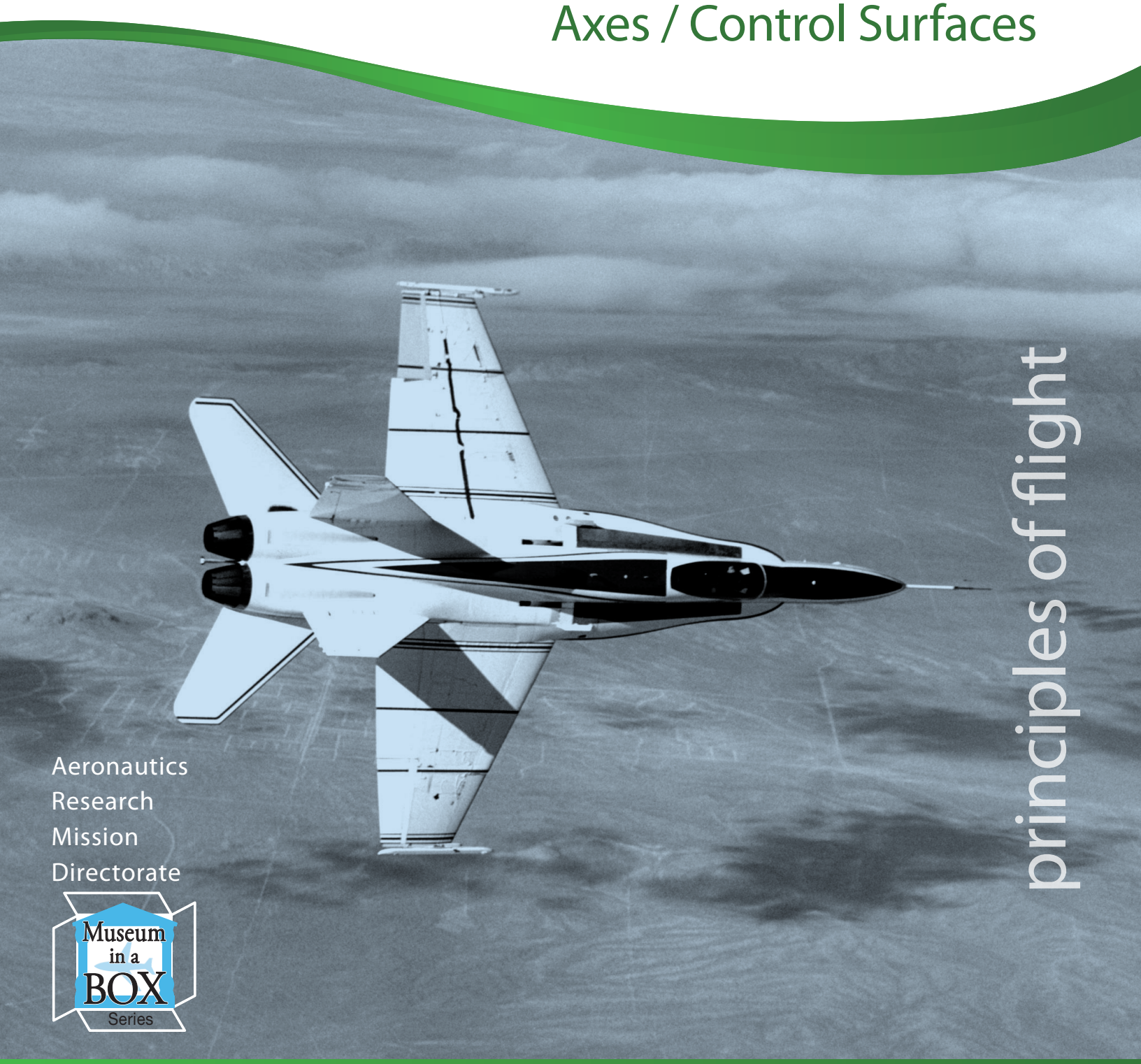
National Aeronautics and Space Administration

GRADES K-4

Axes / Control Surfaces



principles of flight

Aeronautics
Research
Mission
Directorate

Museum in a BOX Series

www.nasa.gov

Axes / Control Surfaces

Lesson Overview

Through hands-on experiments and physical demonstrations, students will learn about position and motion of forces as they are introduced to some of the basic concepts of flight, including the three axes of flight and the control surfaces that guide the aircraft.

Objectives

Students will:

1. Learn how to identify the various parts of an airplane and gain a basic understanding of their functions.
2. Gain an understanding of how the three axes of flight relate to the movement of an aircraft.
3. Study the three axes of flight.

