Hypersonics STEM Curriculum

Energy to Launch

Grade	Time	Subject Area	Key Concepts
6-8	60 min	Physical Science	Energy

Lesson Overview

In this lesson, students will study how energy is transferred as an aircraft is launched from a table using a rubber band and then lands on the ground. The students will start by calibrating a rubber band to see how the distance the aircraft flies is affected by the distance the rubber band is displaced. The instructor will give each group/student a specific landing spot for their aircraft, and they will use their data to determine how far back they should pull the rubber band to have the aircraft land in the desired location.

Prior to this lesson, students should have learned about the different types of energy, specifically kinetic energy, gravitational potential energy, and elastic potential energy, as well as the law of conservation of energy.

NGSS & CCSS Standards

MS-PS3-1 Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

MS-PS3-2 Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

MS-PS3-5 Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

CCSS.MATH.CONTENT.8.F.A.3 Interpret the equation $y = mx + b$ as defining a linear function, whose graph is a straight line; give examples of functions that are not linear.

Learning Objectives

By the end of this lesson, students will be able to:

- Explain the energy transfer that occurs from when an aircraft is launched, to when it is descending in the air, and finally when it lands.
- Create a graphical model of the energy transfer from when an aircraft is launched, to when it is descending in the air, and finally when it lands.
- Collect data on the effect of how far a rubber band is pulled back on how far the aircraft is launched.
- Determine the relationship between how far a rubber band is pulled back and how far the aircraft is launched.

- Estimate how far a rubber band needs to be pulled pack for an aircraft to be launched to its assigned landing spot based on data they collected.

Essential/Overarching Question

How can we horizontally launch an aircraft and land on an intended target?

Key Vocabulary

Speed – the rate at which an object is moving. Speed is calculated by dividing the distance travelled by the time it took to travel that distance.

Speed of Sound – the rate at which sound moves through a medium. The speed of sound depends on both the density and the temperature of the medium. The speed of sound through air at 20° C (68° F) at sea level is 343 m/s (767 mph).

Mach – the ratio of the speed of an object to the speed of sound or how many times the speed of sound an object is moving. It is often followed by a number indicating the ratio; for example: Mach 1 is the speed of sound, Mach 2 is twice the speed of sound, Mach 5 is five times the speed of sound.

Sonic – speeds equal to the speed of sound (Mach 1).

Subsonic – speeds smaller than the speed of sound (less than Mach 1).

Transonic – speeds near (Mach 0.8-1.2) the speed of sound where drag is highest (e.g. sound barrier).

Supersonic – speeds greater than the speed of sound (Mach 1 and greater).

Hypersonic – speeds greater than five times the speed of sound (Mach 5 and greater).

Fluid – a substance with no fixed shape; a liquid, gas, or plasma. A substance that flows when an external force is applied to it.

Flow – the motion of a fluid (liquid, gas, or plasma) when it experiences unbalanced forces.

Energy – the ability to do work. The ability to apply a net force to move an object.

Kinetic Energy – energy of motion. The kinetic energy, measured in joules (J), is equal to one half times the objects mass times the square of the velocity. $K = \frac{1}{2}mv^2$.

Mass – the amount of matter in a body; measure of inertia or resistance to change velocity.

Velocity – the speed of an object is a given direction. Speed is calculated by dividing the displacement of the object by the time interval in which the displacement occurred.

Potential Energy – stored energy. Energy held by an object due to a change in position, shape, or electrical configuration.

Gravitational Potential Energy – stored energy due to an object's position relative to a plane of reference. The gravitational potential energy, measured in joules (J), is equal to the mass of the object, times the acceleration due to gravity, times the object's height, $U_g = mgh$.

Acceleration due to Gravity – the acceleration, rate of change of velocity, at which an object free falls due to the gravitational attraction between the object and a celestial body; on Earth $g = 9.8 \text{ m/s}^2$ towards Earth's center.

