td></td>
<td>-similarities to rocket?</td>
</tr>
<tr>
<td></td>
<td>-talk about equal forces on walls of balloon, draw picture on board</td>
</tr>
<tr>
<td></td>
<td>-drop balloon while still tied shut</td>
</tr>
<tr>
<td></td>
<td>-other forces: gravity, drag</td>
</tr>
<tr>
<td>3-4 min</td>
<td>Untie balloon and let go</td>
</tr>
<tr>
<td></td>
<td>-what makes it move?</td>
</tr>
<tr>
<td></td>
<td>-introduce other force: thrust</td>
</tr>
<tr>
<td>10 min</td>
<td>Summarize all with Newton’s laws</td>
</tr>
</tbody>
</table>

Narrative:
Have you ever wondered what it is that a rocket scientist does? The term “rocket science” actually refers to a combination of various fields in physics and engineering. The physicists and engineers who build and test rockets must work together in order to complete a project.

Our class will learn what it is like to be rocket scientists who must evaluate a new rocket motor design. We will need to gather as much data as we can from a scale model and then answer questions posed by various engineers about our rocket. To do this we will run several experiments and calculate the information that the engineers need.

The engineers involved are:
- The Range Officer, who looks at how high the rocket will go.
- The Propulsion Engineer, who is interested in how much energy, work, and power the motor puts out.
The Mission Director, who is in charge of the project and needs to compare the actual data with the predictions that you have made about the motor performance.

Please take a copy of the worksheet entitled “Preliminary Design Review”. The first step in proposing and designing a new rocket or motor is always to review the current knowledge of what we know works. This is called “flight heritage”. Please speak up with your ideas on the following questions, and record your notes and ideas on the Design Review page.

[Show the students the model rocket.]
What are rockets used for? Why do you think it has the shape that it does? What is the purpose of the various parts (nose cone, body, fins, parachute, motor)? Please remember to write your notes in the appropriate places on Design Review sheet. [Note 1]

[Show the students the deflated balloon.]
What are the similarities between this balloon and the rocket? [Note 2]

[Inflate the balloon and tie it closed with a twist tie.]
Now what are the similarities between this balloon and the rocket? [Note 3]

There are equal and opposite forces pushing on the inside and outside walls of the balloon, which makes the balloon keep its shape. The forces are from the air molecules constantly bombarding the inside walls of the balloon pushing outward, and the stretched rubber of the balloon pushing inward.

[Draw a picture on the board of an inflated balloon, with several arrows pointing opposite each other on either side of the balloon wall. Arrows should be of the same length.]
Draw this picture in the appropriate space on your papers. The arrows represent the forces.

What force will act on the balloon if it were to be dropped? [Gravity]. How would it be shown on the picture on the board? [Draw a longer arrow on the picture on the board pointing straight down from the balloon.]
[Drop the inflated balloon (while it is still tied) and also a deflated balloon.]
Which balloon falls more slowly? On the diagram, how would we show a force slowing the balloon down? [Draw a shorter arrow pointing up from the balloon.] This force is called the drag. The drag force is greatly influenced by the shape of the object.

[Now untie the twist tie and let go of the balloon.]
Why doesn’t the balloon just fall to the floor like it did before? The movement of the balloon is evidence of an unbalanced force acting on the balloon. This force is called the thrust. What is the source of thrust? Also, notice that the balloon’s erratic flight path is due to the lack of fins to keep it flying straight. [Note 4]

[Summarize what the students have seen today with Newton’s Laws of Motion.]
3rd Law: Every action has an equal and opposite reaction. We saw this in the forces that opposed each other on the walls of the balloon. In thrust, the air molecules move one direction out the opening, the balloon moves in the opposite direction.

2nd Law: An unbalanced force will cause a mass to be accelerated, or F = ma. For example thrust is the result of the balloon pushing (i.e., accelerating) air molecules (which have mass) out of the opening. The air pushes back on the balloon and makes it move. The downward acceleration of the dropped balloon is the result of the force of gravity (what we normally call “weight”) that exists between any objects with mass. The Earth felt the same equal and opposite force as the falling balloon, but because of the Earth’s enormous mass it did not noticeably accelerate.

1st Law: The law of inertia—a body at rest tends to stay at rest and a body in motion tends to stay in motion until acted upon by an outside force. For example, letting go of the tied balloon resulted in it falling. The outside force acting on it was gravity. When we let go of the untied balloon, the forces acting on it were gravity, drag, and thrust. [Note 5]

[Ask students to complete the last question on the Design Review, then hand in their page.]