Materials:

In the Box

Pencils (3 per student)
Tape
Scissors

Provided by User

Colored pencils or crayons
Chair (1 per student)

GRADES **K-4** **Time Requirements:** 1 hour 50 minutes

Background

The mechanics of flight are highly complex, encompassing principles such as the four forces and axes, as well as technical terms such as control surfaces, adverse yaw and coordinated flight. While this lesson covers all of these topics, its purpose is to provide just a very basic insight into the true mechanics of flight and body-axis systems. Wind-axis systems, which refer to aircraft forces in relation to the direction of the aircraft's velocity, are not discussed here to avoid confusion. Also, some of the explanations given are highly simplified in order to allow educators to help students visualize the principle being discussed. For educators with an aviation background and capable students, modification of these activities and background information is encouraged.

The Forces of Flight

Every aircraft, whether an airplane, helicopter or rocket, is affected by four opposing forces: Thrust, Lift, Drag and Weight (Fig. 1). Control surfaces, such as the rudder or ailerons, adjust the direction of these forces, allowing the pilot to use them in the most advantageous way possible.

A force can be thought of as a push or pull in a specific direction. It is a vector quantity, which means a force has both a magnitude (amount) and a direction.

For this lesson we will deal specifically with fixed-wing airplanes. Other aircraft, such as hot-air balloons and helicopters, use the same basic principles but the physics are very different.

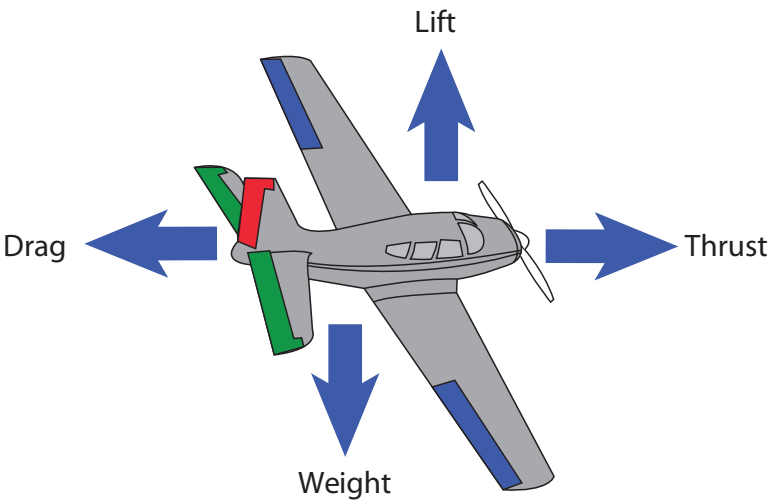


Fig. 1 Four forces of flight

Thrust

Thrust is produced by an aircraft's propulsion system or engine. The direction of the thrust dictates the direction in which the aircraft will move. For example, the engines on an airliner point backwards, which means that generally speaking, the airplane's thrust vector will point forwards.

Lift

Lift is generated by the motion of air passing over the aircraft's wings. The direction of lift is always perpendicular to the flight direction (Fig. 2) and its magnitude depends on several factors, including the shape, size and velocity of the aircraft.

Drag

Drag is simply resistance of the aircraft against the air. There are many types of drag, but each is a force opposing thrust.

Weight

Weight is a force that is always directed toward the center of the earth due to gravity. The magnitude of the weight is the sum of all the airplane parts, plus the fuel, people and cargo. While the weight is distributed throughout the entire airplane, its effect is on a single point called the center of gravity.

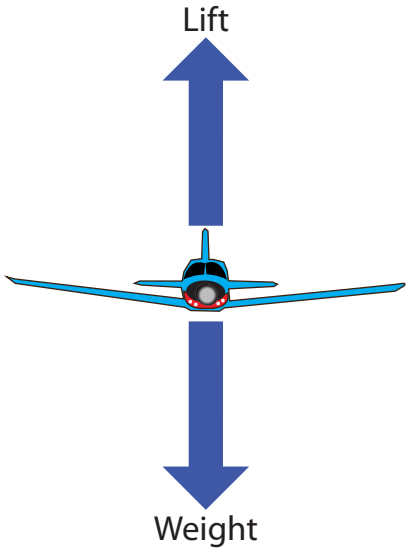


Fig. 2 The lift and weight forces of flight

Controlling the Motion of Flight

In order for an aircraft to reach its destination, the forces of flight have to be precisely manipulated. To do this, the aircraft has control surfaces (Fig. 3) which can direct airflow in very specific ways.

