Newton's Laws: Keys to Understanding the Physical World

Activities for the Classroom

Newton's Laws of Motion as Related to Flight

Introduction

Newton's Laws of Motion

I. Any object in motion tends to remain in that same motion unless affected by an external force. Conversely, any object at rest tends to remain at rest unless affected by an external force.
II. The relationship between an object's mass m, its acceleration a, and the applied force F, is F=ma where the direction of the force vector is the same as the direction of the acceleration vector.
III. For every action there is an equal and opposite reaction.

Two of Newton's Laws of Motion appear to be relatively simple and we hear many people quote them and misquote them. Students at this age will likely be able to readily grasp Newton's first and third laws because these are well within their experiences. The second law tends to be more complex because it requires background knowledge that most students will yet not have. In fact, most adults shy away from this one, because of the vocabulary used.

The first law deals with inertia, which is the tendency of objects to stay put unless something moves them or, conversely, to continue moving unless something slows them down. We feel inertia in a car every time the car speeds up or slows down. The more rapidly the car changes its speed, the more noticeable the inertia is. Our bodies tend to stay still as a car starts forward, so we feel pressed into the seat. Conversely, when a car stops rapidly, our bodies tend to continue forward. This is the reason for seat belts. Inertia affects planes as well. Since planes are objects, it takes some force to get them moving and there are other forces, gravity and air friction (called drag) that work to make them not move the way we want them to move. Friction and gravity are the reasons why most objects don't go moving about without a lot of push. Thank heavens, for if they did, your refrigerator could end up in your bedroom in the middle of the night. Wait, maybe that's not a bad thing . . .

The third law is familiar to anyone who has seen a rocket take off or who has let a full balloon lose before tying the end shut. For every action (rocket/balloon blast from the tail) there is a reaction (rocket/balloon moves forward). With planes there are a variety of ways to produce motion. Two motions we want from a plane are lift (rising away from the ground and staying above it) and thrust (moving forward). We use Newton's third law of motion to make both happen. In fact we balance the forces to achieve control of the plane so that, unlike the balloon, the plane goes where we want it to go.

Now we come to the second law. Understanding the relationship between mass, acceleration and force is a challenge for most adults. As a prerequisite, it requires an understanding of mass (often confused with weight), knowing what is meant by acceleration (often confused with velocity or speed) and knowing what is really meant by force (often confused with energy or motion). For this reason, while some students may be able to grasp the relationship among these three as explained in Newton's second law, most students will gain the level of understanding that they need by just being able to physically explore the relationship among mass, acceleration and force. The goal is for students to be able to apply their knowledge to the design of objects that fly even if they cannot fully explain Newton's second law of motion. In high school classes, Newton's second law of motion is taught using one-dimensional collisions (two objects of different masses smacking into each other to see which one bounces back and how far). They then go on to apply this relationship in different ways, carefully measuring each of the three factors.

While later elementary grade students and early middle school students should not be expected to completely understand the concepts or the relationship described in the second law, it's important to use the correct vocabulary when discussing the concepts. While there are many web sites that address Newton's Laws of Motion, many of them are either complex or have erroneous information. Some good web sites that explain Newton's Laws of Motion in fairly simple terms are:

The Physics Classroom
http://www.physicsclassroom.com/Class/newtlaws/newtltoc.html

Science Master
www.sciencemaster.com/jump/physical/newton_law.php

Beyond Books
http://www.beyondbooks.com/psc91/4.asp

Flight
While getting something up the in air is not so difficult, being able to keep it up there for as long as you want and making it go where you want it to go is much harder. Anyone can throw an object up into the air, or jump up into the air themselves, but the person or the object always comes back down immediately. Sustained flight has been a goal that humankind has sought for millennia, and only in the last hundred years or so achieved. Keeping something in the air requires that the force pulling the object back to the ground (gravity) be constantly balanced by another force that keeps it off the ground.

For this reason, a prerequisite to understanding flight is helping students understand balanced forces. Balancing the force of gravity makes an object

stay in the air. A hot air balloon balances the lighter air inside it against the heavier air outside of it to counteract the pull of gravity. Unfortunately, other factors affect the movement of a balloon, and it must go, literally, where the wind takes it. Someone got the idea to put propellers on a balloon full of light gas and, voila, the blimp was born. Unfortunately, it's a large vehicle that carries a small payload rather slowly and is really just a novelty good for advertising and sightseeing. A kite uses the wind itself to counterbalance gravity, but must stay tethered to one location. Kites are also dependent upon the movement of air (wind) to stay aloft. On the other hand, an airplane travels quickly, has more self-direction and carries a fair amount of payload. But just how planes counterbalance gravity and the friction of the air is complex and took many years for humans to figure out. Students can view a video on Wilbur and Orville Wright to see some of the problems the brothers encountered in trying, basically, to get a fancy kite with one of them in it to fly by itself without any wind. The video is available from The History Channel web site under the title, Modern Marvels: The Technology of Kitty Hawk, Arts and Entertainment Network, The History Channel (AAE-43923).