Notes:
1. Possible answers for rocket uses include putting satellites in orbit or to other planets, taking measurements of the upper atmosphere, or as a means of delivering warheads. Students should recognize that the shape of a rocket makes it pass through the air more easily, and to fly without tumbling. The purpose of the nose cone is to make the rocket more aerodynamic; the same goes for the body, which also protects the internal structure. The fins help control and stabilize the rocket’s flight, and the motor makes the rocket move. The parachute is used to help the rocket return to Earth safely.

2. There may be a variety of answers. All are generally acceptable. If students don’t mention it, point out that both have mass and both have an opening at one end.
3. If not mentioned, point out that both have potential energy.

4. The thrust arises because at the neck of the balloon the outward push of air is not balanced by the inward push of the balloon. As the air molecules “push off” from the balloon, they push the balloon in the opposite direction.

5. Before the next class period, review the students’ notes on all the questions to determine any concepts that need special attention in the rest of the project.
Day 2

Overview:
Build rockets

Supplies:
- Estes generic E2X rockets
- White glue
- Rulers
- Pencil
- Markers and/or stickers to decorating rockets
- Exacto knife (see below)

Outline of Activities:
Building the rockets will likely require the entire class period, depending on class size, number of groups, and amount of guidance given. If you have additional time (at least ten minutes), students may start making the angle measuring devices. Details for this can be found on Day 3.

Narrative:
Today we are going to build our rockets. Make sure that you pre-read all instructions before you start assembling your rocket.

Notes:
It may be necessary to bring in additional helpers or require all of the groups to do each step at the same time in order to keep all of the groups on track.

The Estes generic E2X and similar rockets require cutting a slit in one of the cardboard parts with a sharp knife. If you don’t want the students to cut this slit themselves, then you can pre-cut all of the rocket parts before class. You may also want to make the pencil alignment marks as well to speed up the building process.

The teacher should be thoroughly familiar with the assembly process; we recommend building a prototype ahead of time. Particular attention should be paid that students install the motor mount properly so that the metal clip does not interfere with the fins. Also, the launch lug should be situated between fins so that there is no interference with the launch rod. The shock cord mount may be installed deeper in the tube than indicated, just as long as it is deep enough to clear the nose cone.
Day 3

Overview:
   Bench Test to measure the impulse of the motor. (This needs to be conducted in a classroom with a fume hood or outside.) The mass of the motor should also be found before and after being fired. Finish rockets and make angle measuring devices.

Supplies:

For Angle Measuring Device (AMD):
   - Protractor
   - Straw
   - Tape
   - String
   - Weight (nut/bolt, etc.)

For Bench Test:
   - Rocket Data Sheet handout (Summary of Results should be printed on back or attached for later use)
   - Estes A8-3 rocket motor
   - Igniter
   - Estes launch controller and key
   - Pasco Xplorer-GLX or similar device
   - Pasco Force Sensor
     * With Rocket Engine Test Bracket
   - Computer with USB to connect to the GLX

Outline of Activities:
   While none of these activities take much time individually, moving from one activity to another does require some time. In addition, the “wow” factor of the bench test does take up some time. Because the burn time of the rocket is short, and due to the “wow” factor, you may find it desirable to test two motors.

Narrative:
   Today we will finish the rocket (if you have not already), and also make the angle measuring device. We will also be conducting a bench test on a rocket motor.

     In order to make the angle measuring device (AMD), you should start by taping the straw along the flat outside edge of the protractor. Next, take a piece of string about six inches long and tie one end to your weight. Tie the other end to the hole at the center of the flat side of the protractor. Now, when you sight through the straw at something (with the straw oriented on top of the protractor), the weight will hang straight down to indicate the angle. You should practice measuring angles with your AMD; be sure to pinch the string to the curved part of the protractor before you remove it from your eye to read the angle.
The forces produced by rocket motors can be tested using a stationary, or "bench" test. In this test, we have an Estes A8-3 solid rocket motor, just like the ones we will be using for our launches, attached to a force sensor. [See Notes for setup information.] When we ignite the motor with the launch controller, it will trigger the computer to record the force of the motor over time and graph it on the screen. [Have a student press the button once the exhaust area is clear.] From this graph, we can determine the burn time (by subtracting the start and stop times of the "push") and the total impulse (calculated automatically when the burn is highlighted). Notice the delay and then the ejection charge at the end. Why do you think the ejection charge oscillates up and down? [The force sensor "rings" from the sudden impulse.]

Notes:

To set up the bench test, attach the PASCO Force Sensor to a sturdy vertical post. A lab stand will likely not be heavy enough to be stable; a post attached to the table with a C-clamp or similar device is preferable. If using a fume hood inside, the exhaust should be directed parallel to the face of the hood with the door open. If you face the exhaust into the hood directly the heat may damage the paint on the fume hood. The PASCO test bracket screws onto the Force Sensor and the motor clips inside. Normal motor firing procedure should be followed using an Estes igniter and launch controller. It is highly recommended that a computer be used with the GLX device so that the students can all see the data. It also allows the use of the Data Studio Activity "Rocket Motor Test.ds" available at [link TBD] which automatically calculates the impulse (area under the graph) for a highlighted region. No more than one bench test for every 10 to 15 students should be necessary.

