# Hypersonics STEM Curriculum

## Launch on Target

| Grade | Time | Subject Area | Key Concepts |
|---|---|---|---|
| High School | 60 min | Physics | Kinematics<br>Forces<br>Energy |

**Lesson Overview**

In this lesson, students will combine the computational use of Newton's second law, conservation of energy, and kinematics to calculate how far back to pull a rubber band to launch an aircraft to a desired location. As part of the lesson, the students will have to calculate the spring constant of their rubber band. The instructor will give each group/student a specific landing spot for their aircraft, and they will use their data and calculations to determine how far back they should pull the rubber band to have the aircraft land in the desired location.

**NGSS Standards**

HS-PS2-1 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy

**Learning Objectives**

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

- Collect data on the force needed to extend a rubber band at a variety of distances.
- Calculate the spring constant of a rubber band using a force vs. displacement graph.
- Derive an equation to calculate the necessary launch speed to have an object travel a given distance when launch horizontally from a given height.
- Derive an equation to calculate how far to pull back a rubber band to horizontally launch an object at a given launch speed.

- Calculate the distance a rubber band should be pulled back to reach a given target using their derivations and measurements.
- Give examples of possible places where energy was transferred in or out of the system.
- Explain how their derivations would need to be adjusted for a hypersonic launch (from a moving object and at an angle).

**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.

**Force** – a push or a pull on an object or system.

**Net Force** – the vector sum of all forces acting on an object or system.

**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).

**Displacement** – the change in position of an object.

**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. $K = ½mv^2$.

**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 $g = 9.8 m/s^2$ 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, $U_s = ½kx^2$.

**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 aircrafts. But some engines can only run at those speeds for a short amount of time and/or require help boosting the aircraft to the hypersonic speeds. In many cases, hypersonic aircrafts 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.

Newton's laws can also be used to explain the subsequent motion of the aircraft when it is launched with the rubber band. When the rubber band is pulled back and released, it applies a force to the object. The force applied to the aircraft is proportional to how far the rubber band was displaced and is equal and opposite the force that was applied to the rubber band when stretching it. The force accelerates the object from rest.

Once the object is launched and is no longer in contact with the rubber band, the only force acting on the object is the gravitational force (if we ignore air resistance and lift). Since this is the case, we can use kinematics equations to calculate the distance launched, time in the air, and final velocity of the object.

## 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)

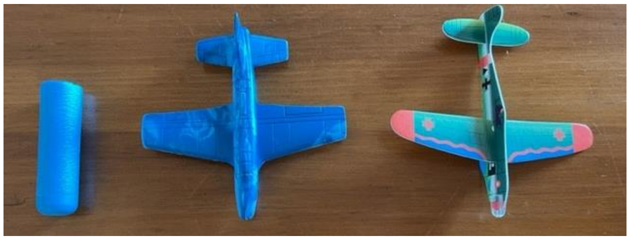
- ☐ Model aircrafts (one per group)
- ☐ Launch pad (one per group/launch area)
    - Wood plank (one per launch pad)
    - Bolts (two per launch pad)
    - Washer (two per launch pad)
    - Nuts (two per launch pad)
    - Acorn nuts (two per launch pad)
    - Clamps (two per launch pad)
- ☐ Balance/scale
- ☐ Spring scales
- ☐ Launch on Target 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 Launch on Target 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 Launch on Target handout.

***Explore, Explain, & Elaborate (45 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. In the Launch Calibration and Derivations section of the Launch on Target handout, students will be asked to calibrate their rubber band launcher – calculate the spring constant of the rubber band. 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 and use that data to calculate the spring constant of the rubber band:

- Place the rubber band on the launcher. Using a spring scale, pull the rubber band back to a specific distance and measure the force required to do so. Record your data in the data table. Repeat for six different distances.
- On the graph provided, graph force vs. distance.
- Draw the line of best fit for the graph. [Hint: Should the line go through the origin (0 m, 0 N)?]
- Calculate the slope of your line of best fit in the space below. Looking at the equation for the force of a rubber band, what does the slope of the line of best fit mean?
- Label your diagram above with the spring constant of your rubber band.

7. Students will derive a set of equations that allow them to calculate how far to pull their rubber band back in order to launch their aircraft and land on a specific target. Students will be stepped through the process by answering the Launch Calibration and Derivations questions on the Launch on Target handout:
    - Given the height of your table and the distance to the target, what physics concept can you use to calculate the necessary launch speed of the aircraft?
    - Using only variables, solve for the launch speed of the aircraft. What, if any, variables do you still need to take measurements?
    - Given the necessary launch speed of the aircraft, what physics concept can you use to calculate the necessary distance you need to pull back your rubber band to reach that speed?
    - Using only variables, solve for the distance you need to pull back the rubber band. What, if any, variables do you still need to take measurements?

