

Intro Screen

Investigate the the factors that affect a projectile's trajectory, such as angle, height, initial speed, and air resistance.

SEE the apex of the trajectory

ADJUST cannon angle (5° steps) and height

FIRE projectile

EXPERIMENT with various projectiles

INVESTIGATE the effects of air resistance

MEASURE the time, range, and height of the projectile along its path

Vectors Screen

View the drag and gravitational forces in a free-body diagram, and explore how the velocity and acceleration are affected by air resistance.

ZOOM in or out

OBSERVE a free-body diagram in real time

SET the initial speed

EXPLORE the effects of diameter, mass, and air resistance

VIEW the vectors as totals or components

Drag Screen

Determine the factors that affect the drag force, and observe the relationship between the drag force and the velocity.

COMPARE up to 5 paths

EXPLORE the relationship between drag coefficient and shape

ERASE the paths

ADJUST the altitude

Lab Screen

Explore the effects of adjusting the projectile's parameters, and investigate the influence of gravity.

DRAG the target to the projectile's landing spot

ADJUST the mass & diameter

ADJUST cannon angle in 1° steps

REVIEW initial conditions

INVESTIGATE gravity

PAUSE and step through the motion

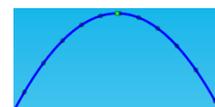
Model Simplifications

- The cannon has crosshairs to mark the initial location of the projectile.
- Changes in air resistance, altitude, and gravity apply immediately and will affect all projectiles mid-flight.
- Vectors are drawn from the center of the image, which may deviate slightly from the center of mass. For better visibility, the vectors do not scale with the zoom level.

- The drag force is modeled using quadratic drag ($F_{\text{drag}} \propto v^2$) which is valid in the high Reynolds number limit appropriate for macroscopic objects like baseballs. Linear drag (Stoke's Law) is only valid in the very low Reynolds number limit (like micron-sized droplets in air).
- The drag coefficient depends on the Reynolds number, which we have assumed to be a constant.
- The drag coefficient also depends on the geometry of the object, so benchmark projectiles (e.g. baseball, car) do not have an adjustable drag coefficient.
- The cross-sectional area of the projectiles is approximated to be a circle, and its area is determined by the diameter.
- Items that stay tangent to the trajectory while in motion (e.g. football, tank shell) are assumed to have the appropriate aerodynamics or weight distribution that leads to this behavior.

Complex Controls

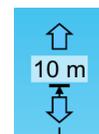
- Up to three projectiles can be queued up if fired while paused.
- The tracer tool can measure the time, range, and height of the projectile at any dot along the path. The black dots are drawn in 0.1s intervals, and the green dot represents the apex.
- The "Custom" projectile on Lab screen allows users to enter precise values for the mass, diameter, gravity, altitude, and drag coefficient. The acceptable range for these values will be displayed at the top of the keypad.



Custom	1 to 5000 kg
Mass	100 kg
Diameter	1 m
Gravity	9.81 m/s ²
<input checked="" type="checkbox"/> Air Resistance	
Altitude	0 m
Drag Coefficient	0.47
	Enter

Insights into Student Use

- Students usually find all the available options in the sim without prompting, like adjusting cannon angle, moving the target, changing the projectile parameters, and turning on vectors.
- The cannon sits on a pedestal with an adjustable height. To cue this behavior, the cannon on the Intro screen starts at 10 m, and has arrows on the height label that will disappear once the cannon's height is adjusted.



Suggestions for Use

Sample Challenge Prompts

- Choose a variable, and design an experiment to determine how it affects the projectile's path.
- Predict how changing the initial conditions will affect the path of the projectile, and explain your reasoning.
- Determine which factors affect the range of the projectile when air resistance is turned on, but have no effect when air resistance is turned off.
- Describe how the behavior of the velocity and acceleration vectors over time, and how they are affected by air resistance.
- Explain why the black dots on the projectile's path are closer together near the top, but further apart when close to the ground.
- Create a situation in which the projectile reaches terminal velocity.

See all published activities for Projectile Motion [here](#).

For more tips on using PhET sims with your students, see [Tips for Using PhET](#).