If you cannot perform the bench test, then you can use sample data from the NAR website (http://www.nar.org/SandT/NARenglist.shtml) to simulate the data that would have been obtained in the bench test.

You can still simulate the bench test by igniting the motor for the class and then showing the data, explaining that this is how it would look if you were to measure the force vs. time (impulse) of the motor.

You could also remove the predictions from the worksheets (the “Flight Readiness Review” and the comparison questions on the “Mission Debrief”) if you cannot perform the bench test or just want to shorten the length of the project.

This project can be made strictly a classroom activity by using the NAR data to make predictions and then not actually launching a rocket (or launching a single rocket not built by the students). We do not recommend this option since the primary purpose of this project is to encourage students to have a vested interest in understanding the principles involved by having them build and launch their own rockets.
Days 4-5

Overview:
Perform calculations using the measurements from the bench test. Make predictions about the launch. Prepare for the launch (discuss the different jobs on the launch site, and who will be doing which part.)

Supplies:
- Flight Readiness Review handouts
- Rocket Data Sheets

Outline of Activities:
The calculations can be very challenging for some students, even with the step-by-step directions and the equations available on the Rocket Data Sheets. Some advanced students may be able to finish in one day, but we recommend allowing two days for this worksheet. If you are teaching an advanced physics course, then you could modify the worksheets to include drag in the initial predictions. Note that the addition of drag will adversely affect the conservation of energy questions.

Narrative:
In our first day of this project, we learned that we were collecting data for a new prototype rocket motor. That first day we went through a typical review that engineers use, called a Preliminary Design Review. We then built the rockets that we will use for testing the motors, and we also conducted a bench test in which we collected data on the motors that we cannot easily collect during flight.

Now we are ready to use the data that has been collected, along with basic laws of physics, to calculate certain characteristics of the motor and the rocket and to predict how high the rocket will go. This is called the Flight Readiness Review. We will work in groups to do these calculations, but periodically we will stop to make sure we all agree with what we are calculating.

[Have groups start on their calculations. When most groups have finished the first 3 questions, stop for a chance to bring everyone back together.]

So what have we done so far? [Note 1]

Why did we have to find the average mass of the rocket and motor? (Why not just use the mass of the rocket and unburned motor?) Why does the mass have to be in kilograms? [Note 2]

In the next several questions we will calculate several variables related to the time when the motor is burning.

[When most of the groups are finished with question 7, stop and “regroup” again.]

What have we learned up to this point? [Note 3]
In question 7, why did we need to use the average velocity, instead of the maximum velocity, to calculate the height? [Note 4]

What happens to the rocket at the moment the motor burns out? Does it begin to fall immediately? [Note 5]
Our next few questions will deal with this coasting phase of the rocket’s flight.

[Have students work on p.3 questions 8, 9 then regroup.]

Okay, so now where are we? [Note 6]
Why is the average velocity during the burn phase and during the coast phase the same? [Note 7]
How does the burn time compare with the coast time? [Note 8]

We’ve now completed the questions that the Range Officer wanted to know, the main question being how high the rocket would go. The Propulsion Officer is in charge of finding out the energy and power associated with the motor.

[Have students do questions 1-5 on pp.4-5. After they are finished, bring the groups back together for wrap-up.]

So what did we find out about the work done by the motor? How did this relate to the kinetic and potential energy of the rocket? [Note 9]

Why do we use the maximum velocity instead of the average velocity to calculate the kinetic energy? [Note 10]

How do these results illustrate the conservation of energy? [Note 11]

Now that we have an idea of how high they will go, we are ready to launch the rockets. When we launch the rockets, two groups will work together for each launch. If your rocket is being launched, one of you will launch the rocket while the other measures the angle of the height with your angle measuring device. The people in the other pair will operate stop-watches, timing how long the rocket rises and how long it takes to come down. Then you’ll switch places and launch the other rocket. The other people in the class can cheer and also go retrieve the rocket when it comes down. (However they must not try to catch it out of the air because it will mess up the time for your calculations, and may even damage the rocket.) We will launch every group’s rocket.
Be sure to copy your answers onto the Summary of Results page.

Notes:
1. So far, we have found the following: the force (often called the “thrust”) produced by the motor, the force due to gravity that acted on the motor, and the total force acting on the rocket – at least while the motor is burning. [Ask a group to describe (or draw on the board) their force diagram and explain the arrows.]
2. Acceleration depends on both the force and the mass, so in order to find the average acceleration from the force the average mass must be used. Kilograms must be used because this is the SI unit of mass; other units like energy (in joules) are defined in terms of kg.

