Strandbeest: An early version of kinetic artist Theo Jansen's wind-powered sculptures that walk on sandy beaches.

Engineering: Using Newton's Laws of Motion

Gregory L. Vogt, EdD, Barbara Z. Tharp, MS, Michael T. Vu, MS, and Nancy P. Moreno, PhD.

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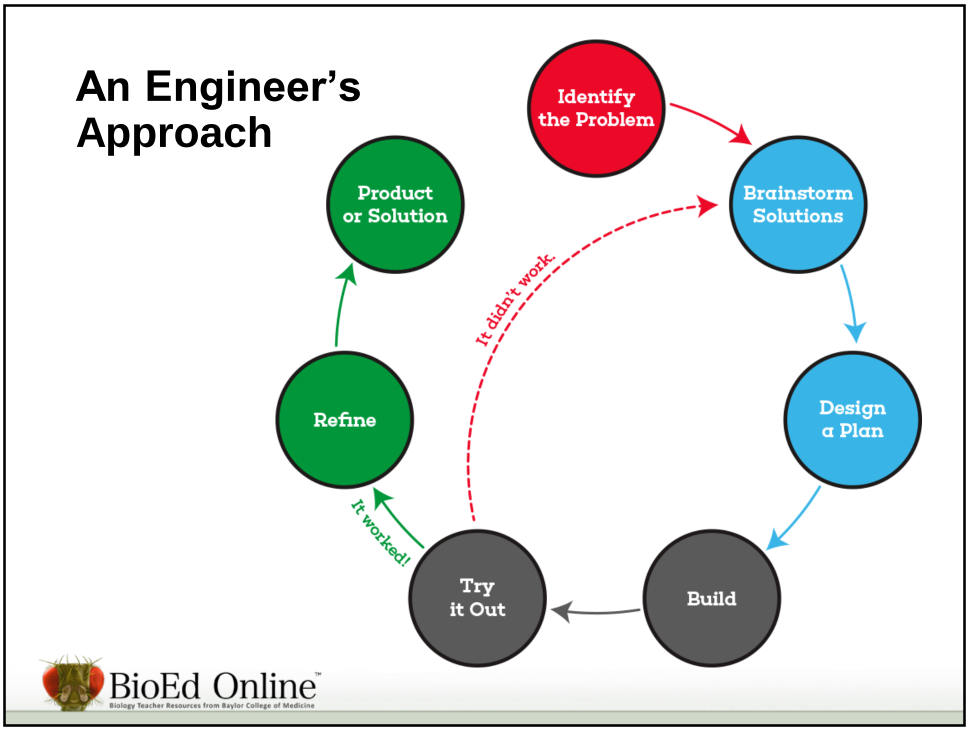
Image Reference

http://commons.wikimedia.org/wiki/Category:Strandbeesten#mediaviewer/File:Strandbeesten_%2814884146284%29.jpg

Theo Jansen: Strandbeest Evolution (video)
http://www.youtube.com/watch?v=MYGJ9jrbpvg

Key Words

physical science, physics, engineering, design, STEM, acceleration, drag, f=ma, flight, force, gravity, kinetic energy, lift, mass, mechanical energy, motion, Newton's Laws, Laws of Motion, physical energy, potential energy, thrust, launch angle, airfoil, ballista, boomerang, catapult, glider, kinetic sculpture, kinetic art, onager, projectile, race car, rocket car, roller coaster, slingshot, trebuchet, wing



An Engineer's Approach

Engineers work with materials to solve problems. Some build bridges across rivers. Others design structures to support heavy loads under many different conditions. Still others design roads over mountain passes and tunnels through mountains.

There are many kinds of engineers: civil, biological, structural, geomechanical, municipal, biomaterials, mechanical, chemical, computer, agricultural, climate, and even laptop carrier engineers.

All engineers follow similar processes as they build and test products or solve problems.

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Image Reference
Graphic by M.S. Young © Baylor College of Medicine.

