Lesson Title	Fan Carts with Tracker Software
Length of Lesson	1.5 hours
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Subject	Physics
Grade Level	11-12
State Standards	Physics: 1 and 2a
DOK Level	DOK 4
DOK Application	Analyze, Draw Conclusions, and Develop a Logical Argument
National Standards	Physics B
Graduate Research Element	The concepts of force, acceleration, and vectors are ubiquitous in engineering. I use and manipulate vectors and higher order tensors to describe physical quantities involved in my research.

Student Learning Goal:
The students will further their understanding and familiarity in manipulating vectors. This lesson is meant to build on their knowledge of position vectors by introducing the idea of force vectors represented by the fan cart thrust whose components can be altered by changing the fan angle.

State Standards
Physics: 1. Apply inquiry-based and problem-solving processes and skills to scientific investigations.

a) Use current technologies such as CD-ROM, DVD, Internet, and on-line data search to explore current research related to a specific topic.
b) Clarify research questions and design laboratory investigations.
c) Demonstrate the use of scientific inquiry and methods to formulate, conduct, and evaluate laboratory investigations (e.g., hypotheses, experimental design, observations, data analyses, interpretations, theory development).
d) Organize data to construct graphs (e.g., plotting points, labeling x-and y-axis, creating appropriate titles and legends for circle, bar, and line graphs) draw conclusions and make inferences.
e) Evaluate procedures, data and conclusions to critique the scientific validity of research.
f) Formulate and revise scientific explanations and models using logic and evidence (data analysis).
g) Collect, analyze, and draw conclusions from data to create a formal presentation using available technology (e.g., computers, calculators, SmartBoard, CBL's, etc.).

Physics: 2a. Use inquiry to investigate and develop an understanding of kinematics and dynamics of physical bodies.

- Vector and scalar quantities
- Vector problems (solved mathematically and graphically)
- Vector techniques and fee-body diagrams to determine the net force on a body when several forces are acting on it
- Relations among mass, inertia, and weight.

National Science Education Standards of Content 9-12

Physics B: Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship F=ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.

Materials Needed (supplies, hand-outs, resources):

One fan cart per group, scale to weigh fan cart, long track for each fan cart (usually bought alongside the fan cart from the original manufacturer) or long tabletop, force meter or spring scale, video capability (smart phones with email capability are best), some sort of mount for the videoing device to keep it stable, ruler or meter stick as a calibration length, Tracker software, Excel, and computer,

Lesson Performance Task/Assessment:

The students will first weigh their fan cart as well as attach it to the force meter or spring scale to determine the thrust at each fan speed setting (use a string to connect the fan cart with the force meter so that the fan cart's movement is away from the force meter). They will then set up the track as seen in Figure 1. The ruler or meter stick (not shown in the figure) will be used as a calibration length in the Tracker software and should be taped in line along the side of the long track.

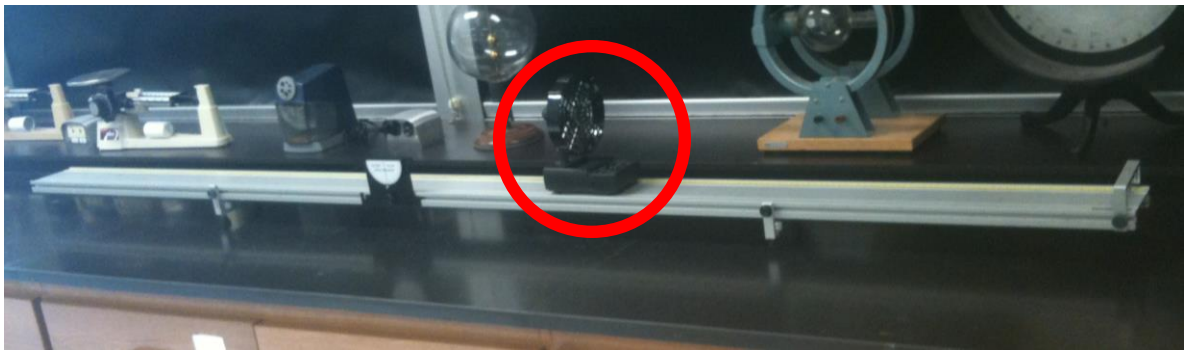

Figure 1. Fan cart sitting on long track, fan cart circled

Make sure that the bumper stop and angle indicator are properly installed on the long track to ensure that the fan cart will not fall off the end of the track and that the track is adequately level. The bumper stop and angle indicator can be seen in Figure 2.