3. We have learned how high the rocket can go while the motor is burning and how fast it is going at the point the motor burns out.

4. Because the rocket does not travel at the maximum velocity the whole time. Using the maximum velocity to calculate height would give a result that is too high.

5. No, it continues rising, coasting to a stop, then it falls.

6. We have now been able to predict how high the rocket will go. How much of the rocket’s height is gained during the thrust (burn) phase?

7. Because the speed increases at a constant rate from zero to the maximum, then from the maximum back to zero. The average speed is not affected by how fast the speed changes, but by the maximum and minimum.

8. The coast time is much longer than the burn time because the only force acting on the rocket while coasting is gravity.

9. The work done by the rocket motor should be approximately equal to the sum of the kinetic and potential energies at all times after burnout.

10. Because we want the kinetic energy at a particular point, not an average kinetic energy over the whole distance. We also calculated the potential energy at the same point, so that we could get the total energy at that point.

11. Conservation of energy is shown by the fact that the amount of energy put into the system (the work done) is equal to the total energy of the system at any later time. You may want to point out to students that this only works because we are ignoring drag forces.
Day 6

Overview:
Launch the rockets and take measurements.

Supplies:
- Completed rockets
- Launch pad
- Launch controller & key
- Rocket Data Sheet
- Tape measure & flags
- Estes A8-3 rocket motors
- Recovery wadding
- Stop-watches
- Completed angle measuring devices
- Large open area (250x250 square feet)
- Low wind speeds

Outline of Activities:
Depending on the number of rockets to be launched and the number of launch pads available, this activity can easily require the entire class period, and maybe even part of another class period.

Narrative:
Today we will launch the rockets. We will collect data on how high the rocket goes, using the angle measuring device, as well as data on how long the rocket is traveling up and how long it takes to fall. The person measuring the angle with the AMD should stand at the marker so that the baseline distance from him/her to the launch pad is known.

Notes:
Instruct the students to pay attention to all activities. When a launch is started, there should not be anyone closer to the rocket than the distance of the launch controller cord (about 10 feet). You will want to use a fairly long baseline, at least 20 meters or so. Use the tape measure and put a flag or marker at the location so each group does not have to measure their own baseline. If possible, locate your baseline perpendicular to the wind direction so that drift due to the wind will have less effect on the angle measured. Also, note that the AMD actually measures the angle between the rocket and straight up, rather than the angle between the rocket and the baseline. This is why the equation in the equation bank is inverted from what would normally be expected. If the students have sufficient trigonometry background, this should be explained to them.
Days 7-8

Overview:
Compare results to predictions and discuss the differences between them. Wrap-up.

Supplies:
- Mission Debrief handout
- Rocket Data Sheet (completed)
- Flight Readiness Review (completed)

Outline of Activities:
This activity will generally take at least one class period, and may go into the next. Any remaining time on Day 8 can be used to wrap everything up and review everything that has been done.

Narrative:
The calculations that we are doing today are to utilize the data from the launch to calculate the height and energy of the rocket. Then, we will compare the actual launch results to what we predicted based on the bench test.

Notes:
Make sure that the students understand that the difference between the predicted and actual results is due to drag. You may want to refer them to the force diagrams they drew on the Preliminary Design Review on Day 1.

During the final wrap-up, you may want to point out other applications for the equations used on the various worksheets.
Preliminary Design Review

1. What are rockets used for?

2. Why do they have the shape that they do?

3. What is the purpose of each main part of the rocket?

4. What are some similarities of the deflated balloon and the rocket?

5. What are some similarities of the inflated balloon and the rocket?

6. Draw a diagram of the forces acting upon the inflated balloon.
Preliminary Design Review

7. What causes the balloon to move when it is released?

8. State Newton’s Laws of motion here:
   a. Newton’s First Law:
   b. Newton’s Second Law:
   c. Newton’s Third Law:

9. Other questions that I have about rockets:
Rocket Data Sheet
Record the following data
(TAKS Objective 1.2B)

Bench Test Measurements
Impulse of the Motor: \( J = \) _______ Ns
Burn Time: \( t_b = \) _______ s
Mass of the Motor before Burn: \( m_i = \) _______ g
Mass of the Motor after Burn: \( m_f = \) _______ g
Mass of the Rocket Alone: \( m_t = \) _______ g

Launch Measurements
Length of Baseline: \( d = \) _______ m
Angle at Highest Point: \( \theta = \) _______ °
Time Up: \( t_u = \) _______ s
Time Down: \( t_d = \) _______ s
Total Time: \( t_t = \) _______ s

