Make it Fly

Concept Statement: Weight, lift, drag, and thrust are the fundamental forces that affect flight. Weight opposes flight, and must be overcome with lift. Airplane wings create lift by exploiting Bernoulli's principle, which states that an increase in airspeed results in a decrease in air pressure. Airplanes must also counteract drag by producing thrust with engines.
List of Materials Needed:

Each of the following is required per group:

- Rubber-ban-powered airplane construction kit
- Wood glue (as required)
- Cardboard (as required)
- Fan (1)
- Clear drinking straws (5)
- Small plastic cup (1)
- Small funnel (1)
- Ping pong ball (1)
- Rectangular eraser (1)
- Wooden one-foot ruler (1)
- Manila folder (1)
- String (as needed)
- Masking tape (as required)
- Popsicle sticks (6)
- Tongue depressor (4)
- Small, durable airplane for Flight Controls section (1)
- Sticky tabs (6)
- Paper clips (2)
- Scissors (1)
- Stop watch (1)
- Mass scale (1)
- Computer with internet access (1)

Each of the following is required per student:

- Calculator (1)
- Safety Glasses (1)

Activity Time Frame:
This is a full-day activity, and shall take approximately six (6) hours to complete.

Environmental Settings:
This beginning of this activity shall be conducted in a large classroom. The authentic assessment may be conducted outdoors, or alternatively, in an indoor facility with a large amount of open space.

PASS Standards:
Science Processes and Inquiry: Physical Science

Process Standard 1: Observe and Measure
1. Identify qualitative and quantitative changes given conditions (e.g., temperature, mass, volume, time, position, length) before, during, and after an event.
2. Use appropriate tools (e.g., metric ruler, graduated cylinder, thermometer, balances, spring scales, stopwatches) when measuring objects and/or events.
3. Use appropriate System International (SI) units (i.e., grams, meters, liters, degrees Celsius, and seconds); and SI prefixes (i.e., micro-, milli-, centi-, and kilo-) when measuring objects and/or events.

Process Standard 2: Classify
1. Using observable properties, place an object or event into a classification system.
2. Identify the properties by which a classification system is based.

Process Standard 3: Experiment
1. Evaluate the design of a physical science investigation.
2. Identify the independent variables, dependent variables, and controls in an experiment.
3. Use mathematics to show relationships within a given set of observations.
4. Identify a hypothesis for a given problem in physical science investigations.
Process Standard 4: Interpret and Communicate
1. Select appropriate predictions based on previously observed patterns of evidence.
2. Report data in an appropriate manner.
3. Interpret data tables, line, bar, trend, and/or circle graphs.
4. Accept or reject hypotheses when given results of a physical science investigation.
5. Evaluate experimental data to draw the most logical conclusion.
6. Communicate or defend scientific thinking that resulted in conclusions.
7. Identify and/or create an appropriate graph or chart from collected data, tables, or written descriptions.

Process Standard 5: Model
1. Interpret a model, which explains a given set of observations.
3. Compare a given model to the physical world.

Process Standard 6: Inquiry
1. Formulate a testable hypothesis and design an appropriate experiment relating to the physical world.
2. Design and conduct physical science investigations in which variables are identified and controlled.
3. Use a variety of technologies, such as hand tools, measuring instruments, and computers to collect, analyze, and display data.
4. Inquiries should lead to the formulation of explanations or models (physical, conceptual, and mathematical). In answering questions, students should engage in discussions (based on scientific knowledge, the use of logic, and evidence from the investigation) and arguments that encourage the revision of their explanations, leading to further inquiry.

Content Standards: Physical Science
Standard 2: Motion and Forces
1. Objects change their motion only when a net force is applied. Laws of motion are used to determine the effects of forces on the motion of objects.

Standard 3: Interactions of Energy and Matter
1. All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.
Lesson Objectives:

Students will be able to accomplish the following:

• Distinguish the fundamental forces of flight, namely, weight, lift, thrust, and drag
• Predict the consequence of unbalanced forces on an airplane
• Experimentally deduce the qualitative relationship between relative airspeed and air pressure
• Calculate relative air pressure using Bernoulli’s equation
• Identify the lift producing mechanisms of an airplane
• Determine how the geometric properties of a wing—angle of attack, thickness, camber, chord, and span—influence its ability to produce lift and drag
• Characterize stall, and explain its detrimental effect on lift
• Simulate aerodynamic forces using the NASA FoilSim application
• Identify the three aircraft rotations—roll, yaw, and pitch—and demonstrate an ability to control them using the appropriate mechanisms—ailerons, rudder, flaps, and elevators
• Determine the importance of center of gravity as it relates to steady level flight
• Calculate the required take-off speed for an airplane given necessary parameters
• Determine whether or not an airplane will fly given necessary parameters