Key Words
physical science, physics, STEM, engineering, engineering process

Engineering Flight

- Aeronautical engineers must account for several factors when designing a new airplane: lift, weight, thrust and drag. These are called the four forces of flight.
- Lift is the force that enables an airplane to get off the ground. Usually, it is generated by the shape of the wings.

Individual civil French jet AOK Spacejet (closed wing design) at the 2013 Paris Air Show.

Engineering Flight

Airplanes come in many sizes and shapes. Most have a body, one or more sets of wings, a tail section and one or more engines. As long as the plane achieves flight, almost anything goes!

In most planes, lift is generated by the shape of the wings. As a plane moves forward, its wings push air downward. The downward push is known as an “action force.” Simultaneously, the airplane experiences an equal and opposite “reaction force” that pushes it up. Aeronautical engineers call this reaction force “lift.”

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Image Reference

AOK Spacejet courtesy of Tangopaso. Public domain.
http://commons.wikimedia.org/wiki/File:AOK_Spacejet_at_Paris_Air_Show_2013.jpg

Key Words

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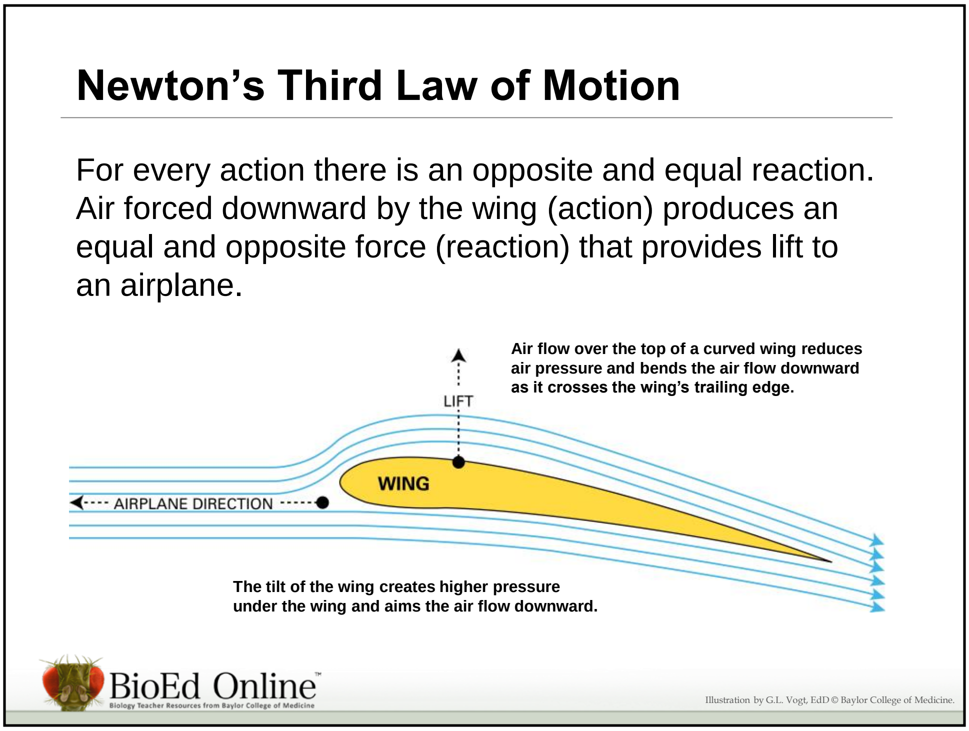

Newton's Third Law of Motion

Most airplane wings are curved on top, flat on the bottom and tilted slightly downward towards the back. The forward edge of the upper surface is rounded, while the backward edge of an airplane wing is gently sloped.

As a plane moves forward, some air moves above its wings and some flows beneath the wings. Because the upper surface is curved, air pressure over the wing is reduced by the airflow. This causes the air to bend downward as it passes the wing's trailing edge, producing a downward force. At the same time, air beneath the wing also is pushed downward by the slightly tilted underside. The downward force produced by the upper and lower wing surfaces creates the opposite and equal force that lifts the plane off the ground.

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Illustration by G.L. Vogt, EdD © Baylor College of Medicine.