Height – an object's vertical position relative to a plane of reference (0 m). Typically, the position above or below sea level or ground level.

Elastic Potential Energy – stored energy due to an object's change in shape. The elastic potential energy, measured in joules (J), is equal to one half times the objects spring constant times the square of the distance the object has been stretched or compressed, $U_s = ½kx^2$.

Spring Constant – a measure of the stiffness of an object. It is the restoring force per unit length. It is represented by the variable k and has units of Newtons/meter (N/m).

Law of Conservation of Energy – energy is neither created or destroyed, it is simply transferred from one object or type of energy to another. The sum of the energy of a system at two instances in time are the same in a closed, isolated system.

Closed System – a physical system that does not exchange mass with its surroundings. Mass cannot be added to nor removed from the system.

Isolated System – a physical system that does not exchange energy with its surroundings. Energy cannot be added to nor removed from the system.

Science Concepts Overview

There are different types of engines that are used in hypersonic vehicles. But some engines can only run at those speeds for a short amount of time and/or require help boosting the vehicle to the hypersonic speeds. In many cases, hypersonic vehicles are launched. When the object is launched, many calculations are done to ensure that the aircraft reaches the precise speed and/or location. To simulate the launch process, we are going to use rubber bands.

The law of conservation of energy states that energy cannot be created or destroyed, it can be transferred from one form of energy to another. The total energy of a system is constant. There are two main types of useful energy: kinetic energy and potential energy. Kinetic energy is energy of motion. Potential energy is energy stored in an object due to its position. When energy is "lost", this useful energy is transformed into heat energy (usually due to friction) and leaves the system.

One type of potential energy, elastic potential energy, is generated when an object's shape is changed. For example, a spring has potential energy stored when it is both stretched and compressed. A rubber band stores potential energy when it is stretched. In both cases, when the object is released, the object returns to its normal shape and the elastic potential energy is transformed to another type of energy, typically kinetic energy. The further an object is displaced, the more elastic potential energy is stored, which generates more kinetic energy when it is released.

Materials List

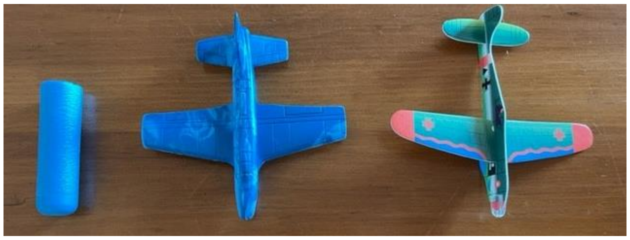
- ☐ Rulers (one per group)
- ☐ Metersticks or measuring tape (one per group)
- ☐ Rubber bands – thicker rubber bands are better for launching (one per group)
- ☐ Model aircrafts (one per group)
- ☐ Launch pad (one per group/launch area)
    - Wood plank (one per launch pad)
    - Bolts (two per launch pad)
    - Washer (two per launch pad)
    - Nuts (two per launch pad)
    - Acorn nuts (two per launch pad)
    - Clamps (two per launch pad)
- ☐ Energy to Launch handout (one per student)
- ☐ Target (one per group/launch area – two options available)

Lesson Preparation

Prior to the lesson, the instructor should make copies of the Energy to Launch handout, gather materials, and build the launch pads.

There is no exact size that the launch pads need to be. You can make adjustments to the launch pad by substituting out materials based on what is available and/or adjusting dimensions to accommodate the size of the model aircrafts used or classroom tables. The instructions below are for the launch pad shown in the picture:

- Cut a piece of ½ inch thick wood to 8 inches by 11 inches. Sand any rough edges to prevent splinters.
- Drill two holes (slightly larger than your bolt) 5 inches part, centered on the piece of wood. The holes in the example were also counter bored from the back so the bolt heads were flush to the bottom which allows for easier clamping.
- Insert the bolts (¼ inch x 4-inch bolts were used for the example) through the holes. Place the washer on the bolt and then tighten the nut on the bolt. Hand tightening at minimum is recommended.
- Screw the acorn nuts on top of the bolts.
- Stretch a rubber band between the two bolts.
- Clamps are used to secure the launch pad to surface (table or bench) from which you will be launching.



