

Dune Buggy Challenge

Projectile motion lab packet · ramp, table edge, and a moving target

Name _____ Period _____ Date _____

A ball is released on a ramp, rolls to the bottom, runs along the tabletop, and leaves the edge horizontally. While it is in the air, a dune buggy drives across the floor carrying an open cup. Your job is to work out **where the buggy must start** so that the ball lands in the cup. You get one shot per setup, and the cup is 7 cm across — so your answer has to be right to within about 3.5 cm.

Open the simulation at brandoncomella-afk.github.io/physics-sims/dune-buggy-challenge.html. Leave it in Challenge mode — it hides the answer until you ask for it. Do not press Reveal until you have finished Part 3.

Part 1 · The quantities

Every symbol below appears either as a slider in the simulation or as something you will calculate. Distances are in metres for the algebra, even though the sliders read centimetres.

Symbol	Meaning	Where it comes from
h	Release height of the ball above the bottom of the ramp	Slider
θ	Ramp angle from the horizontal	Slider
H	Height of the tabletop above the floor	Slider
c	Height of the cup rim above the floor	Slider
v_b	Speed of the buggy across the floor	Slider
v	Speed of the ball as it leaves the table edge	You calculate
t_{ramp}	Time the ball spends on the ramp	You calculate
t_{fly}	Time the ball spends in the air	You calculate
R	Horizontal distance from the table edge to the landing point	You calculate
D	Distance from the base of the table where the buggy must start	Your prediction

Use $g = 9.81 \text{ m/s}^2$ throughout. Keep four figures in your intermediate steps and round only at the end.

Part 2 · Before you open the simulation

Work these out in symbols first. You will reuse them for every setup, so it is worth getting them right once.

1. A solid sphere of mass m and radius r is released from rest and rolls without slipping down through a vertical drop h . Its moment of inertia is $I = \frac{2}{5}mr^2$, and rolling without slipping means $\omega = v/r$. Starting from conservation of energy, show that the speed at the bottom is $v = \sqrt{(10gh/7)}$.

2. Your answer to question 1 contains neither m nor r . Explain, in one or two sentences, why that had to happen.

3. The ball leaves the table edge moving horizontally. It must arrive at the *rim of the cup*, not the floor. Write an expression for the time of flight t_{fly} in terms of H , c and g . Then say in one sentence why the drop is not simply H .

4. Write an expression for the range R — the horizontal distance from the table edge to the landing point.

5. The buggy travels at constant speed v_b and is released at the instant the ball leaves the table edge. Show that the buggy must start at

$$D = R - v_b t_{\text{fly}}$$

6. Now suppose the buggy is released at the same instant the ball is released *at the top of the ramp*. What changes in the expression above? Write the new version.

Part 3 · A worked example

This one is done for you. Set the sliders to these values in the simulation and check that the numbers match before you go on — it confirms you are reading the sliders correctly.

h	θ	H	c	v_b	Release
30 cm	30°	100 cm	8 cm	0.35 m/s	At the table edge

a Exit speed $v = \sqrt{(10 \times 9.81 \times 0.30 / 7)} = \sqrt{4.204} = 2.05 \text{ m/s}$

b Drop to the rim $H - c = 1.00 - 0.08 = 0.92 \text{ m}$

c Time of flight $t_{\text{fly}} = \sqrt{(2 \times 0.92 / 9.81)} = \sqrt{0.1876} = 0.433 \text{ s}$

d Range $R = 2.05 \times 0.433 = 0.888 \text{ m} = 88.8 \text{ cm}$

e Buggy start $D = 0.888 - 0.35 \times 0.433 = 0.888 - 0.152 = 0.736 \text{ m} = 73.6 \text{ cm}$

Notice that the ramp angle never appeared. It changes how long the ball takes to reach the bottom of the ramp, but not how fast it is going when it gets there — and with the buggy released at the table edge, only the speed matters. Question 12 comes back to this.

Part 4 · Prediction A

Set the sliders to the values below, keep the rolling model and release-at-the-edge timing, and work out where the buggy has to start. Show every step.

h	θ	H	c	v_b	Release
45 cm	40°	120 cm	12 cm	0.50 m/s	At the table edge

Predicted $D =$ _____

Now enter your prediction and fire. Result: **in the cup** ☐ **short by** _____ cm ☐ **long by** _____ cm ☐

Part 5 · Prediction B — a harder release

Change the release setting so the buggy and the ball start *at the same instant*. Now the time the ball spends rolling down the ramp counts too, so you will need the ramp length and the ramp angle. The ball starts from rest and accelerates uniformly down the ramp, so its average speed there is $v/2$.

h	θ	H	c	v_b	Release
25 cm	25°	90 cm	6 cm	0.40 m/s	Together, from the top

Predicted D = _____

7. Work out what D would have been for this same setup if the buggy were released at the table edge instead. How many centimetres apart are the two answers?

Part 6 · Rolling versus ideal

Many textbooks would give the speed at the bottom of the ramp as $\sqrt{2gh}$, which assumes all of the released potential energy becomes forward motion. Switch the model to *Ideal* and redo Prediction A.

8. Ideal exit speed and ideal prediction for D :

9. Take the ratio of the ideal range to the rolling range. Show algebraically that this ratio is the same number for every setup — it does not depend on h , H or c . What is the number, as a percentage?

10. What fraction of the ball's kinetic energy at the bottom of the ramp is rotational rather than translational? Does this fraction depend on h ?

Part 7 · Four of your own

Press **New setup** to randomise the sliders, predict, then fire. Record what you get — including the misses. Use the **Copy data** button if you would rather paste the log into a spreadsheet.

Trial	h (cm)	θ (°)	H (cm)	c (cm)	v_b (m/s)	Predicted D (cm)	Miss (cm)	In the cup?
1								
2								
3								
4								

Part 8 · Analysis

11. Go back to the worked example in Part 3 and redo step (c) as if the cup sat flat on the floor — that is, use the full $H = 1.00$ m instead of 0.92 m. How many centimetres would your landing point be off by? The cup is 7 cm wide. Would you still have caught it?

12. Using the release-at-the-edge timing, change *only* the ramp angle. Predict first, then check in the simulation: does R change? Does D change? Now switch to the together-from-the-top release and answer both again.

13. If you double the release height h , by what factor does the range R change? Justify it from your formula rather than by testing.

14. Turn the buggy speed up. At some point the predicted D goes negative. What would a negative D mean physically, and what would you have to do to the setup to make the shot possible again?

15. This simulation has no air resistance, no friction on the tabletop, and a ball that never slips. Pick the *one* of those you think would matter most in a real classroom version of this lab, and say which way it would push your landing point — short or long.

Extension

For any round object rolling without slipping we can write $I = \beta mr^2$, where β is $\frac{2}{5}$ for a solid sphere, $\frac{2}{3}$ for a hollow sphere, $\frac{1}{2}$ for a solid cylinder and 1 for a hoop.

16. Show that the exit speed for a general β is $v = \sqrt{2gh/(1 + \beta)}$. Then rank the four objects above by how far they would land from the table, and explain the ranking in one sentence without using any algebra.

Adapted from the Dune Buggy Challenge Lab, The Physics Classroom (2009). Simulation: brandoncomella-afk.github.io/physics-sims/dune-buggy-challenge.html