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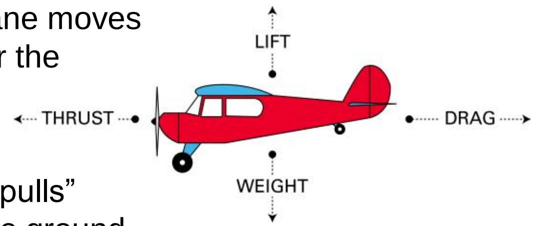
Four Forces of Flight

- The faster an airplane moves forward, the greater the lift produced.
- Weight opposes lift. Earth's gravity "pulls" the plane toward the ground.
- Thrust is the forward force created by the propellers or engines as they blow air or exhaust backward to propel the plane.
- Drag (friction with the air while a plane moves forward) opposes thrust.



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Four Forces of Flight

The faster an airplane moves forward, the greater the lift produced. This is why an airplane accelerates on the runway. When speed and lift have increased to sufficient levels, the plane will become airborne. Conversely, a plane coming in for a landing must be slowed to reduce lift. To compensate for the lower air speed, the pilot tilts segments of the wings downward, thereby pushing more air from under the wings and maintaining sufficient lift to prevent the plane from falling out of the sky.

A second force, weight, opposes lift. Weight is the measure of gravity's effect on the airplane's mass. Earth's gravity "pulls" the plane down toward the ground. To overcome the force of gravity and achieve flight, an airplane must generate more lift than the total weight of the plane, its fuel, and all its contents. If an airplane loses its lift, weight (gravity) causes it to come crashing down.

The other two forces of flight are thrust and drag. Thrust is the forward force created by the propellers or jet or rocket engines as they blow air or exhaust backward to propel the plane. Drag—friction with the air while a plane is moving forward—works in the opposite direction. To fly forward, an airplane must produce thrust greater than the forces of drag impeding it.

Aeronautical engineers try to streamline their airplane designs so that planes cut through the air smoothly. A plane with a lot of drag will not be very efficient. As long as lift is greater than weight and thrust is greater than drag, any shape of airplane will fly.

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Boomerangs: Spinning Wings

The returning boomerang was raised to a high art by the Australian Aborigines. It was used for hunting, and as a battle club, musical instrument and even fire-starter. Shown above are Aboriginal boomerangs in the rain forest near Cairns, Australia.

- A boomerang is basically a rotating wing, curved like an airfoil.
- Non-returning boomerangs are straight. Returning boomerangs can have many shapes.
- Large boomerangs with open designs tend to travel furthest, while smaller boomerangs with tighter shapes and extra wings tend to follow shorter paths.

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Boomerangs: Spinning Wings

Most students may envision boomerangs as wooden throwing sticks, but these fascinating flying devices can be made of many different materials, including metal, plastic and even paper. Some boomerangs are designed to return, but others do not. Both tools have been used for millennia.

The non-returning boomerang goes back to the Stone Age. Used as a throwing stick for hunting, it was shaped to travel long distances on a very straight flight path. Versions of the non-returning boomerang were used in Europe, Australia and Egypt, and among some western Native American tribes.

The returning boomerang was raised to a high art by the Australian Aborigines. It was used for hunting, and as a battle club, musical instrument and even fire-starter. Hunters would throw returning boomerangs near roosting birds, seeking to scare them into flight so they could be caught in nets. Hunters also would throw boomerangs through flocks of flying birds, hoping to clip a wing and bring down dinner.

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Image Reference

Aboriginal boomerangs © Guillaume Blanchard. CC-BY-SA 1.0. http://commons.wikimedia.org/wiki/File:Australia_Cairns_Boomerang.jpg