There are a range of materials that you can use as model aircrafts such as foam airplanes, gliders, large foam projectiles, etc. Each type of model aircraft has its pros and cons for use in the lesson. Some are easier to launch, some are more consistent in their flight path, some are more stable, etc. For example, model aircrafts with wings will experience lift and may have less predictable flight patterns as compared to the foam projectiles. Just as a scientist or engineer would, students will have to fiddle with and adjust their data collection procedures to get the most reliable data.

Depending on the rubber bands and model aircrafts used, the launch sites could require a long, clear stretch of space. This would be a great lesson to do in the hallway, gymnasium, or cafeteria. Working outside could be another option, but the wind will affect flight patterns.

Safety

Due to the nature of this lesson, it is recommended that the class take the following safety precautions:

- Participants should wear eye protection.
- Participants should be reminded the proper use of equipment.
- Participants should be reminded to be mindful of where they walk in the classroom, so they do not walk in the path of a launch zone.
- Participants should be reminded to make sure their launch area is clear before launching.

Procedure

Engage (10 minutes)

1. Watch a video of the HOT (High Operational Tempo) Shot sounding rocket being launched. A sounding rocket collects scientific data and can travel at hypersonic speeds. https://www.youtube.com/watch?v=xGjdE7JdsK8

2. Pose the following questions to the class. You can either have a discussion as an entire class or use a think-pair-share:
    - What did you notice about the sounding rocket launch?
    - What wonders do you have about the sounding rocket launch?
3. Read The Challenge section of the Energy to Launch handout.

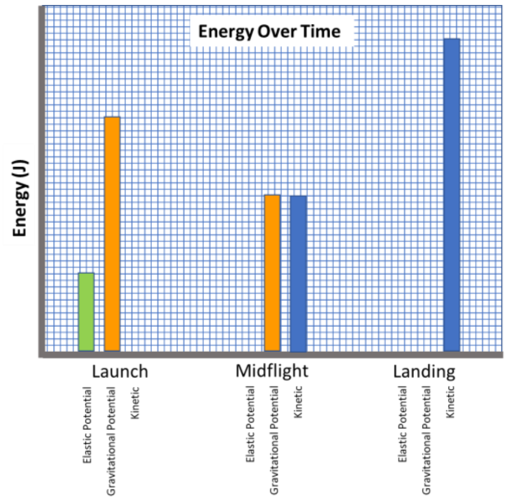
Explore (20 minutes)

4. Students should ideally work in groups of 2-3 for this lesson.
5. Each group will be given a launch pad, a rubber band, and an aircraft. Students will be asked to calibrate their rubber band launcher – figure out how far the aircraft flies for a variety of distances the rubber band is pulled back. Prior to taking measurements, students will be asked to draw a diagram of their launch site:
    - Draw a diagram of your launch site. Be sure to include measurements of how high your launch site is off the ground.
    - There are a variety of ways that you can measure the distance the rubber band is stretched and the distance the aircraft travels. How do you plan to measure these distances (Hint: Measure from ___ to ___.) Label these distances in your diagram above.
6. Students will then collect data. They will pull back a rubber band, launch their aircraft, and measure how far the aircraft flies. They will do this for a total of five rubber band distances, with three trials and an average taken for each distance. Students will use the data table in the Launch Calibration & Analysis section of the Energy to Launch handout to collect their data.
7. Students should make sure that they are launching horizontally, with their rubber band level with the launch surface. They may need to tinker with the set-up to get a consistent launch.

Explain & Elaborate (20 minutes)

8. Students will explain and elaborate on how conservation of energy played into their launch calibration by answering the Launch Calibration and Analysis questions on the Energy to Launch handout:
    - What were the different types of energy involved in the launch?

