“What Is Flight Testing?”
Or
"How Do We Know an Aircraft Will Fly Right?"

Grades 9-12

Objective: Upon completing this lesson, the student will be able to explain the flight testing process. They will be able to describe testing maneuvers and the forces that define their motion.

National Science Standards:
- Standard A: Science as inquiry - Abilities necessary to do scientific inquiry
- Standard B: Physical Science - Position and motion of objects

Vocabulary:
- Flight Testing – method to determine how well a vehicle performs in the air
- Flight Vehicle - airplane, helicopter, balloon, rocket, anything that flies through the air.
- Axis System – graphical way to represent forces and moments acting on an aircraft.
- Manuvers – controlled motions of an aircraft along a flight path
- Force – a push or pull that causes movement of an object
- Moments – rotation of a body that occurs when a force is applied
- Lift - upward force
- Thrust - forward force
- Weight/gravity - downward force
- Drag - backward force
Websites:

- http://www.grc.nasa.gov/WWW/K-12/airplane/forces.html
  Forces of flight

  How to Explain Bernoulli's Theorem Experiment to Kids | eHow.com

  Aerospace Activities and Lessons

- http://www.grc.nasa.gov/WWW/K-12/TRC/Aeronautics/AeronauticActivitiesHome2.htm
  Aeronautics Classroom Activities

- http://www.grc.nasa.gov/WWW/K-12/aerores.htm
  Aerospace Resources

- http://women.nasa.gov/a2i/
  Women in Science, Technology, Engineering & Math Careers Info
**What Is Flight Testing?**

Flight testing is a method to gather information, called data, which will describe how a particular vehicle will perform. Flight testing of a vehicle is done when very little data exists to prove that the vehicle will be safe and perform as desired. The data obtained from flight tests are then used to design future vehicles. In flight testing various motions, called maneuvers, are used to obtain this data. These maneuvers will be discussed later.

**What Is An Axis System?**

To understand the data that comes from a flight test, it is necessary to understand what an axis system is. An axis system is a graphical way to show how forces, moments, and other test data describe aircraft motion. Aircraft motion is described in terms of motion in three different directions, in which each direction is a different axis. Figure 1 shows the direction of these motions. The translational or straight line motion of an aircraft can be described as movement forward and back in the x-direction, movement side to side in the y-direction, and up and down in the z-direction. The 3 pictures below on the left side of the page show these motions. The rotational motion of an aircraft can be described as rotation around the same x, y, and z axes, where pitch rotation, where the nose rotates up or down, is around...
the y-axis, **roll rotation**, where one wing rotates up or down, is around the x-axis, and **yaw rotation**, where the nose rotates right or left, is around the z-axis. The 3 pictures on the right side of the previous page show these rotations.

**What Is Performance?**

Once we know what an axis system is, we can describe how the aircraft performs in the air. “Performance” refers to the motion of the airplane along its flight path, forward and aft, up or down, right or left, as described on the axis system. The term "Performance" also refers to how fast, how slow, how high and how far. It may also refer to the ability of an airplane to successfully do its job, or what it is trying to accomplish. “Performance” includes such items as minimum and maximum speed, maximum altitude, maximum rate of climb, maximum range and speed, rate that fuel is used, distance to take-off and land, and the weight of what it can carry.

**What Are Flight Test Maneuvers?**

Maneuvers are the motions of the aircraft done by the pilot to determine aircraft performance. A maneuver is a translational or rotational motion of the aircraft during a flight test to obtain performance data. There are specific test maneuvers which are used to measure these performance qualities for each airplane. Sometimes, flight testing is a competition to select the best airplane to do a particular job. All of the performance measurements are strongly affected by differences in the weather conditions, such as temperature, pressure, humidity, and wind.