Key Words

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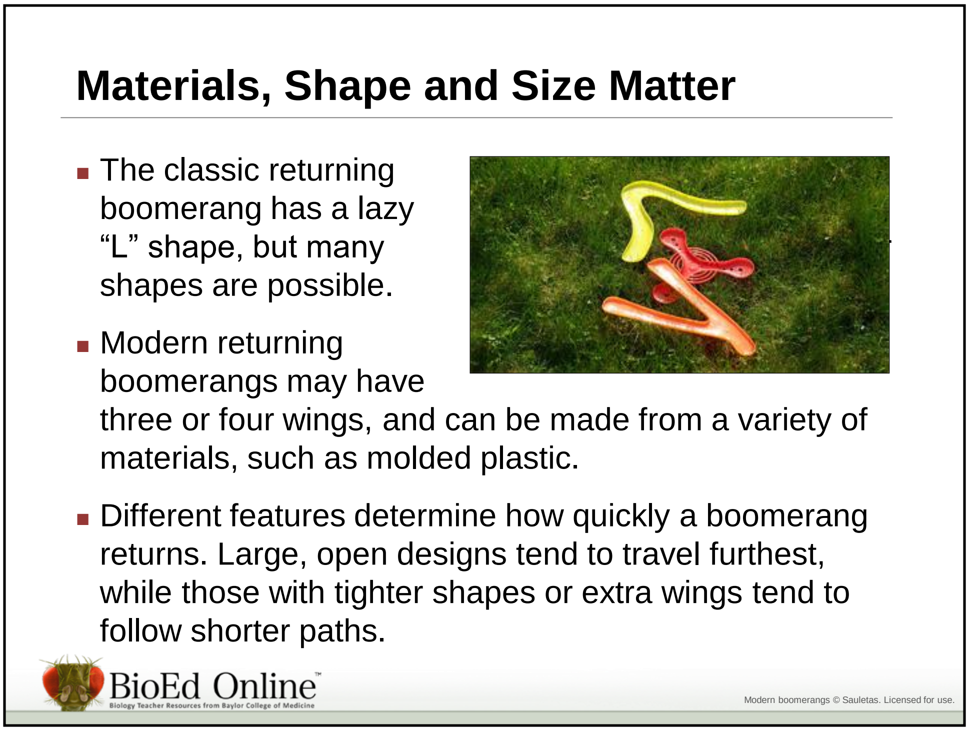

Materials, Shape and Size Matter

Several physical processes make a returning boomerang work: aerodynamic lift, gyroscopic precession, drag and gravity.

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Image Reference

Modern boomerangs © Sauletas. Licensed for use.

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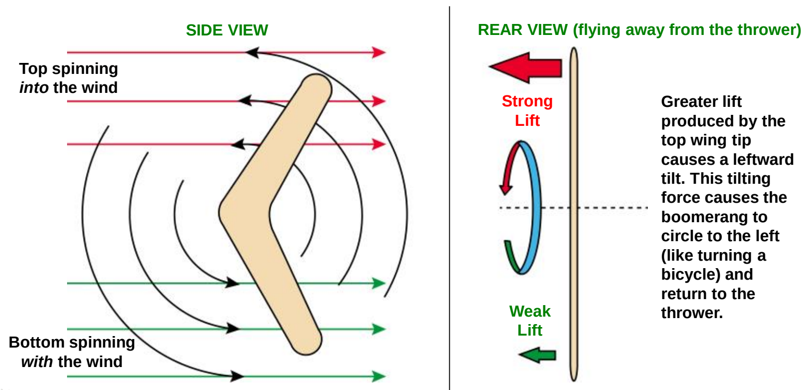
Lift and Air Speed

The net air speed of the top wing tip (spinning *into* the wind) is greater than the net air speed of the bottom wing tip (spinning *with* the wind).



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Lift and Air Speed

The forces influencing the flight of a boomerang are similar to the gyroscopic effect that keeps a bicycle upright and stable. To turn a bike, the rider merely tilts to one side or the other. This puts a sideways force on the spinning wheels, causing them to turn in the direction of the rider's lean.

The leaning force on the boomerang is caused by an imbalance in lift between the top and bottom wings as they spin forward through the air. The top wing moves against the airflow and produces a strong sideways lift. Simultaneously, the lower wing moves in the same direction as the airflow, which produces a weaker sideways lift.

The difference in lifting forces causes the boomerang to lean sideways. As with a bicycle wheel, the gyroscopic effect of the boomerang lean causes the boomerang to turn in a circle and return to the thrower.