Equation Bank

<table>
<thead>
<tr>
<th>( F = ma )</th>
<th>( v = \frac{d}{t} )</th>
<th>( p = mv )</th>
<th>( g = 9.81 \frac{m}{s^2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_b = \frac{J}{t_b} )</td>
<td>( PE = mgh )</td>
<td>( W = Fd )</td>
<td>average = ( \frac{\text{final} + \text{initial}}{2} )</td>
</tr>
<tr>
<td>( a = \frac{v}{t} )</td>
<td>( KE = \frac{mv^2}{2} )</td>
<td>( p = \frac{W}{t} )</td>
<td>( d_{ta} = \frac{d}{\tan \theta} )</td>
</tr>
</tbody>
</table>
Summary of Results

Forces
Force during the Burn: \( F_b = \ldots \) N
Force Due to Gravity: \( F_g = \ldots \) N
Force of Drag: \( F_d = \ldots \) N
Total Force Applied to Rocket: \( F_t = \ldots \) N
G-Force: \( G = \ldots \)

Mass
Average Total Mass: \( M_{avg} = \ldots \) kg

Times
Burn Time: \( t_b = \ldots \) s
Coasting Time: \( t_c = \ldots \) s

Distances
Height Gained during the Burn: \( d_b = \ldots \) m
Height Gained during Coast: \( d_c = \ldots \) m
Total Predicted Height: \( d_{tp} = \ldots \) m
Total Actual Height: \( d_{ta} = \ldots \) m

Velocities
Maximum Velocity during the Burn: \( v_b = \ldots \) \( \frac{m}{s} \)
Average Velocity during the Burn: \( v_{avg} = \ldots \) \( \frac{m}{s} \)
Upward Velocity: \( v_u = \ldots \) \( \frac{m}{s} \)

Accelerations
Acceleration during the Burn: \( a_b = \ldots \) \( \frac{m}{s^2} \)

Work & Energy
Potential Energy at Total Predicted Height: \( PE_t = \ldots \) J
Potential Energy at Total Actual Height: \( PE_{ta} = \ldots \) J
Work Done on Rocket by Motor: \( W = \ldots \) J

Power
Power Output: \( P = \ldots \) \( \frac{J}{s} = \ldots \) W
Flight Readiness Review

The Range Officer’s Questions:

The Range Officer would like you to find the total predicted height for your rocket, \(d_f\).

1. First things first: using the impulse (\(J\)) and the burn time (\(t_b\)), calculate the average force during the burn (\(F_b\)) applied to the rocket by the motor.

2. Since gravity is always present, you will need to consider this force (\(F_g\)) during the launch. To calculate the gravitational force, you need to find the average total mass of the rocket and motor (\(M_{\text{avg}}\)). \(M_{\text{avg}}\) is the average of the mass of the rocket and motor before the burn (\(m_r + m_i\)) and the mass of the rocket and motor after the burn (\(m_r + m_f\)).

   Calculate \(M_{\text{avg}}\). Be sure to convert your final result from grams (\(g\)) to kilograms (\(kg\)). There are 1000 grams in a kilogram.

   Using \(M_{\text{avg}}\) and the acceleration due to gravity (\(g\)), calculate \(F_g\).

3. Draw a diagram of the rocket and the forces acting on it during the burn. Based on your drawing, calculate the total force applied to the rocket (\(F_t\)). (At this point we are ignoring drag.)
4. Using total force ($F_t$) and the average total mass ($M_{avg}$), calculate the average acceleration of the rocket during the burn ($a_b$).

5. Calculate the maximum velocity during the burn phase ($v_b$), using the average acceleration ($a_b$) and the burn time ($t_b$).

6. The velocity of the rocket during the burn increases from an initial value of zero to the maximum value of $v_b$. Find the average velocity ($v_{avg}$) of the rocket during the burn phase.

7. Using the average velocity ($v_{avg}$) and the burn time ($t_b$), calculate the height gained during the burn ($d_b$).
8. After the motor stops burning, the rocket enters into a coasting phase. We need to find the distance traveled (d_c) during this phase. The only force acting on the rocket during the coast phase is the force due to gravity (F_g).

We can use the equation for acceleration to find the time (t_c) that the rocket is coasting. Using the acceleration due to gravity (g), the maximum velocity at burn out (v_b), and the velocity at the highest point, calculate the coast time (t_c).

How would you calculate the average velocity during the coast phase? Is this the same as a velocity you have already calculated? Why?

Using the coast time (t_c) and the average velocity (v_avg), calculate the height gained during the coast phase (d_c).

9. Using both heights (d_b and d_c), calculate the total predicted height for your rocket (d_t).
Propulsion Officer’s Questions:

The Propulsion Officer would like you to find the motor’s work (W), power (P), and total energy (E) at burn out.

1. Using the average force ($F_b$) applied to the rocket by the motor and the height at burn out ($d_b$), calculate the work done on the rocket by the motor (W).