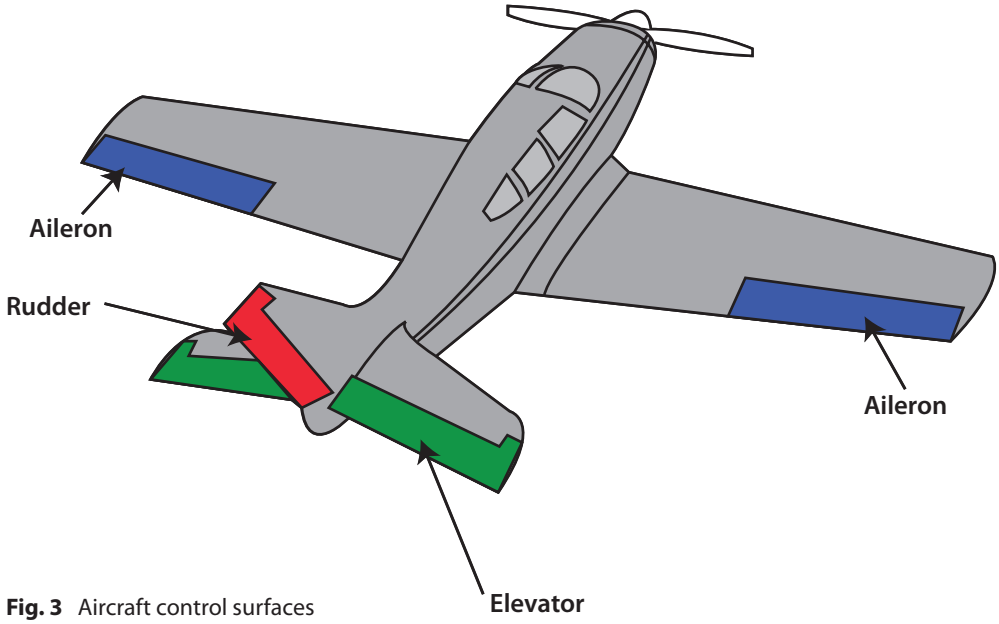


Fig. 3 Aircraft control surfaces

Elevator | Pitch

As the name implies, the elevator helps "elevate" the aircraft. It is usually located on the tail of the aircraft and serves two purposes. The first is to provide stability by producing a downward force on the tail. Airplanes are traditionally nose-heavy and this downward force is required to compensate for that. The second is to direct the nose of the aircraft either upwards or downwards, known as pitch, in order to make the airplane climb and descend. (Fig. 4).

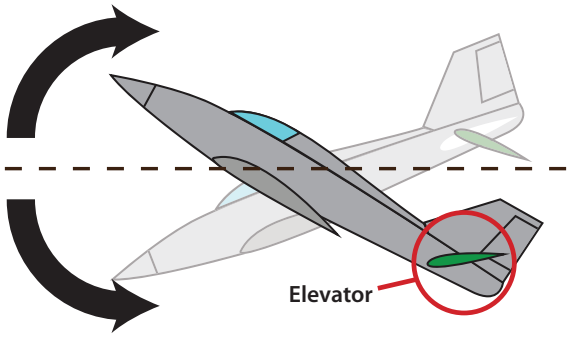


Fig. 4 Elevator and pitch movement

Ailerons | Roll

The ailerons are located at the rear of the wing, one on each side. They work opposite to each other, so when one is raised, the other is lowered. Their job is to increase the lift on one wing, while reducing the lift on the other. By doing this, they roll the aircraft sideways, which allows the aircraft to turn. This is the primary method of steering a fixed-wing aircraft (Fig. 5).

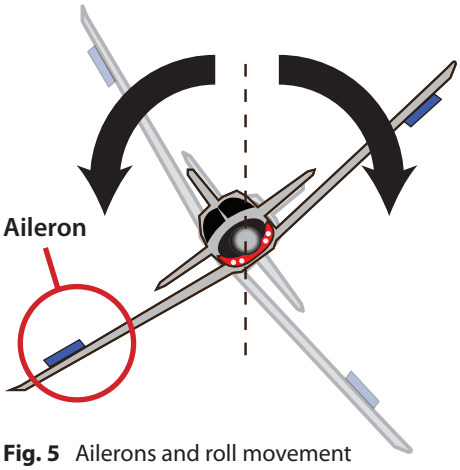


Fig. 5 Ailerons and roll movement

Rudder | Yaw

The rudder is located on the tail of the aircraft. It works identically to a rudder on a boat, steering the nose of the aircraft left and right. Unlike the boat however, it is not the primary method of steering. Its main purpose is to counteract the drag caused by the lowered aileron during a turn. This adverse yaw, as it is known, causes the nose of the airplane to point away, or outwards, from the direction of the turn. The rudder helps to correct this by pushing the nose in the correct direction, maintaining what is known as coordinated flight (Fig. 6).

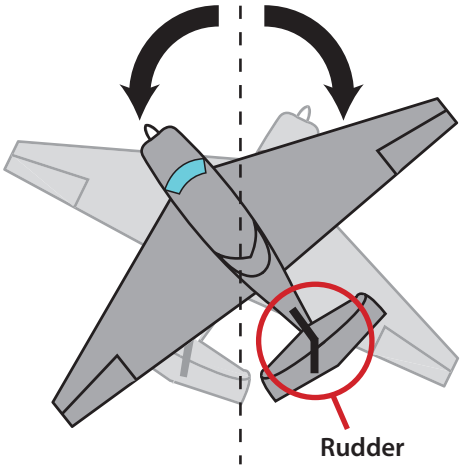


Fig. 6 Rudder and yaw movement

The Axes of Flight

Each axis of flight is an imaginary line around which an airplane can turn. Think of an airplane rotating around an axis like a wheel rotates around an axle.