Scholars will need to begin to explore how ailerons and flaps work on the tail and wings of an airplane. Some excellent web sites that explain the forces that are used to counterbalance gravity to get a heavier-than-air craft to stay off the ground are:

The Octave-Chanute Aerospace Museum
http://www.aeromuseum.org/Education/Lessons/HowPlaneFly/HowPlaneFly.html

NASA's Observatorium
http://observe.arc.nasa.gov/nasa/exhibits/planes/planes_0.html

Aeronautics and Learning Laboratory for Science, Technology, and Research (ALLSTAR)
http://www.allstar.fiu.edu/aero/flight40.htm

Airline Owners and Pilots Association (OAPA) elementary student web page with free downloadable booklet for students
http://www.aopa.org/learntofly/apple/apple_request.cfm#elementary_students

Science Inquiry and Investigation
The following elements are important to developing and conducting what is known as a "well-designed investigation."

Control of variables (fair test): a science investigation always tries to match something that happens with the effect it produces and to find out what the relationship is between the cause and the effect. "What will happen when a ball

is rolled downhill on an incline?" is a seemingly simple question, but a lot of factors, known as variables, can affect how fast and how far the ball rolls (angle of the incline, surface of the incline and the floor, mass (weight) of the ball, height at which it is placed on the incline, force with which the ball is pushed as it starts, etc.) In getting something to fly, many more variables are at play than with a rolling ball. In order for students to be able to explain what makes something fly well, they must be able to isolate and test one variable at a time. If, for example, in the rolling ball investigation we change the angle of the incline at the same time we move the ball further up the incline, then the ball will move differently, but we don't know exactly how each change affected it. In order to find out what effect each variable has on results, students have to learn to change only one variable at a time in a structured way. With upper grade elementary students, especially bright ones, this can seem tedious and they will want to rush through the investigations. Reinforcing the idea of a "Fair Test," one in which only one thing at a time is changed, will give them more advanced skills in science that will be useful later on in school and in life.

Multiple trials: In almost any science investigation, there are variables that are hard to control. In rolling a ball down an incline, things like how carefully it is let go, or whether the ball rolls straight down the incline or off to one side or another can have an effect on the outcome. Professional scientists almost always repeat their tests (trials) at the very least three times, and, in medical work, usually ten times or more, with all variables unchanged. In this way, scientists get an average result that is likely to be the way the result will turn out almost all the time. To students, at first it seems redundant, and they resist doing multiple trials each time they change a variable. However, it is an important habit that should be expected of them and will also benefit them later on in science.

Recording and charting data: It is easy to lose track of what the results were when there are so many variables to change, as is the case in many investigations into flight. It is important to encourage data record keeping throughout the module and use of data to support statements that students make about the outcome of an investigation. Placing these results in a prominent place in the home reinforces how important you think they are.

Scientists recognize that collecting and managing data is more than can be done in one's head. Good scientists take meticulous notes and record each trial carefully. A mistake in data can lead to a wrong conclusion. In addition, scientists recognize that graphs (which are called charts in the science community) can provide a "picture" of the data that shows a trend or pattern.

Trends and patterns are what scientists are always looking for, because a trend or pattern can be evidence of a true cause and effect relationship. If you had

the opportunity to view the Wright Brothers video, students learned how the brothers found out that data they were using from another scientist was incorrect and that this had caused their design to fail.

A good web site that explains the process of student inquiry and a well-designed investigation as well as the Student Inquiry Project is: *http://www.mcps.k12.md.us/curriculum/science/instr/inqprojs.htm*

Overview

Introduce the idea of balanced forces by having your students experiement with simple balanced forces, such as a balance beam with weights, and progress to making an object become airborne by balancing the four forces at work in flight (gravity, lift, thrust and drag).

The essential questions explored are:

- What are the ways we get objects to go up in the air by themselves?
- How are balanced forces, as described by Newton's laws of motion, used to get things to fly?
- How does a well-designed investigation help scientists to improve objects that fly?
- How do scientists learn from each other?