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How to Throw a Boomerang

Young woman in Australia learning how to throw a classic boomerang.

- A boomerang should be thrown in a vertical plane, tossed slightly upward, with a rapid spin.
- The rapid spinning of a boomerang's wing tips produces a strong lifting force.

How to Throw a Boomerang

The proper way to throw a boomerang is in a vertical plane, tossed slightly upward and with a rapid spin. The spin produces a gyroscopic effect that keeps the boomerang moving along its plane without flipping and fluttering. As the boomerang travels forward, the rapid spinning of its wing tips produces a strong lifting force. Because the boomerang is oriented vertically, the lift pushes sideways, causing the boomerang to turn and return to the thrower.

Reference

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Image Reference

Boomerang training © Small World Journeys: Educational Adventures in

Australia. Used with permission. www.smallworldjourneys.com.au

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Launch Angle and Target Distance

- There is a relationship between launch angle and flight distance.
- To achieve maximum distance, a javelin, rocket, etc. must be launched at the optimum angle and speed.

Bregje Crolla in competition, 2010. A javelin thrower must propel the javelin overhand, over his or her shoulder or upper arm, toward a sector covering an angle of 28.96 degrees extending outward from the arc at the end of the runway.

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Launch Angle and Target Distance

Through experience, we learn to throw or hit a ball at the correct angle and speed to reach our target.

Of course, many sports involve throwing or hitting balls or other implements as far and accurately as possible. In baseball, a center fielder has to pick up a ground ball and throw it at the right angle and speed to the catcher waiting at home plate. A quarterback must be able to pass the football to a receiver running full speed toward the end zone. A golfer selects a driver with the right angle on the club face to launch a golf ball toward the hole. Athletes who throw javelins try to throw a javelin farther than their competitors.

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Image Reference

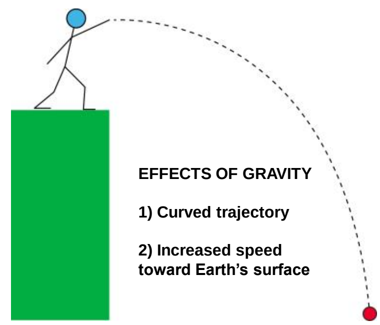
Bregje Crolla © Erik van Leeuwen. CC-BY-SA 3.0.
http://commons.wikimedia.org/wiki/File:20100619_Bregje_Crolla_EK_Landenteams_dag1.jpg

Key Words

physical science, physics, engineering, design, STEM, acceleration, drag, f=ma, flight, force, gravity, kinetic energy, lift, mass, mechanical energy, motion, Newton's Laws, physical energy, potential energy, thrust, launch angle, javelin, projectile

Compensating for Gravity

- Earth's gravity bends the trajectory of objects thrown horizontally across its surface downward. It also causes the falling objects to accelerate.
- To compensate for the effects of gravity, an object thrown a long distance must be aimed upward so that its curved path ends at the target.



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Compensating for Gravity

If a ball is thrown horizontally from a tall structure, it will be falling at a rate of 9.8 meters per second after one second. At the end of two seconds, it will be traveling 19.6 meters per second. After three seconds, it will be traveling at a speed of 29.4 meters per second.

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Catapults: Powering Projectiles

- Catapults harness physical and mechanical energy to launch projectiles.
- There are many types catapults, including slingshots, hurling devices used in castle sieges, and steam-powered machines that launch planes off aircraft carriers.

NOAA uses a pneumatic catapult to launch the ScanEagle, an unmanned monitoring aircraft.

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ScanEagle courtesy of NOAA\Erin Moreland.

Catapults: Powering Projectiles

Throughout history, warriors and hunters have developed weapons to aid in their battles and pursuit of food. War machines, in particular, have been a focus of technological innovation. As warfare grew more complex, so did weapons. Javelins and boomerangs were tools for both hunting and war. Another device, the atlatl, extended the throwing arm and greatly increased throwing force. Eventually, catapults were invented. Catapults harness physical and/or mechanical energy to launch projectiles. Examples of catapults include slingshots, hurling devices used in castle sieges, and even steam-powered machines that launch airplanes off aircraft carriers.