Regardless of the type of aircraft, there are three axes upon which it can move: Left and Right, Forwards and Backwards, Up and Down. In aviation though, their technical names are the lateral axis, longitudinal axis and vertical axis.

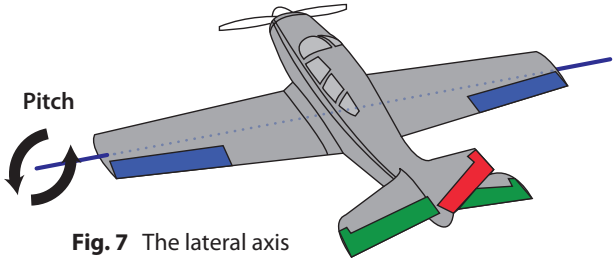


Fig. 7 The lateral axis

The Lateral Axis (Pitch)

The lateral axis runs from wing tip to wing tip. The aircraft pitches around this axis (Fig. 7).

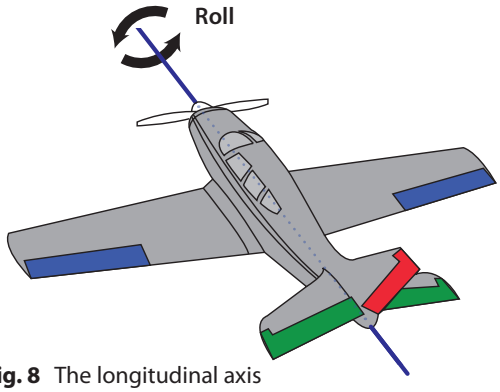


Fig. 8 The longitudinal axis

The Longitudinal Axis (Roll)

The longitudinal axis runs from the nose of the aircraft to the tail. This is the axis around which the aircraft rolls (Fig. 8).

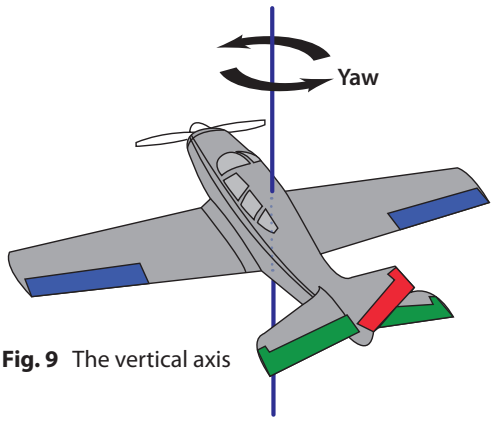


Fig. 9 The vertical axis

The Vertical Axis (Yaw)

The vertical axis is slightly different to the others, running vertically through the center of the aircraft. The aircraft yaws around this axis (Fig. 9).

The Center of Gravity

The center of gravity, also known as CG, is the effective point whereby all weight is considered to be. The CG is also the same point where the axes of flight meet (Fig. 10). This point isn't fixed on any aircraft, but moves forwards or backwards along the longitudinal axis, depending on how the aircraft is loaded. It is vital that its center of gravity remain within certain limits however, as an aircraft that is too nose- or tail-heavy will either not fly, or be so difficult to control that it becomes too dangerous to try. These limits are referred to as its operational envelope.