***Evaluate (15 minutes)***

8. Students will be given a specific location to land their aircraft. Students will need to use their derived equations and measurements to calculate how far to pull back their rubber band to reach their intended location.
9. Once students have calculated how far to pull back their rubber band, they will have three attempts to hit their target. Students should make sure that they are launching horizontally, with their rubber band level with the launch surface. The multiple attempts allow them to tinker with the launch pad to ensure a good launch.
10. Students will plan for and analyze their launch by answering the Launch on Target Analysis questions on the Launch on Target handout:
    - What is the distance that your aircraft must fly to hit your target?
    - Using the equations you derived above, calculate 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 and by how much? How should you adjust your launcher?
    - What issues did you have with the launch? How did you troubleshoot those issues?

- 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."
- 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?
- Hypersonic aircrafts are frequently launched from another moving aircraft. How does this change how you calculate your launch?
- Hypersonic aircrafts are also launched from the ground at an angle. 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.

## References & Resources

Adventure Academy. (2020, April 2). *Our world: Potential and kinetic energy* [Video]. YouTube. https://www.youtube.com/watch?v=zCKeniklH_c

Alliant Energy. (2019, January 24). *The law of Conservation of energy* [Video]. YouTube. https://www.youtube.com/watch?v=Vx0yAS2u8gI

learning junction. (2022, February 28). *Potential and kinetic energy - Law of conservation of energy - Video for kids* [Video]. YouTube. https://www.youtube.com/watch?v=t0ShHdtB8jA

learning junction. (2019, October 14). *Types of energy | Energy forms | Energy sources and uses* [Video]. YouTube. https://www.youtube.com/watch?v=63t0Y2ACoh4

NASA Wallops. (2021, September 11). *HOTShot sounding rocket launch* [Video]. YouTube. https://www.youtube.com/watch?v=xGjdE7JdsK8

National Science Foundation. (2015, January 22). *Projectile motion & parabolas [Science of NFL football]* [Video] YouTube. https://www.youtube.com/watch?v=HB4ws7RoA3M

Professor Dave Explains. (2017, February 2). *Kinematics part 3: Projectile motion* [Video]. YouTube. https://www.youtube.com/watch?v=aY8z2qO44WA

SciShow. (2019, July 8). *A surprisingly simple secret to supersonic flight* [Video]. YouTube. https://www.youtube.com/watch?v=kGefMLHJBKA

Study Animated. (2018, April 2). *What is elastic potential energy* [Video]. YouTube. https://www.youtube.com/watch?v=uVUukHYkgQg

Talented Tuber. (2017, April 11). *Difference between subsonic, supersonic and hypersonic speed* [Video]. YouTube. https://www.youtube.com/watch?v=LBJ3tXCjzN0

TestTube 101. (2015, November 11). *Flying at hypersonic speeds* [Video]. YouTube https://www.youtube.com/watch?v=vL1qAfS0gic

Name: _____________________________________________ Date: ___________________

# Launch on Target

## ✈ 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 focus 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 & Derivations

Your aircraft is going to be launched from a raised platform (desk or table) using a rubber band.

☐ 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.

When a rubber band is stretched with a force, it has elastic potential energy. The amount of elastic potential energy or force depends on how far the rubber band is stretched. The equations for the potential energy and force of a rubber band/spring are: $U_s = \frac{1}{2}kx^2$ *and* $F_s = kx$ where k is the spring constant of the rubber band and x is the distance the rubber band is displaced.

*Therefore, you can take measurements and calculate the spring constant of the rubber band. By doing so, you can use those calculations to predict the landing location of your launch aircraft.*

- ☐ Place the rubber band on the launcher. Using a spring scale, pull the rubber band back to a specific distance and measure the force required to do so. Record your data in the data table. Repeat for six different distances.
- ☐ On the graph provided, graph force vs. distance.
- ☐ Draw the line of best fit for the graph. [Hint: Should the line go through the origin (0 m, 0 N)?]
- ☐ Calculate the slope of your line of best fit in the space below. Looking at the equation for the force of a rubber band, what does the slope of the line of best fit mean?
- ☐ Label your diagram above with the spring constant of your rubber band.

| Distance (m) | Force (N) |
|---|---|
| | |
| | |
| | |
| | |
| | |
| | |

Slope Calculation:

*You will be given a target distance that your aircraft needs to fly. Given that distance, you will need to work backwards to calculate how far to pull your rubber band back to launch your aircraft and land on target.*

1. Given the height of your table and the distance to the target, what physics concept can you use to calculate the necessary launch speed of the aircraft?

2. Using only variables, solve for the launch speed of the aircraft. What, if any, variables do you still need to take measurements?

3. Given the necessary launch speed of the aircraft, what physics concept can you use to calculate the necessary distance you need to pull back your rubber band to reach that speed?

4. Using only variables, solve for the distance you need to pull back the rubber band. What, if any, variables do you still need to take measurements?

✈ **<u>Launch on Target Analysis</u>**

*Your instructor will give your group a specific distance where your aircraft will need to land.*

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

*2.* Using the equations you derived above, calculate how far should you pull your rubber band back to hit your target.

*You will have three attempts to hit your landing location. 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.*

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 and by how much? How should you adjust your launcher?

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

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. 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)?

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

8. Hypersonic aircrafts are frequently launched from another moving aircraft. How does this change how you calculate your launch?

9. Hypersonic aircrafts are also launched from the ground at an angle. How does this change how you calculate your launch?