- In the diagram below, label the types of energy at each of the three positions in the launch.
- Create a bar graph below to show a qualitative representation of the amount of each type of energy present at three positions of the launch. Be sure to give your bar graph a title and label your y-axis.



- Elastic potential energy depends on the distance the object is stretched (or compressed) and the spring constant of the object. The spring constant is a property of the material and tells you how much force it takes to stretch or compress a material. Based on your data, do you think the distance displaced (stretched) has a linear (x) or non-linear (x2) relationship with the elastic potential energy? What data supports your claim?
- Some energy may be "lost," or transferred out of the system, in the launch and trajectory process. Where are places the energy may have been "lost."
- What are things beyond how far you pulled back the rubber band that effected the launch?

Evaluate (10 minutes)

9. Students will be given a specific location to land their aircraft. Students will need to use their calibration data to decide how far to pull back their rubber band to reach their intended location.
10. Students will plan for and analyze their launch by answering the Launch on Target questions on the Energy to Launch handout:
    - What is the distance that your aircraft must fly to hit your target?
    - Based on your data, how far should you pull your rubber band back to hit your target?
    - Did you hit the target on your first and/or second attempt(s)? If not, did your aircraft go too short or too far? How should you adjust your launcher?
    - How would you have to adjust how far you pulled back the rubber band if you had a different rubber band that was more stretchy (less taut)? Less stretchy (more taut)?
    - If you launched your aircraft from a higher launch location, how would you have to adjust how far your pulled back the rubber band?
    - Launch of hypersonics aircraft is often done from another moving aircraft. How does this change how you calculate your launch?

STEM Career Connections

- Aerospace engineering

- Aircraft design
- Pilot – commercial and military
- Systems engineering
- Mechanical Engineering

Extensions

If equipment is available, students could use motion detectors or similar electronic sensors to measure the launch and/or landing speeds of the aircraft as part of the ***explore*** section of the lesson.

As an additional ***explore*** and ***explain***, students could investigate how changing the angle of the launch effects how far and high the aircraft goes when launched from the ground (no vertical displacement – no overall change in gravitational potential energy).

As a further ***evaluation***, students could be given a new launch height and landing distance. Students will need to apply the conservation of energy to account for the difference in launch height with their data or collect new data for that height.

References & Resources

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Name: ____ Date: __________________

Energy to Launch

✈ The Challenge

There is a lot of research going into hypersonic aircrafts. ***Hypersonic*** means that an object is traveling more than five times the speed of sound. Getting an aircraft to those speeds, and then getting the aircraft to maintain those speeds, can be a challenge. Many hypersonic aircrafts need to be launched to be able to get to hypersonics speeds. However, when hypersonic aircrafts are launched, the launch needs to be precise so that the aircraft reaches the intended speed and/or location.

In this lesson, you will be focused on making sure that your aircraft is launched to the correct location. You will be given a model aircraft as well as a launch site to calibrate. You will work to understand how stretching the rubber band on your launch site effects where your aircraft lands. You will then be given a target for your aircraft to fly to and will need to use your data to make sure your aircraft lands in the intended location.

✈ Launch Calibration & Analysis

Your aircraft is going to be launched using a rubber band. When a rubber band is stretched, it has elastic potential energy. The amount of elastic potential energy depends on how far the rubber band is stretched. *Therefore, before you use your rubber band to launch your aircraft, you need to investigate how the distance the rubber band is stretched effects the launch.*

☐ Draw a diagram of your launch site. Be sure to include measurements of how high your launch site is off the ground.

☐ There are a variety of ways that you can measure the distance the rubber band is stretched and the distance the aircraft travels. How do you plan to measure these distances (Hint: Measure from ___ to ___.) Label these distances in your diagram above.