**What Is a Flight Envelope?**

The graph in Figure 2 shows how much a particular aircraft can do. The graph is a plot of altitude on the vertical axis and speed on the horizontal axis. The orange-colored area is called the flight envelope. The orange area shows at what altitudes and at what speeds the aircraft can fly. The left edge of the orange flight envelope is the minimum speed in which the aircraft can safely fly.
Any slower and the aircraft will stall and begin to fall. The right edge of the orange graph is the maximum speed the aircraft can fly at that altitude due to engine power. The very top of the orange graph shows the maximum altitude for the aircraft. The flight envelope is determined by obtaining flight test data.

**What is Stability?**

Stability refers to the rotational motion of an airplane about its three axes; roll, pitch, and yaw. "Stability" is defined as the tendency of an object to return to its initial position when it is disturbed or moved from its initial position.

**What Is a Stable Condition?**

Figure 3 shows the three cases of stability. In case (3a), a marble placed in the bottom of a shallow trough is said to be stable. When moved, the marble will tend to return to that resting place at the bottom of the trough. It may overshoot and move (or oscillate) back and forth, but it will continue to seek the lowest point in the trough (see the red line in the trough). “Static” stability is a measure of how quickly the marble will return to the bottom of the trough. A trough with steep sides will result in a higher level of static stability for the marble than one with shallow sides. This motion that results from a statically stable condition is called "oscillatory".

**What Is a Neutral Condition?**

If we set the marble on a flat table (Figure 3b), there is no tendency for it to return to its initial position. The marble will stay in any location that it is placed on the table. This condition is called "neutral stability". The motion resulting from a condition of neutral stability is called "non-oscillatory".
What Is an Unstable Condition?

If we turn the trough upside down (Figure 3c), we can balance the marble at one point on the top of the trough, but when disturbed it will tend to move away from the balance point at an increasing rate. This is an example of an unstable condition, or "static instability". The motion that results from static instability is called a "divergence".

What Is Damping?

Damping is resistance to motion. Damping only exists when actual movement is occurring. For an airplane, it is usually characterized as being proportional to the rate of movement, or velocity. (Note that "velocity" can be either translational - speed, or rotational - revolutions). Damping is usually related to some form of friction. In Figure 4, if we line the trough referred to in the stability example with a towel, the marble will still seek the lowest point in the trough (still statically stable), but the towel has increased the friction between the marble and the smooth sides. The marble will not move as rapidly and will not oscillate back and forth as much as in the previous example (Figure 3a). The towel has added damping to the motion of the marble.

What Are Specific Maneuvers?

A maneuver is defined as the controlled change of flight path by changing the speed and direction of an airplane. A highly maneuverable airplane, such as a fighter plane, has a capability to accelerate or slow down very quickly, and also to turn sharply, Figure 5. Quick, sharp turns place large forces on the wings, as well as the pilot. These forces, or loads, are referred to as "g forces" and the ability to "pull g's" is considered one measure of maneuverability. One “g” is the force acting on the airplane in level flight.
imposed by the gravitational pull of the earth. Five “g’s” in a maneuver means that 5 times the gravitational force of the earth is felt by the airplane and the pilot. Flight tests of other aircraft, such as a passenger plane, experiences much lower “g’s” while in flight.

How Is Flight Test Data Obtained?

Gathering Data
The purpose for flight testing is to gather data about the flight characteristics of an airplane and its subsystems for subsequent analysis on the ground. This data gathering process starts with sensors or transducers which have been mounted throughout the airplane. Transducers are devices which convert mechanical measurements into electrical signals. Different kinds of transducers are used to measure control positions, pressures, temperatures or loads. The electrical signal from each transducer is routed through special instrumentation wiring to a central location in the airplane where it is connected to signal conditioning equipment. The signal conditioner "conditions" each transducer signal to a common format and organizes all of the signals for efficient recording. Many different terms are used to describe the various phases or processes that are included in this "conditioning", such as multiplexing, commutating, sub-commutating, digitizing, analog-to-digital converting, time-code generating, pulse-code-modulating, etc.

