Opposing Cart Fans

When you drop a piece of paper to the ground, it does not accelerate the way a ball or rock would. Air friction opposes the gravitational force and the resulting motion of the paper is different—it may tumble, fall slowly, or float a bit side to side. While the motion can be somewhat unpredictable, it is generally easy to observe that the paper falls more slowly.

How do two opposing forces, acting at the same time, affect the motion of an object? We can investigate this question using two Cart Fans on a single dynamics cart. With one Cart Fan pointed forward and one backward, we can measure the motion of the cart as the two fans turn on and off.

Objectives

- Explore how two forces reinforce or hinder one another, depending on their direction and magnitude.
- Describe mathematically how to treat two forces acting on the same object.

Materials

- ☐ Chromebook™, computer, or mobile device
- ☐ Vernier Graphical Analysis® app
- ☐ (2) Cart Fans
- ☐ Cart Fan mounting plate
- ☐ Dynamics track

Sensor Options

Option 1	**Option 2**
☐ Go Direct® Sensor Cart	☐ Vernier Dynamics Cart ☐ Motion detector or motion encoder receiver ☐ Vernier data-collection interface (if required for your motion detector/encoder)

Pre-Lab

Draw a free-body diagram for an ordinary piece of notebook paper as it falls to the floor. For the vectors that indicate the air friction and gravitational force, be sure to

- Draw the force vectors in the direction they are pushing.
- Indicate the relative strength of the forces by how long you draw the force vectors (i.e., if one force is stronger than the other, its force vector should be longer).

In this investigation, you will attach two Cart Fans to a cart. The fans will be pointing either in the same direction or in opposite directions. How does the free-body diagram for the falling paper compare to a free-body diagram for the dynamics cart?

Investigation

Set up for data collection

1. Launch Graphical Analysis and connect your Go Direct Sensor Cart or Motion Detector/Encoder via Bluetooth® wireless technology:
    a. Click Sensor Data Collection.
    b. Find your sensor cart or motion detector/encoder in the list of available devices and click Connect.
    Tips:
        - The ID is located on the label of your sensor (e.g., sensor cart or motion detector).
        - Ensure the sensor is powered on (red blinking LED) and that Bluetooth is enabled on your device.
    c. Click Done.
2. Set up Graphical Analysis for data collection.
    a. For this experiment, you need to view two graphs: position vs. time and velocity vs. time. If necessary, use View Options, , to display 2 graphs. Click the vertical axis on the second graph and use the Plot Manager to plot velocity vs. time.
    b. Click Mode and change End Collection to 10 seconds.
3. Set up the equipment.
    a. Position the cart at one end of the track.
        - If using a Motion Detector, make sure the cart is on the same end of the track as the Motion Detector but is at least 20 cm away from the detector.
        - If using the Motion Encoder or Go Direct Sensor Cart, click the position meter, and then choose Zero.
    b. Attach two Cart Fans to the cart, both pointing in the forward direction.
    c. Press the Start/Stop buttons to turn on the Cart Fans. The default settings (low thrust, 3 s duration) are good for this experiment.

Investigation Part 1: Equal forces, same direction

4. For this part of the experiment, you will collect position and velocity data for the cart with one, the other, or both Cart Fans on.
    a. With the cart at rest at one end of the track, press the Start/Stop button for one Cart Fan.
    b. Click Collect to start data collection.
    c. When the cart reaches the end of the track, catch it and hold it still until data collection ends.
5. Repeat data collection for two more trials:
    a. The other Cart Fan on
    b. Both Cart Fans on
6. Click the vertical axis label. Use the Plot Manager to turn on an off columns from the data sets to verify that you have three sets of position and velocity data. If necessary, repeat data collection to gather additional data.
    - When the first Cart Fan is on
    - When on the second Cart Fan is on
    - When both Cart Fans are on

Investigation Part 2: Equal forces, opposite directions

7. Reposition the cart at its starting position and press the Thrust/Duration button on both Cart Fans to adjust the thrust to the second level.
8. Flip one Cart Fan around so it points backwards (opposite direction the direction of motion).
9. For this part of the experiment, you want to collect position and velocity data for the cart while both Cart Fans are on.
    a. Press the Start/Stop button on the first Cart Fan (pointing in the direction of motion), wait a split second, then press the Start/Stop button on the second Cart Fan (pointing opposite the direction of motion).
    b. Start data collection. Once the first fan starts, it will push the dynamics cart down the track, unimpeded until the second fan starts. The first fan will turn off before the second fan. For a split second, the second fan will run.
    c. If necessary, catch the cart at the far end and hold it still until data collection ends.
10. Verify that the position and velocity data appear smooth and consistent. If necessary, repeat data collection to gather additional data.