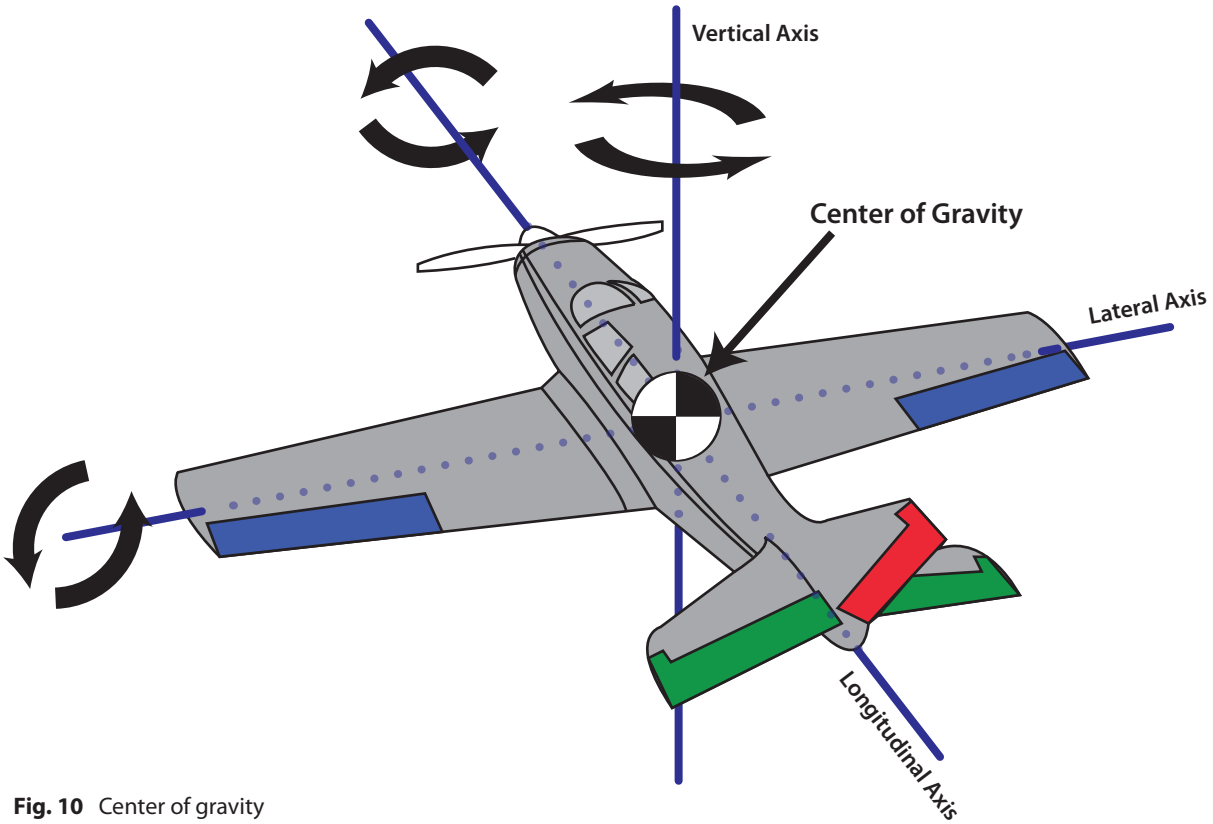


Fig. 10 Center of gravity

For additional information on aerodynamics and the principles of flight in general, please refer to the Museum in a Box lessons "Four Forces" and "Bernoulli Principle".

Activity 1 Parts of an Airplane

GRADES K-4

Time Requirements: 20 minutes

Materials:

In the Box

None

Provided by User

Colored pencils or crayons

Worksheets

Parts of an Airplane (Worksheet 1)

Reference Materials

None

Key Terms:

Aileron
Elevator
Rudder

Objective:

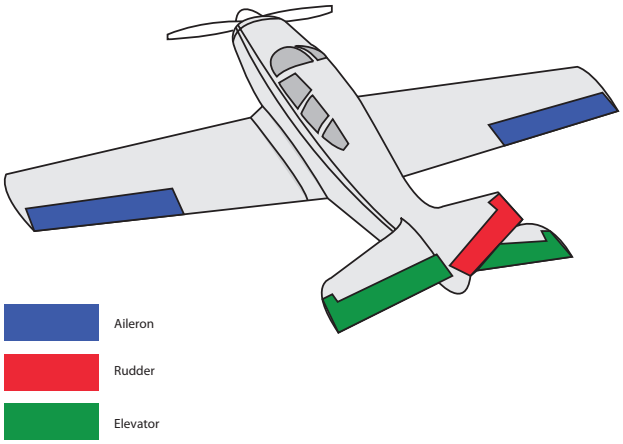
In this activity, students will learn about position and motion of forces as they learn to identify the various parts of the airplane and gain a basic understanding of their functions.

Activity Overview:

Students will label or color various parts of the aircraft, learning the purpose or function of each component in the process.

Activity:

1. **Provide each student with a copy of the Parts of an Airplane worksheet.**
2. **Using the Background information, discuss each of the control surfaces with the students as a group.**
   Remember that younger students may not understand the vast majority of the concepts being presented.
3. **Depending on the age and ability of the students, have them either color-code or label each control surface.**
   You can do this step either during your discussion or afterward.



Discussion Points:

1. **Where are the ailerons?**
   The ailerons are on the trailing, or rear, edge of the wings.

2. **What is their purpose?**
   The ailerons are used to turn the airplane left and right.

3. **Where is the rudder?**
   The rudder is at the back of the airplane, on the tail.

4. **What is its purpose?**
   The rudder is used to keep the nose and tail of the airplane pointing in the same direction.

5. **Where is the elevator?**
   The elevator is also on the tail of the airplane, below the rudder.

6. **What is its purpose?**
   The elevator is used to turn and make the airplane climb and descend.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2 The Axes of Flight

GRADES K-4

Time Requirements: 30 minutes

Materials:

In the Box

None

Provided by User

Chair (one per student)

Worksheets

None

Reference Materials

None

Key Terms:

Lateral axis
Longitudinal axis
Pitch
Roll
Vertical axis
Yaw

Objective:

In this activity, students will learn about the position and motion of objects as they gain an understanding of the three axes of flight and how they relate to the movement of an aircraft.