Later, more powerful catapults were created to launch large stones, biological weapons (e.g., a hornets' nest), incendiary bombs, and even terror projectiles like the heads of captured warriors! There are many catapult varieties, and each has a different purpose.

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ScanEagle courtesy of NOAA\Erin Moreland.
http://www.afsc.noaa.gov/nmml/polar/research/images/UAStestflight.jpg

Key Words

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Ballista: A Giant Crossbow

Catapult technology, first thought to have been developed in Greece as early as 50 BCE, was initially used to increase the range and penetration of arrows. When released, a catapult would shoot a large arrow toward the enemy. It also shot javelins, fire arrows and other sharp objects at opponents.

Shown above is a replica of a Roman ballista near the ancient ruins of Gamla in Israel.

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Onager: Mobile Catapults

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Onagers courtesy of Karelj. Public domain.

Onagers: Mobile Catapults

Later, more powerful catapults were able to launch large stones, biological weapons (e.g., a hornets' nest), incendiary bombs, and even terror projectiles like the heads of the captured! The history of catapults includes a large variety of designs, each with a different purpose.

These mobile Medieval Onager catapults, each with a fixed bowl on an arm, were capable of hurling several projectiles at one time. Twisted ropes (torsion) provided power to Onager catapults, which propelled heavy boulders against city or castle walls.

The Onagers shown above are in front of fortress Cuknštejn in South Bohemia, Czech Republic.

Reference

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Trebuchet: Largest of Siege Weapons

A trebuchet catapult used a raised counterweight and a sling to send huge stones or incendiary ammunition over or through walls.

Shown above is a Medieval trebuchet in Château des Baux, France.

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Wind-up Cars: Potential Energy

- Potential energy can be stored in objects such as rubber bands, bungee cords, springs, etc. The amount of energy stored is related to the amount of stretch in the device.

A toy car's winding mechanism adds energy to a spiral spring, which releases energy to gears that control speed and force.

- Kinetic energy is the energy an object has because of its motion or movement.

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Wind-up Cars: Potential Energy

The amount of stretching a rubber band (potential energy from muscle power) affects the distance a rubber band travels (kinetic energy) when released.

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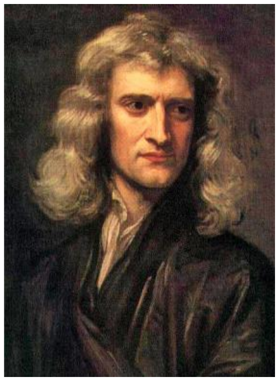
Rocket Cars: Acceleration and Force



Portrait of Sir Isaac Newton painted two years after publishing his Laws of Motion.

All vehicles, whether designed for land, sea, air or space, are governed by Sir Isaac Newton's three Laws of Motion.

- An object at rest stays at rest, and an object in motion stays in motion with the same speed and in the same direction, unless acted upon by an unbalanced force.
- An object's acceleration is directly proportional to the force exerted on it and inversely proportional to its mass.
- Every action is accompanied by an equal and opposite reaction.

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Rocket Cars: Acceleration and Force

Rockets are an excellent example of the Laws of Motion at work. This activity demonstrates all three laws. Students construct and test a lightweight "rocket" car propelled by the action/reaction force of air escaping from an inflated balloon. The escaping air exerts an unbalanced force on the car, shifting it from a state of rest to a state of motion. The force of the balloon squeezing on air inside accelerates the car when the air is released. Because the car's mass is very low, it impedes the acceleration minimally. If the car were heavier, it would accelerate more slowly. Finally, the balloon's wall exerts an action force on the air, causing it to shoot out the nozzle. This creates an equal and opposite reaction force that propels the car. When the balloon's air runs out, there is no more force to push the car, which coasts until friction brings it to a stop.

First Law of Motion

An object at rest stays at rest, and an object in motion stays in motion with the same speed and in the same direction, unless acted upon by an unbalanced force. For example, If two equally strong people push against each other, neither will move because the opposing forces are balanced. If one person is stronger than the other, the forces are unbalanced and the weaker person will be pushed backward.