The resulting organized stream of data is then transferred to an onboard tape
recorder and also to a telemetry transmitter. The tape recorder records the data on magnetic tape in much the same way that music is recorded on a tape cassette. The telemetry transmitter transmits the same data stream from the airplane to a ground station on a selected radio frequency, in much the same way as commercial radio stations broadcast music to our homes.

The ground station receives the data stream and also records all of the data on another, ground based tape recorder. The ground station also converts portions of the data stream into electrical signals that can be displayed on indicators or strip charts in the ground control room. In this way engineers on the ground can monitor flight activities and can assist the pilot in the safe conduct of the flight. If an aircraft is expected to remain within easy range of the ground station for all of its flights, it may not be equipped with an on-board recorder. This decision reduces complexity and saves weight. The data is transmitted from the airplane to the ground and the ground recorders are the only source of data for post flight analysis.

What Is the Instrumentation Needed to Obtain Data?

Nose Boom
Nose boom installations are fairly standard on test aircraft. The nose boom allows critical measurements of both pressure and the flow angles to be measured well in front of the fuselage where the measurements are not influenced by the shape of the aircraft.
**Pitot-Static System**
The pitot-static system is the basic measurement method for determining speed and altitude. It includes two pressure measurements. Total pressure (or pitot pressure) represents the pressure being applied to the front of the airplane as it moves through the air. It is measured by using a pressure transducer to measure the pressure inside a forwarding-facing tube at the front of the nose boom. Static pressure represents the undisturbed pressure of the atmosphere at the altitude that the airplane is flying. It is measured by side-facing tubes or holes on the top and bottom of the nose boom. The static pressure measurement can be related directly, through a mathematical formula, to the altitude that the airplane is flying. The difference between the pitot and static pressure can be related (through another mathematical formula) to the speed of the airplane through the air.

**Angle of Attack and Sideslip Vanes**
Immediately behind the total and static pressure tubes on the nose boom are two vanes (very much like miniature weather vanes) that pivot freely on posts extending vertically and horizontally from the nose boom. A transducer measures the position of these vanes relative to the fuselage centerline. The resulting angles are called angle of attack and angle of sideslip. Both are key measurements for determining the stability of an airplane.

**Gyros and Accelerometers**
Miniature gyroscopes (gyros) measure the rate of rotation about the three axes mentioned earlier (pitch rate, roll rate, and yaw rate). Accelerometers measure the linear acceleration along the same three axes (fore and aft - X, sideways - Y, and up and down - Z). The three accelerometers and three gyros are usually very carefully aligned and mounted near the aircraft's center of gravity, often on the same mounting platform.

**Strain Gages**
Loads are measured by mounting strain gages on the structural parts to be monitored. These sensors are very small wires which are bonded to the structure. When the structure is under load there will be a slight expansion or contraction of the part due to the load. This minute change in dimension is sensed by the strain gage which produces an electrical signal in much the same manner as the other transducers.
Fact Sheet
Flight Testing
"Forces of Flight"

**Four Forces of Flight**
Lift, thrust, weight, drag

**Sir Isaac Newton (1642 - 1727)**
First presented his three laws of motion in the "Principia Mathematica Philosophiae Naturalis" in 1686.

**Newton's Laws of Motion**

**Newton's First Law of Motion** states that a body at rest will remain at rest unless an outside force acts on it, and a body in motion at a constant velocity will remain in motion in a straight line unless acted upon by an outside force.

**The Second Law of Motion** states that if an unbalanced force acts on a body, that body will experience acceleration (or deceleration), that is, a change of speed.

**The Third law of Motion** states that for every action force there is always an equal and opposite reaction force.

**Bernoulli's Principle**
States that an increase in the speed of moving air or a flowing fluid is accompanied by a decrease in the air or fluid's pressure.
Flight Testing
K-W-L

K - What do I know about flight testing?

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W - What do I want to know about flight testing?

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L - What did I learn about flight testing?

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