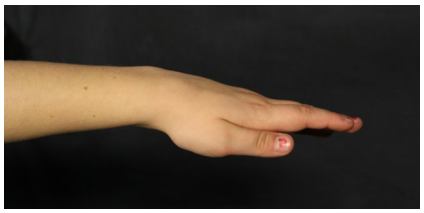
Activity Overview:

Students will work in pairs to visualize the three axes of flight.

Activity:

1. **Use the Background information to discuss each of the airplane's axes of flight.** Then explain to the students that they will pretend to be airplanes in order to demonstrate the ways in which an airplane can move.
2. **Divide the students into pairs and have them take turns performing the remaining steps.**
3. **Have one student in each pair (Student A) stand with their arms outstretched, representing wings.** Have the other student in the pair (Student B) place their hands on Student A's waist. Now, have Student B twist Student A around the waist. This demonstrates the effect the rudder has on the airplane, which is a rotation around the vertical axis.
   If available, an excellent alternative would be to have Student A lay on the seat of a swivel chair, with arms outstretched, while Student B rotates the chair.

4. **Place both students' chairs together so that Student A can lie face down on them, again with arms outstretched.** Have Student B hold the waist of Student A, rotating Student A side to side on the chair. This demonstrates the effect ailerons have on an airplane, which is a rotation around the longitudinal axis. *For older students, have the students rotate their hands to symbolize the raising and lowering of the individual ailerons. For a left turn, the left hand should be twisted up, while the right hand is twisted down. Do the opposite for a right turn .*



Use caution demonstrating the next axis. It should only be performed with mature students on a carpeted area. A second, less accurate, method is also given should it be deemed safer.

5a. **The lateral axis demonstration requires two pairs of students.**

a) Place the two chairs back to back, slightly apart. Have two of the students sit on the chairs for support and stability.

b) Have Student A stand in between the two chairs, placing one hand on the back of each chair. Student A should now take a step backwards while leaning forwards into a standing push-up position .

c) Student B should lift Student A's feet off of the ground, so that student A's weight is now supported by their arms on the backs of the chairs.

d) Student B can now raise and lower Student A's feet, demonstrating movement around the lateral axis.

5b. **Alternatively, have each student stand with their arms outstretched as in step 3.** Next, have them bend forwards and backwards at the waist.

Regardless of the step performed above, this demonstrates the effect the elevator has on the airplane, which is a rotation around the lateral axis.

Discussion Points:

1. **What does the aircraft do around the lateral axis?**
   The aircraft pitches around the lateral axis. This makes the aircraft climb or descend.

2. **What does the aircraft do around the longitudinal axis?**
   The aircraft rolls around the longitudinal axis. This makes the aircraft turn left or right.

3. **What does the aircraft do around the vertical axis?**
   The aircraft yaws around the vertical axis. This makes the nose of the aircraft point left or right.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 3 Paper Axes

GRADES K-4

Time Requirements: 60 minutes

Materials:

In the Box

None

Provided by User

Pencils
(3 per student)

Tape

Scissors

Worksheets

Airplane Template
(Worksheet 2)

Reference Materials

None

Key Terms:

Lateral axis

Longitudinal axis

Pitch

Roll

Vertical axis

Yaw

Objective:

In this activity, students will improve their understanding of motions and forces, and transfer of energy, by studying the three axes the three axes of flight.

Activity Overview:

Students will build a model airplane and use pencils to demonstrate how the aircraft moves around each axis.

Activity:

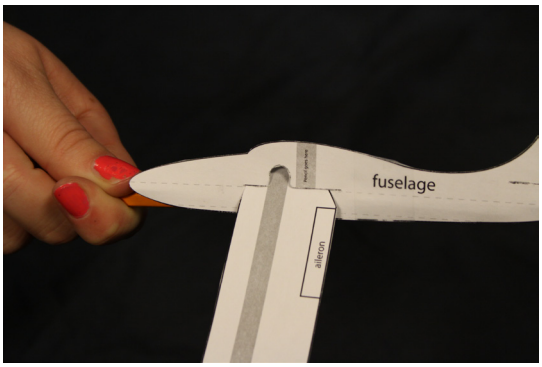
1. **If you have not completed Activity 2 – The Axes of Flight, use the Background information to discuss with the students each of the airplane's axes of motion.**

2. **Provide each student with a copy of the template (from the Airplane Template worksheet), a pair of scissors and 3 pencils.** Have the students perform each of the following steps, demonstrating as you go.
If available, printing the worksheet on heavy cardstock will greatly improve the quality of the final product.

3. **Cut out each of the airplane components.** Make holes in the center of the wing and fuselage where directed on the diagram.