As you try activities with your students, keep in mind these two major concepts– balanced forces and a well-designed investigation. More complete definitions of these concepts are found in the information included here. Students often wish to move quickly through tests and trials without stopping to write down their results. Introduce students on how to conduct multiple trials, record data from each trial in writing, repeat each trial for accuracy, and look for patterns in the results. This helps solidify good science habits that will be needed for lab work they will do later on in school. As you do activities with your students, you will need to decide at what point it is appropriate to follow strict scientific methods and when it is time to just have some fun. If your students do record the results in writing or on a graph, placing the charted data in a prominent place, in the classroom, reinforces its importance and your pride in their work.

Access to the internet will provide your students with a window into some excellent web sites that explain flight. It will also put you in touch with resources that you can use with your students as well as places to visit that will expand their knowledge of flight. Some recommended web sites are listed here in this material.

Consider performing the following science explorations:

- Developing a Fair Test – in which students learn the importance of changing only one variable at a time in an investigation by designing changes.
- Exploring inertia – in which students learn about Newton's First Law and how objects require force to start moving or speed up as well as to stop moving or slow down.
- Balancing forces – in which students explore the balance of gravitational forces with a balance beam.

Suggested Activities

People and Places to Visit
Most towns have a local small plane airport and a telephone call to that airport will likely turn up a group of amateur pilots who want to encourage young people to learn to fly. Larger airports will be less likely to have such opportunities, although visiting them to observe planes taking off and landing can be rewarding. Here is a sampling of web sites for amateur pilot groups:

http://www.aopa.org/learntofly/apple/apple_request.cfm#elementary_students (Aircraft Owners and Pilots Association, APPLE: American Pilots Participating in Local Education project) There is a free, downloadable activity booklet on flight for elementary students on this page (PDF for Acrobat Reader).

http://www.wingsonline.com/links.html#groups (locate local pilot associations)

Some cities have aerospace museums. Places like Washington, D.C. or Dayton, Ohio have notable museums dedicated to flight. In addition, local hobby shops usually have connections to model airplane and rocket clubs. These are great next steps in extending your child's understanding of flight.

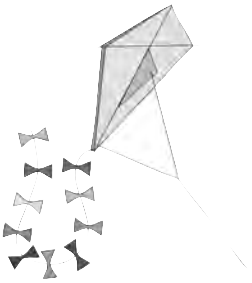
Reading
Scientists read all the time. In fact most scientists will tell you that reading and writing are about 80% of their work, with the other twenty percent being their lab or field investigations. Scientists read published papers and books about what other scientists have learned from their experiments, including scientists going back in history. From this information they get ideas and form questions for the experiments they want to try.

As students read about flight, they will form questions in their minds about some things that they would like to try out. Encourage your child to read about flight and to connect the information to their investigations. Visit a local book store, and ask for help finding books on flight that are at the right reading level for your child. Also consider novels, stories and biographies about flight. Many of these contain valuable factual information and can inspire children.

Kites
Kites can be purchased or made. They range from simple to complex shapes and vary in cost accordingly. Kites work best in a mild breeze, a steady 5 – 10 miles per hour is best. Wind above 15 miles per hour will prove challenging and can destroy a homemade kite that took hours to build. When flying a kite, go to a local park or ball field and be aware of any trees or power lines nearby. Most kites use inexpensive kite string; however, more complex or larger models require lightweight monofilament (fishing) line (usually 4 lb test or lighter).

You may wish to try some commercial models first. Include your students in choosing the model, asking them to use what they have learned about flight and balanced forces to make the selection. Kites that have dual controls can make the flight more interesting and challenging. Keep in mind that until about two years before their famous flight, the Wright Brothers took turns traveling aloft at Kitty Hawk on huge airplane shaped kites held in place by several men. They used these kites to explore the designs that eventually led to powered flight.

Designing and building kites takes time, but can be quite rewarding. After working with a commercial kite, you and your students may want to try to modify that design, or to come up with one of your own. There are also several designs found on internet web sites that include materials needed and directions. The American Kite Flyers Association, *http://www.aka.kite.org/* a non-profit group, is a good starting place, but a simple web search using the keyword, "kite" will turn up a plethora of good sites, commercial and non-commercial. One particularly good site, by Leslie Hunt, is *http://www.inquiry.net/outdoor/spring/kites/making.htm*. This site gives directions for making 25 different kites and has a section just for parents.