Vocabulary Terms:

Aileron: Control surface on the trailing edge of the wing used to maneuver an aircraft in roll; ailerons work in differential—one moves up as the other moves down

Aircraft: A vehicle capable of flying or being supported by air

Airfoil: The shape of a wing as seen in cross-section

Airplane: An aircraft capable of flight using forward motion that generates lift as the wings move through the air

Airspeed (v): The speed of an aircraft relative to the air through which it is moving

Angle of Attack (α): The angle between the chordline of an airfoil and the flow direction of the air

Camber: A measure of an airfoil’s curvature

Center of Gravity: The mean location of all mass in a body

Chord: The distance between the front and back of an airfoil

Drag (D): A fluid flowing past a body exerts a force on its surface. Drag is the component of the force parallel to the oncoming flow direction.

Elevator: Control surface on the horizontal stabilizer used to maneuver an aircraft in pitch; elevators are often used to increase an airplane’s angle of attack

Endurance: The maximum length of time an aircraft can fly before running out of fuel and landing

Flap: Control surface on the trailing edge of the wing used to increase the effective angle of attack, camber, and surface area; useful in low speed conditions such as takeoff and landing

Force: A push or a pull that causes a free body to undergo acceleration—measured in Newtons (N)

Fuselage: An aircraft’s main body section that typically holds crew, passengers, and cargo
Lift (L): A fluid flowing past a body exerts a force on its surface. Lift is the component of the force perpendicular to the oncoming flow direction.

Pitch: Rotation about the horizontal axis of an airplane

Pressure: Force distributed over an area; the force per unit area applied in a direction perpendicular to the surface of an object—measured in Pascals (Pa)

Propeller: A fan that transmits power by converting rotational motion into thrust

Range: The maximum distance an airplane can fly

Roll: Rotation about the longitudinal axis of an airplane

Rudder: Control surface on the vertical stabilizer used to maneuver an aircraft in yaw

Simulation: A prediction of a physical phenomenon using computer software

Stabilizer: Surfaces used to help control the flight of an aircraft; fins on the rear section of an airplane

Stall: The drastic reduction in lift associated with flow separation at large angles of attack

Streamlines: A family of curves that align with the velocity vectors of a flowfield; they indicate the direction of the flow as a function of space and time

Thrust (T): The force that pushes an airplane forward—it is produced by the engines, and points in the direction of flight

Weight (W): The force exerted on the mass of a body by a gravitational field

Wingspan: Distance from one wingtip to the other wingtip of an airplane

Yaw: Rotation about the vertical axis of an airplane

Background Knowledge:
Throughout history, mankind has been fascinated by the idea of powered flight. Inspired by natural flyers—birds, bats, and insects—early inventors often risked their lives and reputations to be the first flying human. Perhaps the most well-known early student of flight, Leonardo da Vinci documented his conceptual machines, which resembled helicopters and ornithopters, in the form of drawings.

Leonardo da Vinci’s flying machines
Until the Wright brothers’ monumental achievement in 1903, powered flight was only a dream. Soon thereafter, World War I inspired the idea that the airplane could be used as a weapon. As a result, the war served as a catalyst for aerospace engineering research. Following WWI, aircraft technology continued to flourish—the overarching goal being higher and faster. Charles Lindbergh became the first person to fly solo over the Atlantic in 1927. The airplane played a pivotal role in World War II, perhaps most notably during the battles of the Pacific, Pearl Harbor, and the battle of Britain. Following WWII, Chuck Yeager was the first to break the sound barrier in 1947. By the 1950s, the role of the aircraft expanded from military weapon to commercial transport.

Modern flying machines include airplanes, gliders, helicopters, airships, micro air vehicles, and spacecraft. We will focus on the airplane, which has arguably had the greatest impact on everyday life.

Before we proceed, we emphasize the fact that the physics of flight changes as the aircraft approaches, or exceeds, the speed of sound through air (\(a\))—which varies as a function of temperature, and is roughly equal to 343 m/s (768 mph) at sea level. When an object travels faster than the speed of sound, shock waves form, resulting in a nearly discontinuous change in air properties. The Mach number is defined as \(M = \frac{v}{a}\), where \(v\) is the airspeed and \(a\) is the speed of sound. Using this parameter, the following flight regimes are defined: subsonic (\(M < 0.8\)), transonic (0.8 < \(M < 1.2\)), supersonic (1.2 < \(M < 5\)), and hypersonic (\(5 < M\)). The scope of this lesson is restricted to subsonic flight.

There are four fundamental forces that affect flight; two are beneficial—lift and thrust—and two are detrimental—weight and drag.