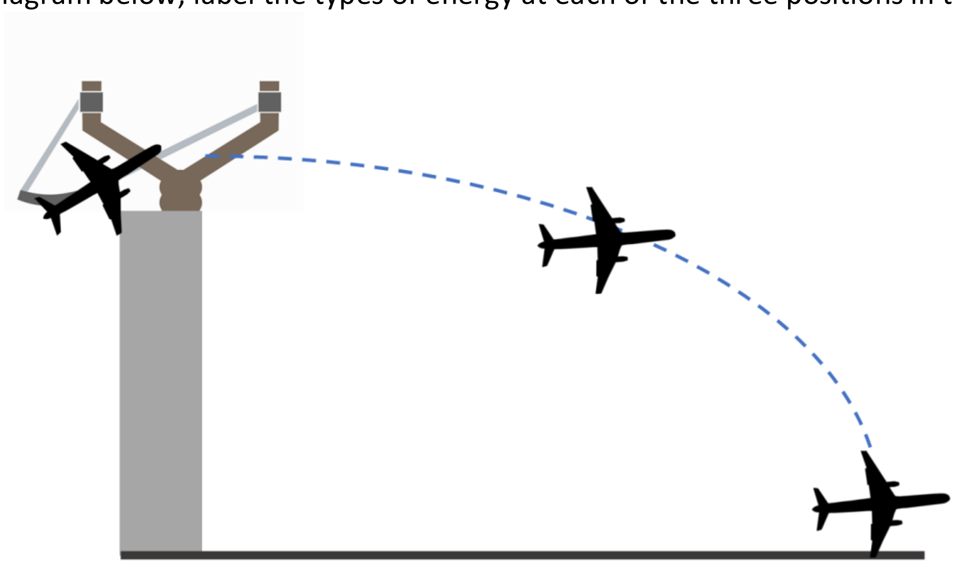
Pull your rubber band back to a variety of distances to launch your aircraft. Measure how far the aircraft flies and record your data in the table below. For each distance stretched, complete three trials and calculate the average distance traveled. There is also a column to make any notes on your aircraft's flight.

When launching your aircraft, try to make sure that the rubber band stays level with the launch surface and that you are not launching at an angle. You may need to adjust your launch pad to make sure your launches are as consistent as possible.