Glossary of Terms Used in Flight Investigations

Note that these definitions are specific to the study of flight. Many words on this list have additional meanings.

Aerodynamic – having to do with the ability to fly

Ailerons – Ailerons are the outward movable sections of an airplane's wings. They move in opposite directions (if one goes up, the other goes down). They are used in making turns, and they control movement around the longitudinal axis (imagine a line through the airplane from the nose to the tail).

Airplane – An airplane is a vehicle heavier than air, powered by an engine, which travels through the air via the forces of lift and thrust.

Air pressure – the pressure exerted by air on an object

Balance – equal forces applied toward each other in exactly opposite directions; typically, when forces are in balance, no movement occurs

Chart – sometimes referred to as a graph: a chart can also include a data table from which the graph is made

Cockpit – In general aviation airplanes (all except those operated by airlines and the military) the cockpit is usually the space in the fuselage for the pilot and passengers; in some aircraft it is just the pilot's compartment.

Conclusion – a general statement of cause and effect based on the results of an investigation

Drag – the effect of air friction on a flying object as it moves through the air; drag is balanced by thrust – the forward force moving the object

Flaps – Flaps are the movable sections of an airplane's wings that are closest to the fuselage. They move in the same direction on both wings at the same time, and enable the airplane to fly more slowly.

Elevator – The elevator is the movable horizontal section of the tail of a plane that causes the plane to move up and down the data indicate that as the angle of the ramp becomes steeper, the ball will roll farther)

Data – specific information gathered during an investigation or experiment; numerical data requires some form of measurement

Data table – a grid on paper in which the data from an investigation or experiment is kept

Fair test – a test in which only one variable is changed at a time

Flight – movement away from gravity

Flight path – an imaginary line showing where a flying object went during a flight

Force – a push or pull in one direction

Friction – the resistance to forward motion as an object moves through the air or along a surface

Fuselage – The fuselage is the central body portion of an airplane, designed to accommodate the pilot/crew and the passengers and/or cargo.

Glide – move through the air without continuous power but with enough air resistance to not drop straight to the ground

Graph – sometimes called a chart, in science investigations a graph shows the numerical relationship between a cause and the effect (e.g. the distance a ball travels compared to the angle of a ramp down which it is rolled); graphs are plotted points within two axes (perpendicular lines)

Gravity – a natural force that "pulls" objects toward the Earth or other object in space

Horizontal Stabilizer – The horizontal stabilizer is the horizontal surface at the rear of the fuselage designed to balance the airplane.

Hypothesis – a prediction based on background knowledge and data; hypotheses generally describe the expected results of an investigation in terms of the data that will be collected

Inertia – the tendency of an object that is not moving to stay still and of an object that is moving to continue moving

Inquiry – seeking answers to a question; curiosity

Investigation – looking for a cause and effect relationship by making changes in the cause and collecting data about the effect these changes make happen

Landing Gear – A landing gear is underneath the airplane and supports it while on the ground. A landing gear usually includes a wheel and tire.

Lift – movement or force opposite the pull of gravity

Mass – the amount of matter in an object; mass is independent from weight (e.g. an object floating in space still has mass that requires a certain amount of force to move)

Motion – the change of an object's location

Prediction – description in advance of what effect will probably occur in response to a specific action (cause)

Procedure – step by step directions to complete a science investigation, including a description of all materials being used

Propeller – A propeller is a rotating blade on the front of the airplane. The engine turns the propeller, which pulls the airplane through the air.

Reaction - movement or force that occurs opposite to and as the result of another force

Rudder – The rudder is the movable vertical section of the tail that controls lateral (side-to-side) movement. When the rudder moves one direction, the aircraft nose moves the same direction, while the tail moves in the opposite direction.

Testable question – a question that can be answered by a well-designed science investigation; testable questions are specific to the investigation (e.g. How is the flight of the plane affected by making the wings longer?)

Thrust – the force that makes a plane or rocket move forward

Variable – a single change of any feature of a flying object (e.g. the length of the wings); variables are changed one at a time so that the effect of the single change can be measured separate from any other changes

Weight – the effect of gravity on the mass of an object (measured by how hard the object is being pulled toward the earth)

Well-Designed Investigation – a science investigation that is based on a testable question and a prediction (or hypothesis) and in which all variables are carefully controlled, data is carefully collected and recorded and the conclusion is based on the data

Wings – Wings are the parts of airplanes that provide lift and support the entire weight of the aircraft and its contents while in flight.

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