Investigation Part 3: Unequal forces, opposite directions

11. Reposition the cart at its starting position. Press the Thrust/Duration button on the second Cart Fan (backwards facing) to adjust the thrust to the lowest level.
12. For this part of the experiment, you want to collect position and velocity data for the cart while both Cart Fans are on. But this time, the first Cart Fan will exert more thrust than the second Cart Fan.
    a. Press the Start/Stop button on the first Cart Fan (pointing in the direction of motion), wait a split second, and then press the Start/Stop button on the second Cart Fan (pointing opposite the direction of motion).
    b. Start data collection. Once the first fan starts, it will push the dynamics cart down the track, unimpeded until the second fan starts. The first fan will turn off before the second fan. For a split second, the second fan will run.
    c. If necessary, catch the cart at the far end and hold it still until data collection ends.
13. Verify that the position and velocity data appear smooth and consistent. If necessary, repeat data collection to gather additional data.

Analysis

1. On the graph, select the data that represent when the cart was accelerating. Click Graph Options, , and choose Apply Curve fit to apply linear curve fits to the Part 1 velocity-time data. Enter the slope values in the table below.

	Slope (m/s/s)
First Cart Fan on	
Second Cart Fan on	
Both Cart Fans on	

2. The slope of the velocity-time graph is the cart's acceleration. How does the acceleration of the cart change when both fans are on compare to when a single fan is on?
3. Look at the velocity-time graph when both Cart Fans were on, but they were pointing in opposite directions (Part 2). What is the slope of the velocity graph when both fans were on? How would you explain this result?
4. Look at the velocity-time graph when both Cart Fans were on, but the forward-facing Cart Fan had greater thrust (Part 3). What is the slope of the velocity graph when both fans were on? How would you explain this result?
5. In general, how would you explain the effect of multiple Cart Fans acting on the dynamics cart's acceleration?

Extensions

1. Explore additional combinations of Cart Fan thrust level and orientation. Does the measured acceleration fit your explanation from Step 5 in the Analysis?
2. By tilting the dynamics track, you can apply a portion of the gravitational force along the track; the cart will “want” to roll down the incline. Find the angle at which the dynamics cart stays still when one Cart Fan is on its highest thrust level.

Opposing Cart Fans

Compared to using a string with a hanging mass or ramping up a dynamics track, Cart Fans have a great advantage: they provide a simple, easily understandable force. And because students can mount more than one Cart Fan to a single dynamics cart, it is easy for students to explore balanced and unbalanced forces. In this investigation, students do just that.

Target Audience

High school

Time Estimate

45–60 min

Objective(s)

- Explore how two forces reinforce or hinder one another, depending on their direction and magnitude.
- Describe mathematically how to treat two forces acting on the same object.

Prepare for the Lesson

Preparation Instructions

1. The Cart Fan (order code: DTS-CFAN) can be used with Dynamics Cart and Track (order code: DTS) carts or Go Direct® Sensor Carts (order code: GDX-CART). Students with DTS carts should use a motion detector. Students with Go Direct Sensor Carts can use the Sensor Cart's built-in position sensor to perform the investigation.

2. Each lab station will require two fans. The Cart Fan (DTS-CFAN) includes a single fan, with a mounting plate and charging cable. You can provide a second fan by "doubling up" lab stations or purchasing additional fans (Cart Fan Add-on, order code DTS-CFAN-FAN).

3. For additional tips for using the Cart Fan, visit https://www.vernier.com/video/motion-three-ways-experiments-with-the-new-vernier-cart-fan/

   A video demonstration of this experiment with a Sensor Cart begins at 21:30.

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Data Collection and Analysis Tips

1. In order to collect good data in this investigation, the dynamics tracks should be level. Place a dynamics cart in the middle of the track and use the adjustable leveling feet to raise or lower each end so that the cart stays motionless until it's pushed.

2. The Cart Fan has a 2-second countdown between when the Start/Stop button is pressed and the fan turns on. Generally, it is easier to press the Start/Stop button first and then click Collect to start data collection.

3. In this investigation, the velocity graph is generally more helpful in understanding the effect of the two fans on the dynamics cart. Students will see changes in the slope of the velocity curve when the fans turn on and off. Those changes in slope reflect the change in net force on the cart.