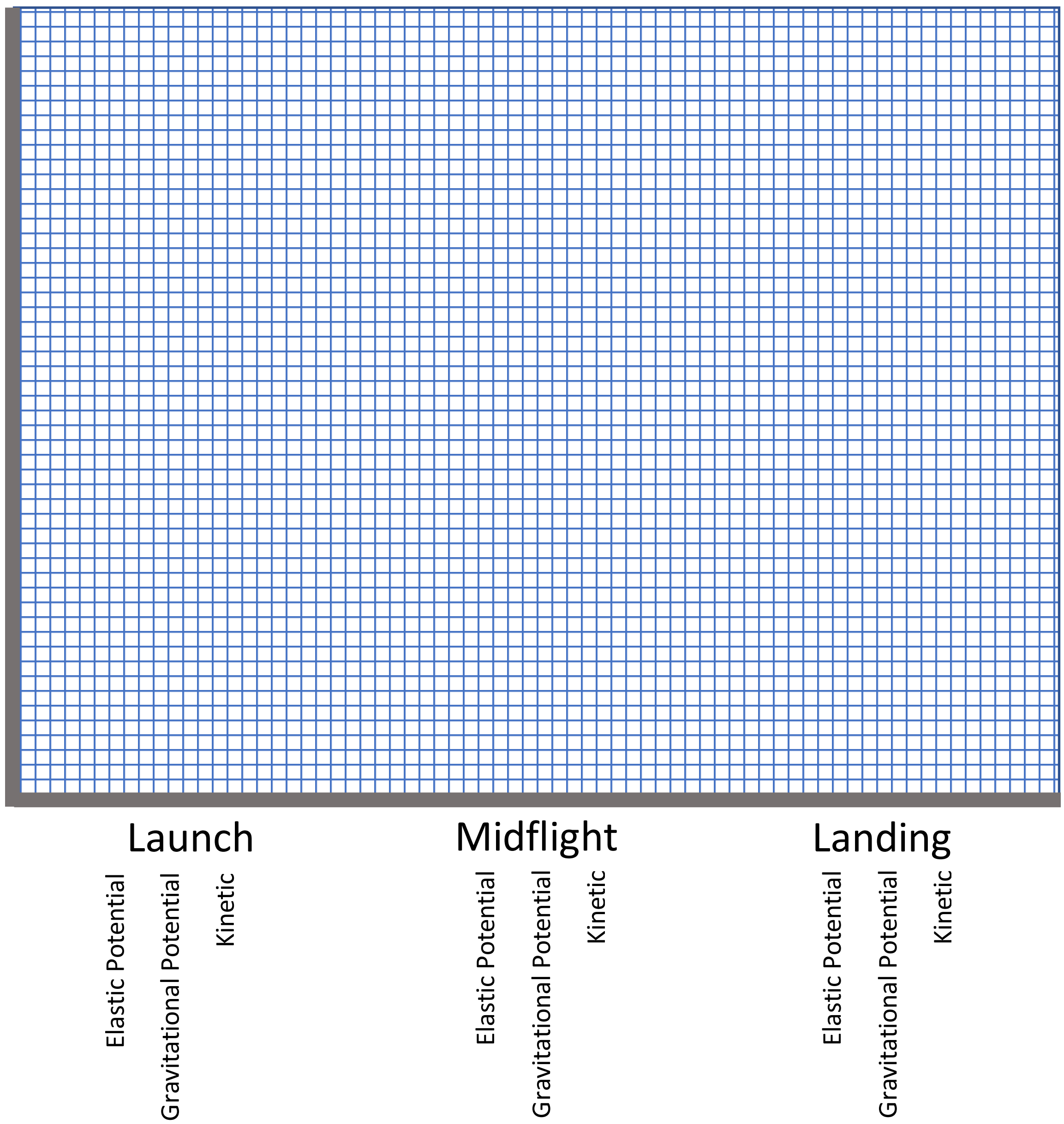
Distance Stretched (cm)	**Distance Traveled**				**Notes**
	Trial 1 (cm)	**Trial 2 (cm)**	**Trial 3 (cm)**	**Average (cm)**	

1. What were the different types of energy involved in the launch?

2. In the diagram below, label the types of energy at each of the three positions in the launch.



3. Create a bar graph below to show a qualitative representation of the amount of each type of energy present at three positions of the launch. Be sure to give your bar graph a title and label your y-axis.



4. Elastic potential energy depends on the distance the object is stretched (or compressed) and the ***spring constant*** of the object. The spring constant is a property of the material and tells you how much force it takes to stretch or compress a material. Based on your data, do you think the distance displaced (stretched) has a linear (x) or non-linear (x^2) relationship with the elastic potential energy? What data supports your claim?

5. Some energy may be “lost,” or transferred out of the system, in the launch and trajectory process. Where are places the energy may have been “lost.”

6. What issues did you have with the launch? How did you troubleshoot those issues?

✈ Launch on Target Analysis

Your instructor will give your group a specific distance for your aircraft to land. You will have two attempts to hit your landing location.

1. What is the distance that your aircraft must fly to hit your target?

2. Based on your data, how far should you pull your rubber band back to hit your target?

3. Did you hit the target on your first and/or second attempt(s)? If not, did your aircraft go too short or too far? How should you adjust your launcher?

4. How would you have to adjust how far you pulled back the rubber band if you had a different rubber band that was more stretchy (less taut)? Less stretchy (more taut)?

5. If you launched your aircraft from a higher launch location, how would you have to adjust how far your pulled back the rubber band?

6. The launch of a hypersonics aircraft is often done from another moving aircraft. How does this change how you calculate your launch?