Second Law of Motion

An object's acceleration is directly proportional to the force exerted on it and inversely proportional to its mass. Therefore, acceleration can be increased if the force is increased or the mass is decreased.

Third Law of Motion

Every action is accompanied by an equal and opposite reaction. For example, when someone fires a shotgun, the pellets fly out of the barrel and the shooter is pushed back by a strong "kick."

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Image Reference

Photo of Godfrey Kneller's portrait of Sir Isaac Newton. 1689. Public domain. http://en.wikipedia.org/wiki/Isaac_Newton#mediaviewer/File:GodfreyKneller-IsaacNewton-1689.jpg

Key Words

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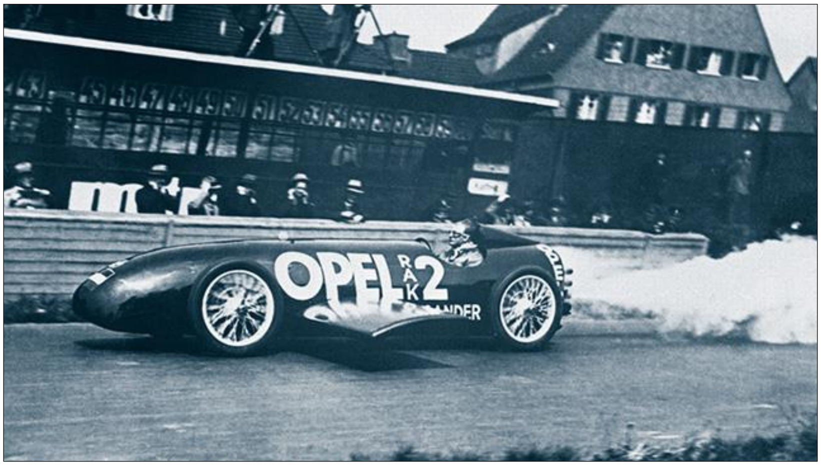
A Rocket Car with Wings



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OPEL RAK2: Public domain.

A Rocket Car with Wings

On May 23, 1928, Fritz von Opel (known as “Rocket Fritz”) drove the OPEL RAK2 at 238km/h. The car was powered by 24 powder rockets (ignited by a foot pedal), and had wings to compensate for uplift, which kept the car on the ground.

To learn more about the engineer and his machine that helped usher in the Rocket age, visit http://media.opel.com/media/intl/en/opel/news.detail.html/content/Pages/news/intl/en/2008/opel/05_07_Fritz_von_Opel.html.

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Image Reference

OPEL RAK2: Public domain. https://opelpost.com/03/2014/the-first-launch/

Key Words

physical science, physics, engineering, design, STEM, acceleration, drag, f=ma, flight, force, friction, gravity, kinetic energy, Laws of Motion, lift, mass, mechanical energy, motion, movement, Newton’s Laws, physical energy, potential energy, speed, thrust, race car, rocket car, weight, OPEL RAK2

Formula Student Race Car Design

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Formula Student Race Car Design

The fully electric Formula Student car shown on this slide was developed and built by 60 students at Eindhoven University of Technology, The Netherlands, for the annual engineering competition held by the Institution of Mechanical Engineers, UK.

For more information about the competition, visit http://events.imeche.org/formula-student/.

Reference

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Roller Coasters: Defying Gravity

The Texas Giant wooden roller coaster at Six Flags Texas.

- To provide an exciting, but safe ride, a mechanical engineer must have an excellent understanding of force, gravity, motion, momentum, and potential and kinetic energy.
- All roller coasters go through an extensive design and testing process.

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Roller Coasters: Defying Gravity

Mechanical engineers design and improve machinery and systems upon which we depend. One special kind of mechanical engineer designs roller coasters for amusement parks. A roller coaster propels riders through exhilarating drops, turns, twists and loops that simulate the movements of an aerobatic plane.