4. While the Cart Fans are all built from the same component, no two fans are identical. Thrust levels vary from unit to unit. When using multiple fans to increase the net force on a single cart, as in Part 1, slight variations in thrust are insignificant. But when using multiple fans to show balanced/unbalanced forces, as in Parts 2 and 3, variation from unit to unit will be more obvious. For example, two fans set to the same thrust level and pointed in opposite directions may propel the dynamics cart at a close-to, but not exactly, constant speed.

   If a student group has a pair of particularly mismatched fans, they may need some help interpreting their velocity graphs.

Pre-Lab Responses

Students should draw a free-body diagram like the one shown in Figure 1. The magnitudes of the gravitational force and air friction should be about equal, meaning the vectors should be about the same length.

When two opposing fans are mounted to a dynamics cart, the two opposing forces are similar to the gravitational force and air friction: equal in magnitude but opposite in direction.

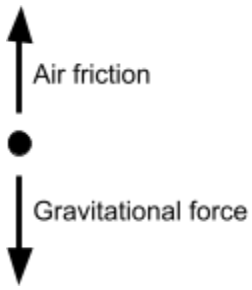

Figure 1

Sample Results

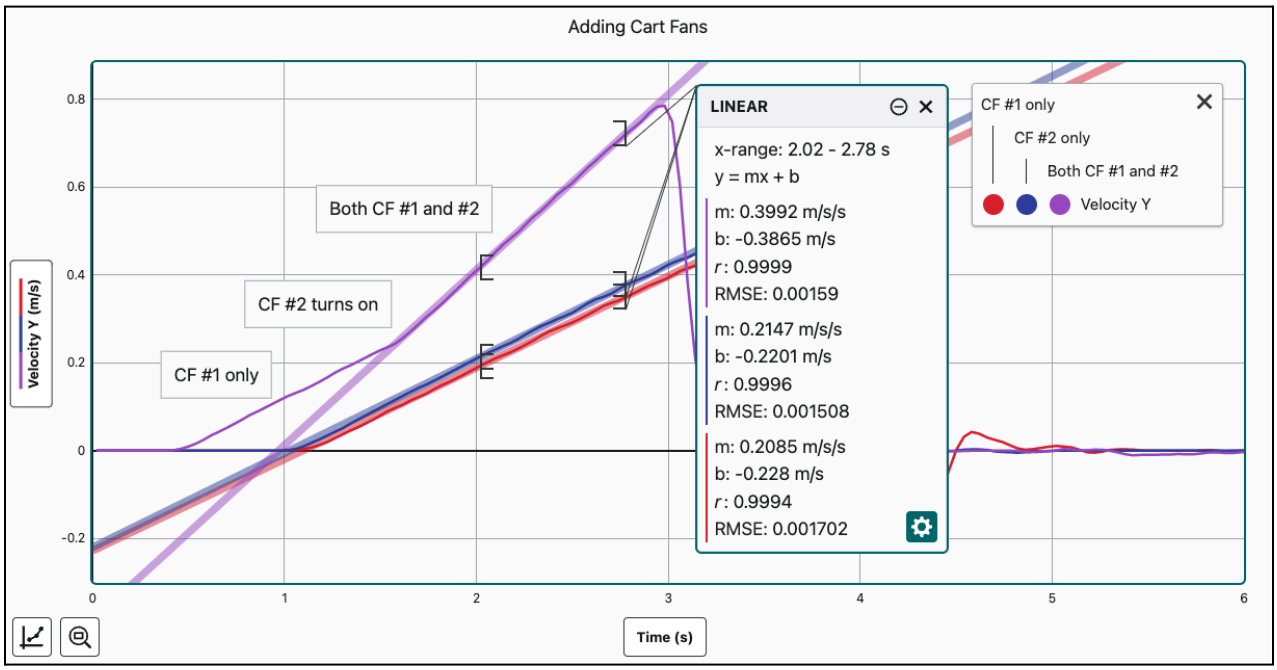

Figure 2 Velocity graphs for two fans pointing in the same direction

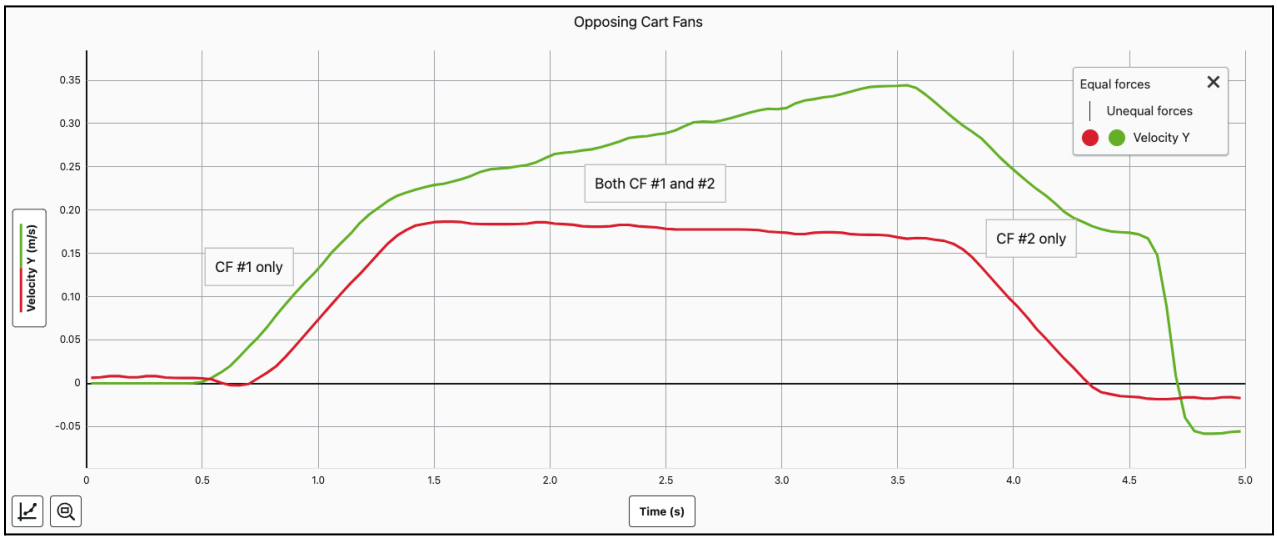

Figure 3 Velocity graphs for two fans pointing in opposite directions

Answers to Analysis Questions

1. For the sample data, the slopes of the velocity-time graph are

	Slope (m/s/s)
First Cart Fan on	0.2085
Second Cart Fan on	0.2147
Both Cart Fans on	0.3992

2. The acceleration of the cart doubled (approximately) when both fans were on.

3. When both fans were on, the slope of the velocity-time graph was –0.0082 m/s/s. This slope or acceleration is very close to zero. In other words, when both fans were on the cart was moving at a constant speed.

4. When both fans were on—but the first fan was on a higher thrust level—the slope of the velocity-time graph was 0.0591 m/s/s. This slope or acceleration is small. In this case, the first fan "overpowers" the second fan and causes the cart to continue accelerating.

5. The thrust from the two fans can either combine together, as they did in Part 1, to generate a larger acceleration. Or they can cancel (or partially cancel) each other out, as they did in Parts 2 and 3.