2. From the work done on the rocket by the motor (W), calculate the power output (P) of the rocket during the burn time ($t_b$).

3. Next, we need to calculate the potential and kinetic energy of the rocket at burn out.
   Using the average total mass ($M_{avg}$), acceleration due to gravity (g), and the height ($d_b$), calculate potential energy ($PE_b$).

   Using the average total mass ($M_{avg}$) and maximum velocity at burn out ($v_b$), calculate kinetic energy ($KE_b$).

   Using $PE_b$ and $KE_b$, calculate the total energy (E).
**Flight Readiness Review**

4. Finally, we need to know the potential energy of the rocket at the maximum height. Using the total average mass of the rocket ($M_{\text{avg}}$), acceleration due to gravity ($g$), and the total height ($d_t$) from the Range Officer’s request, calculate this potential energy ($PE_t$).

5. Compare the work done by the motor ($W$), the total energy at burn out ($E$), and the potential energy at the highest point ($PE_t$). Are they similar? If so, can you explain why? What law does this demonstrate?
The Range Officer wants you to find the actual height that your rocket traveled \( (d_{ta}) \), the average velocity up and the average velocity down \( (v_u \text{ and } v_d) \).

1. Using the angle measured during launch \( (\theta) \) and the baseline distance from the launch pad \( (d) \), calculate the total actual height \( (d_{ta}) \). Make sure your calculator is set to degrees.

2. Using the measured time up \( (t_u) \) and the total actual height \( (d_{ta}) \), calculate the velocity \( (v_u) \) of the rocket during the burn and coast phases.

3. Using the measured time down \( (t_d) \) and the total actual height \( (d_{ta}) \), calculate the velocity \( (v_d) \) during the descent phase.

4. Using the average total mass \( (M_{avg}) \), acceleration due to gravity \( (g) \), and the total actual height \( (d_{ta}) \), calculate the actual potential energy \( (PE_{ta}) \) at the height reached by the rocket.

5. The g-force \( (G) \) is the multiple of Earth’s gravity experienced by the rocket. Using the average acceleration \( (a_b) \) from the Flight Readiness Review and the acceleration due to gravity \( (g) \), calculate the g-force \( (G) \) the rocket experienced during launch.
Mission Debrief

Mission Director’s Questions:

The Mission Director would like you to compare your results for the total actual height ($d_{ta}$) to the total predicted height ($d_t$), and the actual velocity up ($v_u$) to the predicted average velocity ($v_{avg}$).

1. Compare $v_u$ to $v_{avg}$: which one is higher and by how much?

2. Compare $d_t$ to $d_{ta}$: which one is higher and by how much?

3. Why are the predicted and actual values not the same?

4. Find the difference between the predicted potential energy ($PE_i$) and the actual potential energy ($PE_{ta}$) at the highest point. This difference in energy is the work done by drag ($W_d$).

Using this value for work ($W_d$) and the actual distance over which the rocket traveled ($d_{ta}$), calculate the force of drag ($F_d$).
Preliminary Design Review: Answer Key

1. What are rockets used for?
   
   Possible answers include: putting satellites in orbit or to other planets, taking measurements of the upper atmosphere, delivering warheads.

2. Why do they have the shape that they do?
   
   The shape allows the rocket to pass through the air more easily, and to fly without tumbling.

3. What is the purpose of each main part of the rocket?
   
   The purpose of the nose cone is to make the rocket more aerodynamic. The purpose of the body is to make it more aerodynamic and to protect the internal structure. The fins help control and stabilize the rocket’s flight, and the motor makes the rocket move. The parachute is used to help the rocket return to Earth safely.

4. What are some similarities of the deflated balloon and the rocket?
   
   Possible answers include: both have mass and they both have an opening at one end. (TAKS Objective 1.3.B)

5. What are some similarities of the inflated balloon and the rocket?
   
   Possible answers include: both have potential energy, both have forces acting on them. (TAKS Objective 1.3.B)

6. Draw a diagram of the forces acting upon the inflated balloon.
   
   (TAKS Objective 5.4.B)
7. What causes the balloon to move when it is released? 

Gravity (TAKS Objective 5.4.B)

8. State Newton’s Laws of motion here:
   d. Newton’s First Law:

   The law of inertia – a body at rest tends to stay at rest and a body in motion tends to stay in motion until acted upon by an outside force (TAKS Objective 5.4.B)

   e. Newton’s Second Law:

   An unbalanced force will cause a mass to be accelerated, or F=ma.
   (TAKS Objective 5.4.B)

   f. Newton’s Third Law:

   Every action has an equal and opposite reaction.
   (TAKS Objective 5.4.B)

9. Other questions that I have about rockets:
The Range Officer’s Questions:

The Range Officer would like you to find the total predicted height for your rocket, dₜ.