The basic roller coaster shape (a series of progressively smaller hills) has been used since the roller coaster was created in the 1400s. Early modern-style roller coasters were built with wood supports and steel rails. But wooden roller coasters, which tend to feature hills and steep turns, can make for a rough ride.

Reference

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Image Reference

Texas Giant roller coaster © Brandon R. CC-BY-SA 3.0. http://commons.wikimedia.org/wiki/Roller_coaster#mediaviewer/File:Wooden_roller_coaster_txgi.jpg

Key Words

physical science, physics, engineering, STEM, acceleration, drag, f=ma, force, friction, gravity, kinetic energy, lift, mass, mechanical energy, momentum, motion, Newton's Laws of Motion, physical energy, potential energy, roller coaster, thrust, weight

Design Changes: From Wood to Steel

In 1959, Disneyland unveiled the first all-steel roller coaster, the Matterhorn Bobsled. Steel generally provides a smoother ride and allows more extreme maneuvers. That's why most roller coasters today use steel supports and tracks. Of course, loops, turns and gravity-defying spirals now are standard elements of roller coaster design.

Reference

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Image Reference

port_aventura_spain.jpg

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Kinetic Art: Sculptures in Motion

The 71-foot tall steel sculpture, “Tyne Anew,” by Mark di Suvero, combines art with engineering. Three huge tripod-style legs support a top piece that moves gently with the direction of the wind. Thus, the sculpture’s shape constantly changes as the wind swirls around it.

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Kinetic Art: Sculptures in Motion

On blustery days, we commonly hear people use the phrase, “Look at the wind.” Have you ever wondered what it actually means? When air is moving, we feel wind, but of course, we don’t actually “see” it. Instead, we observe the movement it causes in the objects around us. Flags wave, leaves rustle, and if the wind is very strong, rain may even fall sideways. In this investigation, students will create and study unique sculptures that move in interesting ways when acted upon by the force of the wind.

The term, “kinetic art” is most often used to refer to three-dimensional sculptures that move naturally in an environment (powered by wind, water, etc.), or that are machine-powered. Sometimes, it also is used in reference to paintings on canvas, such as those done by impressionist painters. Kinetic art may include sound, light (lumino kinetic art), gas (for example, water vapor), and robotic features.

Reference

1. CultureScape. Tyne Anew by Mark di Suvero. Royal Quays Marina. http://culturescape.co.uk/mobile/mobile%20pages/clients/ntc/public%20art/royal%20quays/tyne%20anew.html

2.Vogt, G.L., B.Z. Tharp, M.T. Vu, and N.P. Moreno. 2014. *Think Like an Engineer Teacher's Guide.* Baylor College of Medicine (ISBN: 978-1-888997-64-4). Development of Think Like an Engineer educational materials was supported, in part, by National Science Foundation grant number DRL-1028771.

Image Reference

"Tyne Anew" photo © Ian Britton. CC-BY-NC 2.0.
https://www.flickr.com/photos/freefoto/sets/72157603617714044/page4/

Key Words

physical science, physics, engineering, design, STEM, acceleration, gravity, kinetic, kinetic art, kinetic energy, kinetic sculpture, mass, mechanical energy, motion, Newton's Laws of Motion, physical energy, potential energy, Tyne Anew

Artists as Engineers

Anthony Howe's Otherworldly Kinetic Sculptures
http://www.youtube.com/watch?v=RshSaF_juGs

Kinetic Sculptor Puts Cyber Dreams in Motion
http://www.youtube.com/watch?v=FoM8UoMuvl8

Reuben Margolin
http://www.youtube.com/watch?v=dehXio-MIKg0

Reuben Heyday Margolin: Waves
http://www.reubenmargolin.com

Theo Jansen: Strandbeest Evolution
http://www.youtube.com/watch?v=MYGJ9jrbpvg

Theo Jansen's Strandbeests
http://www.youtube.com/watch?v=HSKyHmjyrkA

Time-Lapse: Mark Di Suvero Installation
http://www.sfmoma.org/explore/multimedia/videos/563

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Artists as Engineers

Many kinetic sculptures evolve over time, as artists refine their work based on new criteria.

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Key Words

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