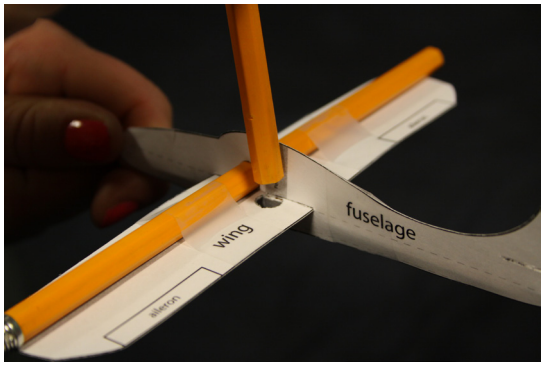
4. **Tape one pencil to the fuselage as marked on the diagram.**

5. **Slide the wing through the slot in the fuselage.**

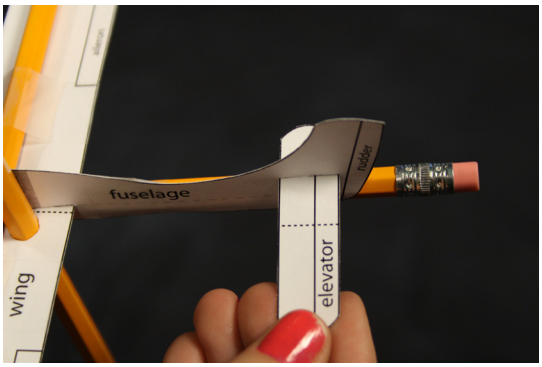


6. **Insert a pencil through the hole in the fuselage and tape it to the wing.**

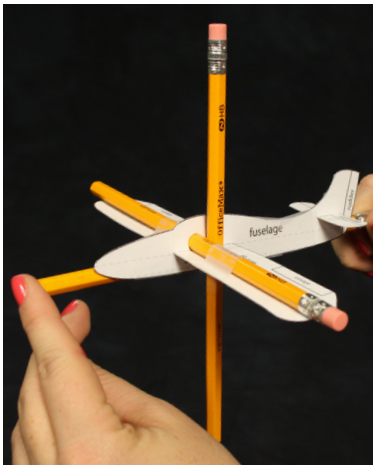
7. **Insert the third pencil through the hole made in the left wing, again taping it to the fuselage.**

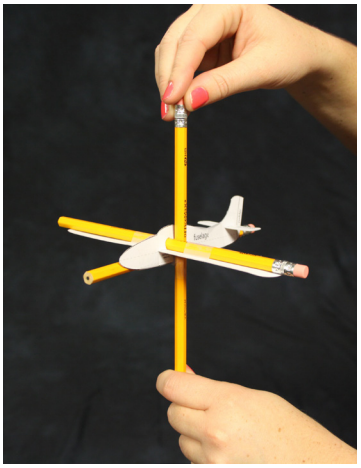


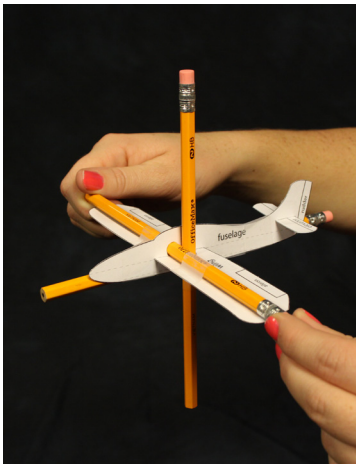
8. **Slide the elevator into the slot in the tail and tape it in place on either side.**



9. **Demonstrate to the students how the airplane rotates around each axis by twisting the pencils.** Have the students "fly" the aircraft, climbing, descending and turning the aircraft while moving it around the room.







Discussion Points:

1. **What axis does the aircraft pitch around?**
   The aircraft pitches around the lateral axis, making the aircraft climb or descend.

2. **What axis does the aircraft roll around?**
   The aircraft rolls around the longitudinal axis making the aircraft turn left or right.

3. **What axis does the aircraft yaw around?**
   The aircraft yaws around the vertical axis, keeping the nose and tail of the plane flying in a straight line.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Reference Materials

Glossary

Aileron:
The part of the airplane, located at the rear of the wing, that increases the lift on one wing while reducing the lift on the other in order to roll the aircraft sideways and allow it to turn

Axis:
An imaginary line around which an airplane can turn

Center of gravity (CG):
The effective point whereby all weight is considered to be; the same point where the axes of flight meet

Control surface:
Any part of an aircraft which can be moved to direct airflow, enabling the aircraft to roll, pitch and yaw

Drag:
The resistance of air against an aircraft's forward motion

Elevator:
The control surface usually located on the tail of an aircraft, used to stabilize the plane and enable pitch adjustments

Fuselage:
The body of an aircraft

Lateral axis:
The imaginary line, from wingtip to wingtip, about which an airplane pitches

Lift:
The force generated primarily by the motion of air passing over an aircraft's wings