Weight (\(W\)) is the gravitational pull of the Earth on the aircraft. An airplane cannot fly forever, and in the end, gravity always wins.

Lift (\(L\)) is the upward force generated by air moving across the surface of the wings. In other words, lift is the aerodynamic force that points perpendicular to the direction of the airflow. In order to achieve steady level flight, the vertical forces must balance; meaning lift must equal the weight of the airplane (\(L = W\)). For climbing flight, \(L > W\), and for descending flight, \(L < W\).

Airplane wings are engineered—with respect to geometry, curvature and orientation—for air to move across the top surface faster than the bottom surface. According to Bernoulli’s principle, this difference in airspeed will result in a difference in relative air pressure. This difference in air pressure multiplied by (integrated over) the surface are of the wing results in a net force—lift.

Bernoulli’s principle can be succinctly stated as: an increase in airspeed (\(v\)) results in a decrease in relative air pressure (\(P\)). The relative air pressure (\(P\)) can be calculated by Bernoulli’s equation:

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P = P_{\text{atm}} - \frac{1}{2} \rho v^2
\]
where \( v \) is the airspeed, \( \rho \) is the air density, and \( P_{\text{atm}} \) is the atmospheric pressure. Note that Bernoulli’s equation neglects the effects of viscosity, and is only good for incompressible flows. For most subsonic airplanes, Bernoulli’s equation is a very good approximation.

Thrust (\( T \)) is the force that pushes the airplane forward through the air. It can be produced using jet-, rocket-, or propeller-driven engines. Each of these operates using a combustion process in which a fuel is mixed with an oxidizer and burned to release energy. Without thrust, an airplane is restricted to gliding flight and must eventually land.

Drag (\( D \)) is the opposite of thrust—it is the force that points in the direction of the flow and slows the aircraft down. A common misconception for airplanes is the notion that skin friction (due to viscosity) is the primary cause of drag. It is important to recognize that other types of drag are present, including form drag (the net force due to the unbalanced pressure field exerted on airplane), which typically dominates skin friction at high speeds.

Aerospace engineers try to reduce drag as much as possible. Careful consideration goes into wing design and control surface placement. With drag reduction, less thrust—and less fuel—are required to operate the airplane.

Myriad factors go into calculating the aerodynamic forces—\( L \) and \( D \)—produced by airplane wings. The most important parameters include airspeed, angle of attack, wingspan, chord length, wing thickness, and camber (curvature of the wing). For the sake of simplicity, a theoretical development for subsonic aerodynamics will not be discussed in this lesson. See Refs [1-2] for more details on the popular planar wing theory.

As an alternative to manual calculation of aerodynamic forces, we use a simulation approach in this lesson. FoilSim is a user-friendly application developed by NASA for simulating aerodynamic forces [3]. The software is based on planar wing theory, and is modified to include stall behavior.

With the FoilSim application, students are able to calculate the lift produced by an airplane given its wing geometry, airspeed and angle of attack. If the weight of the airplane is known, students can deduce whether or not it will fly.

References:

Additional Online Resources:
Science Olympiad Wright Stuff competition
- http://soinc.org/wright_stuff_b

Beginner airplane kits

Keys to competitive flying

NASA Quest

Aerodynamics activities for high school students
- http://ethemes.missouri.edu/themes/739

History of Flight
- http://www.ueet.nasa.gov/StudentSite/historyofflight.html
**Activity Procedures:**
Students will engage in the following activities:
- Watch three short videos containing flight footage from the past (Wright brothers), present (Fighter jets), and future (micro air vehicles)
- Hypothesize the mechanisms of flight
- Construct a rubber-band-powered airplane
- Explore the fundamental forces of flight using a paper airplane
- Conceptualize the four forces of flight
- Explore Bernoulli’s principle using four brief exercises
- Conceptualize Bernoulli’s principle, and how it is exploited by airplanes to produce lift
- Explore the effects of angle of attack and wing geometry on lift and drag using a fan and wing section
- Simulate aerodynamic forces using the NASA *FoilSim* application
- Explore how flight controls affect aircraft rotations using a durable balsa wood glider
- Explore the importance of center of gravity and balance using a durable balsa wood glider
- Determine whether a Boeing 737 will be able to take-off for a hypothetical scenario
- Determine whether their constructed rubber-band-powered airplane will fly
- Demonstrate an ability to modify the flight path of the airplane
- Optimize the airplane for maximum endurance

**Technology Component:**
Students will use the NASA *FoilSim* application to predict aerodynamic forces.

**Engineering Application:**
Students will modify the flight path of an airplane by manipulating flight control surfaces. They will optimize the airplane for maximum endurance.

**Assessment Tools:**
Students will be graded in accordance with the Authentic Assessment rubric.