1. First things first: using the impulse (J) and the burn time (tᵇ), calculate the average force during the burn (Fᵇ) applied to the rocket by the motor.

\[ Fᵇ = \frac{J}{tᵇ} = \text{____[N]} \]

(TAKS Objective 5.4)

2. Since gravity is always present, you will need to consider this force (Fᵍ) during the launch. To calculate the gravitational force, you need to find the average total mass of the rocket and motor (M_avg). M_avg is the average of the mass of the rocket and motor before the burn (mᵣ + mᵢ) and the mass of the rocket and motor after the burn (mᵣ + mᶠ).

Calculate M_avg. Be sure to convert your final result from grams (g) to kilograms (kg). There are 1000 grams in a kilogram.

\[ M_{avg} = \frac{(mᵣ + mᵢ) + (mᵣ + mᶠ)}{2} [g] = \text{____[g]} \cdot \frac{1[kg]}{1000[g]} = \text{____[kg]} \]

Using M_avg and the acceleration due to gravity (g), calculate Fᵍ.

\[ F = ma \quad \Rightarrow \quad Fᵍ = M_{avg} \cdot g = \text{____[N]} \]

(TAKS Objective 5.4)

3. Draw a diagram of the rocket and the forces acting on it during the burn. Based on your drawing, calculate the total force applied to the rocket (Fₜ). (At this point we are ignoring drag.)

\[ Fₜ = Fᵇ - Fᵍ = \text{____[N]} \]

(TAKS Objective 5.4)
4. Using total force \((F_t)\) and the average total mass \((M_{avg})\), calculate the average acceleration of the rocket during the burn \((a_b)\).

\[
F = ma
\]

\[
a_b = \frac{F_t}{M_{avg}} = \left[\frac{m}{s^2}\right]
\]

(TAKS Objective 5.4.A)

5. Calculate the maximum velocity during the burn phase \((v_b)\), using the average acceleration \((a_b)\) and the burn time \((t_b)\).

\[
v_b = a_b t_b = \left[\frac{m}{s}\right]
\]

(TAKS Objective 5.4.A)

6. The velocity of the rocket during the burn increases from an initial value of zero to the maximum value of \(v_b\). Find the average velocity \((v_{avg})\) of the rocket during the burn phase.

\[
v_{avg} = \frac{v_f + v_i}{2} = \frac{v_b + 0}{2} = \left[\frac{m}{s}\right]
\]

(TAKS Objective 5.4.A)

7. Using the average velocity \((v_{avg})\) and the burn time \((t_b)\), calculate the height gained during the burn \((d_b)\).

\[
v = \frac{d}{t}
\]

\[
d_b = v_{avg} t_b = [m]
\]

(TAKS Objective 5.4)
Flight Readiness Review: Answer Key

8. After the motor stops burning, the rocket enters into a coasting phase. We need to find the distance traveled \((d_c)\) during this phase. The only force acting on the rocket during the coast phase is the force due to gravity \((F_g)\).

We can use the equation for acceleration to find the time \((t_c)\) that the rocket is coasting. Using the acceleration due to gravity \((g)\), the maximum velocity at burn out \((v_b)\), and the velocity at the highest point, calculate the coast time \((t_c)\).

\[
a = \frac{v}{t} \\
t_c = \frac{v_b}{g} = ____[s]
\]

(TAKS Objective 5.4)

How would you calculate the average velocity during the coast phase? Is this the same as a velocity you have already calculated? Why?

\[
v_{avg} = \frac{v_i + v_f}{2} = \frac{v_i + 0}{2} = \frac{m}{s}
\]

Observe that during the coast phase the initial velocity is the velocity during at burnout. The final velocity during the coast phase is zero. The average velocity during the coast phase is the same velocity that was found earlier during the burn phase.

(TAKS Objective 5.4)

Using the coast time \((t_c)\) and the average velocity \((v_{avg})\), calculate the height gained during the coast phase \((d_c)\).

\[
v = \frac{d}{t} \\
d_c = v_{avg}t_c = ____[m]
\]

(TAKS Objective 5.4)

9. Using both heights \((d_b\) and \(d_c\)), calculate the total predicted height for your rocket \((d_t)\).

\[
d_t = d_b + d_c = ____[m]
\]
Propulsion Officer’s Questions:

The Propulsion Officer would like you to find the motor’s work (W), power (P), and total energy (E) at burn out.