Figure 2. Left: Bumper stop installed at end of track Right: angle indicator

The students will then make four videos of their fan cart traveling down the track. In each of these videos the entire track should be in frame, and the videoing device has to be oriented perpendicular to the track. The fan angle will be varied in each between 0 and 90 degrees. Each group must use 0 degrees as one of their angles, but they are free to choose the remaining three. See Figure 3 for examples of altered fan angles.

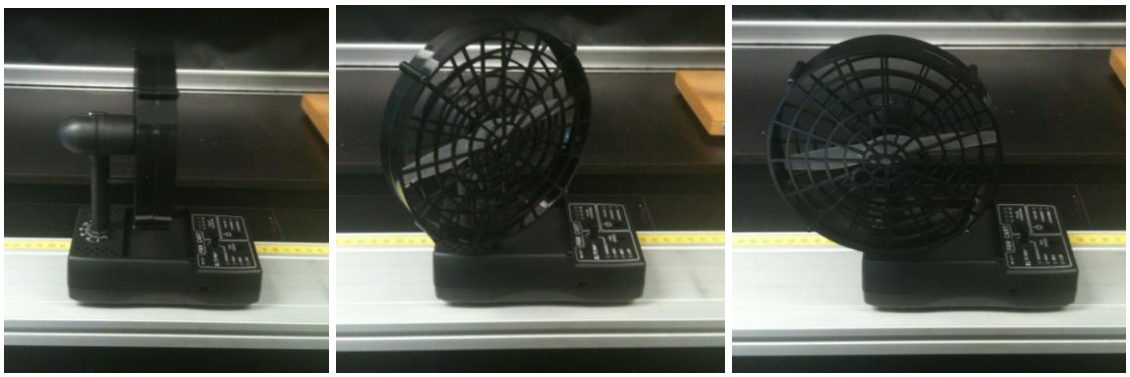

Figure 3. Left to right: fan angle of 0, 45, and 90 degrees

These videos will be imported and analyzed using Tracker to obtain position vs. time plots. The Tracker software is simple to use and includes a step by step example in its help files. It can be downloaded at http://www.cabrillo.edu/~dbrown/tracker/. The data from these plots will then be used in Excel to produce velocity and acceleration vs. time plots for each. They will then use F=ma and vector components to calculate an acceleration for each which they can compare to the acceleration evident in the plots the made. Note that when summing forces, friction and air resistance can be neglected leaving the fan cart thrust as the only force.

The students will then attach the sail in both the forward and backward positions as seen in Figure 4. They will then investigate what happens when the fan cart is turned on in each case. What are their explanations in each case?

Figure 4. Left: sail attached forward, Right: sail attached backward

Lesson Relevance to Performance Task and Students:
The students will further their understanding of vector components.

Anticipatory Set/Capture Interest:
The class will be asked how a propeller produces thrust. After their opinions the instructor will explain basic propeller concepts. The following links might be helpful for those not familiar with the topic:

http://www.explainthatstuff.com/how-propellers-work.html
http://www.pilotfriend.com/training/flight_training/fxd_wing/props.htm

Guided Practice:
The instructor will discuss the lesson procedures and demonstrate how a fan cart operates. The students will then break into groups and perform the lesson.

Independent Practice:
The students will carry out the entirety of the lesson on their own without direct instruction from the instructor. The instructor will move around the room during the lab in order to answer any questions or offer advice if a group is obviously performing the lesson incorrectly.

Remediation and/or Enrichment:
Remediation: Individual IEP

Enrichment: Have the students produce free body diagrams and calculations which could explain the motion of the fan carts with the sail attached.

Check(s) for Understanding:
The acceleration value they computed using Newtonian mechanics should be very close to the value they obtained after plotting acceleration vs. time for each fan angle. Also their explanation of why the forward sail produced better performance should include that the air was turned by the lip of the sail.

Closure:
Following the lab, the instructor will lead a short discussion of why it is so convenient that vectors are broken into components and can be manipulated. The instructor could demonstrate why components are important when using higher order tensors such as the Cauchy stress tensor I use in my solid mechanics research. The fact that the 27 individual pieces of information which make up the stress tensor can be represented using a single variable and relatively easily manipulated allows me and other engineers to describe very complicated physical ideas in a compact and manipulative form.

Here are some provocative questions to ask the class:

- How could you determine the moment produced at the fan motor support?
- If you were designing a fan cart, how could you justify your design using your calculations (engineers don't get to build something and test it to see if it works…predictions must be made using calculations)?
- Can you relate the effect of changing the fan angle to the effect of a plane flying in a crosswind?

Possible Alternate Subject Integrations:
Data acquisition and manipulation

Teacher Notes:
Make sure the students are EXTREMELY careful with the fan carts. They can be very fragile. They can also cause bodily harm if the fan cage somehow becomes detached.