3D Elements in the Lesson

Science and Engineering Practices	• **Analyzing and interpreting data** [DATA-H1] Analyze data using tools, technologies, and models (e.g., computational, mathematical) in order to make valid and reliable scientific claims. • **Planning and carrying out investigations** [INV-H4] Select appropriate tools to collect, record, analyze, and evaluate data. • **Obtaining, Evaluating, and Communicating Information** [INFO-H5] Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).
Crosscutting Concepts	• **Patterns** PAT-H4 Mathematical representations are needed to identify some patterns. • **Stability and change** SC-H2 Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

Codes for the elements come from *The NSTA ATLAS of the Three Dimensions* (Willard, 2020) and the elements are described in *A Framework for K–12 Science Education* (NRC, 2012).

Performance Expectation(s) from NGSS

This lesson builds towards

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.

[Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object sliding down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.]

NGSS Lead States. (2013). Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press

TEKS

TEKS Physics	4A

Connecting to Students' Cultures and Backgrounds

Student Culture Focus

Connect instruction to students' homes, neighborhoods, communities, and cultures as appropriate, and provide multiple opportunities for students to support their learning with questions and ideas from their own funds of knowledge. For instance, students should use their own funds of knowledge in the pre-lab exercise.

Varied Classroom Discourse Strategies

Help all students make productive contributions to classroom discourse by providing for individual thinking time and small group sharing before whole group discussion.

Multiple Ways to Learn

Provide multiple access points and modalities for students to learn. For instance, students can construct understanding through use of the SEPs using various modalities, including reading both text and diagrams; writing, drawing, and gesturing to develop models; and speaking and listening through argumentation and evidence-based discourse. Provide support for all students to make thinking visible in ways that are less dependent on English language proficiency.