1. Using the average force (F_b) applied to the rocket by the motor and the height at burn out (d_b), calculate the work done on the rocket by the motor (W).

\[ W = F_b d_b = \square [J] \]  
(TAKS Objective 5.4.A)

2. From the work done on the rocket by the motor (W), calculate the power output (P) of the rocket during the burn time (t_b).

\[ P = \frac{W}{t_b} = \square [J/s] = \square [W] \]  
(TAKS Objective 5.4.A)

3. Next, we need to calculate the potential and kinetic energy of the rocket at burn out. Using the average total mass (M_avg), acceleration due to gravity (g), and the height (d_b), calculate potential energy (PE_b).

\[ PE_b = M_{avg} g d_b = \square [J] \]  
(TAKS Objective 5.6)

Using the average total mass (M_avg) and maximum velocity at burn out (v_b), calculate kinetic energy (KE_b).

\[ KE_b = \frac{M_{avg} v_b^2}{2} = \square [J] \]  
(TAKS Objective 5.6)

Using PE_b and KE_b, calculate the total energy (E).

\[ E = PE_b + KE_b = \square [J] \]  
(TAKS Objective 5.6)
4. Finally, we need to know the potential energy of the rocket at the maximum height. Using the total average mass of the rocket ($M_{avg}$), acceleration due to gravity ($g$), and the total height ($d_t$) from the Range Officer’s request, calculate this potential energy ($PE_t$).

\[ PE_t = M_{avg}gd_t = \text{____}[J] \]

(TAKS Objective 5.6)

5. Compare the work done by the motor ($W$), the total energy at burn out ($E$), and the potential energy at the highest point ($PE_t$). Are they similar? If so, can you explain why? What law does this demonstrate?

The answers to the work, total energy, and potential energy at maximum height are all nearly the same. This is because the rocket gains energy from the work of a motor. All of the work done by the motor is converted to potential energy at the highest point in the rocket’s trajectory. The total energy is always the sum of the potential energy and kinetic energy, and this total energy comes from the work of the motor. This illustrates the law of conservation of energy.

(TAKS Objective 5.6.A)
Mission Debrief: Answer Key

Range Officer’s Questions:

The Range Officer wants you to find the actual height that your rocket traveled \( (d_{ta}) \), the average velocity up and the average velocity down \( (v_u \text{ and } v_d) \).

1. Using the angle measured during launch \( (\theta) \) and the baseline distance from the launch pad \( (d) \), calculate the total actual height \( (d_{ta}) \). Make sure your calculator is set to degrees.

\[
d_{ta} = \frac{d}{\tan \theta} = \text{[m]}
\]

2. Using the measured time up \( (t_u) \) and the total actual height \( (d_{ta}) \), calculate the velocity \( (v_u) \) of the rocket during the burn and coast phases.

\[
v_u = \frac{d_{ta}}{t_u} = \text{[m/s]}
\]

(TAKS Objective 5.4.A)

3. Using the measured time down \( (t_d) \) and the total actual height \( (d_{ta}) \), calculate the velocity \( (v_d) \) during the descent phase.

\[
v_d = \frac{d_{ta}}{t_d} = \text{[m/s]}
\]

(TAKS Objective 5.4.A)

4. Using the average total mass \( (M_{avg}) \), acceleration due to gravity \( (g) \), and the total actual height \( (d_{ta}) \), calculate the actual potential energy \( (PE_{ta}) \) at the height reached by the rocket.

\[
PE_{ta} = M_{avg}gd_{ta} = \text{[J]}
\]

(TAKS Objective 5.6)

5. The g-force \( (G) \) is the multiple of Earth’s gravity experienced by the rocket. Using the average acceleration \( (a_b) \) from the Flight Readiness Review and the acceleration due to gravity \( (g) \), calculate the g-force \( (G) \) the rocket experienced during launch.

\[
G = \frac{a_b}{g} = \text{[ ]}
\]

*Note that the G-Force is unit-less because it is a ratio of two forces.*
Mission Debrief: Answer Key

Mission Director’s Questions:

The Mission Director would like you to compare your results for the total actual height ($d_{ta}$) to the total predicted height ($d_i$), and the actual velocity up ($v_u$) to the predicted average velocity ($v_{avg}$).

1. Compare $v_u$ to $v_{avg}$: which one is higher and by how much?

\[
v_{avg} - v_u
\]

*Note: $v_{avg}$ should be higher than $v_u$. 

2. Compare $d_i$ to $d_{ta}$: which one is higher and by how much?

\[
d_i - d_{ta}
\]

*Note: $d_i$ should be higher than $d_{ta}$. 

3. Why are the predicted and actual values not the same?

The predicted and actual values were not the same because we ignored the force of drag acting down on the rocket.

(TAKS Objective 1.3.A)

4. Find the difference between the predicted potential energy ($PE_i$) and the actual potential energy ($PE_{ta}$) at the highest point. This difference in energy is the work done by drag ($W_d$).

\[
PE_i - PE_{ta} = W_d = ____[J]
\]

Using this value for work ($W_d$) and the actual distance over which the rocket traveled ($d_{ta}$), calculate the force of drag ($F_d$).

\[
F_d = \frac{W_d}{d_{ta}} = ____[N]
\]