Longitudinal axis:
The imaginary line, from nose to tail, about which an airplane rolls

Operational envelope:
A range in which the aircraft's center of gravity must be located in order to fly

Pitch:
The motion of an aircraft about the lateral axis, resulting in the nose and tail moving upwards and downwards

Roll:
The motion of an aircraft about the longitudinal axis, resulting in one wing raising while the other lowers (the plane rolls side-to-side)

Rudder:
An airplane's control surface, located on the tail, which helps to steer the aircraft

Thrust:
The force generated by the aircraft's propulsion system

Vertical axis:
The imaginary line that runs vertically (perpendicular to the longitudinal and lateral axes) through an aircraft's center of gravity, about which the plane yaws

Weight:
The force due to gravity which acts upon every object on Earth

Yaw:
The motion of an aircraft about the vertical axis, resulting in the plane moving horizontally left and right

Fig. 1 Four forces of flight

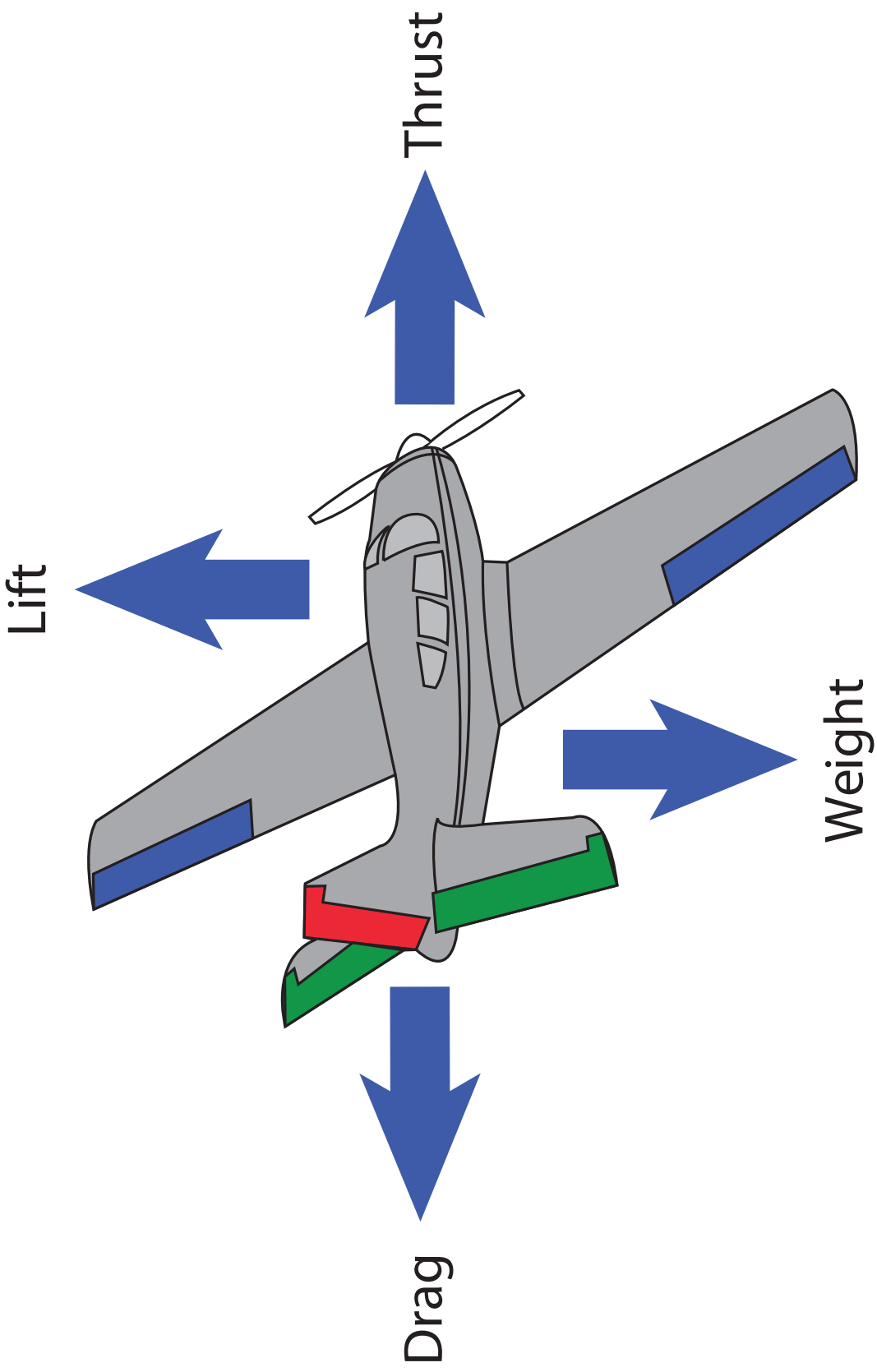


Fig. 2 The lift and weight forces of flight

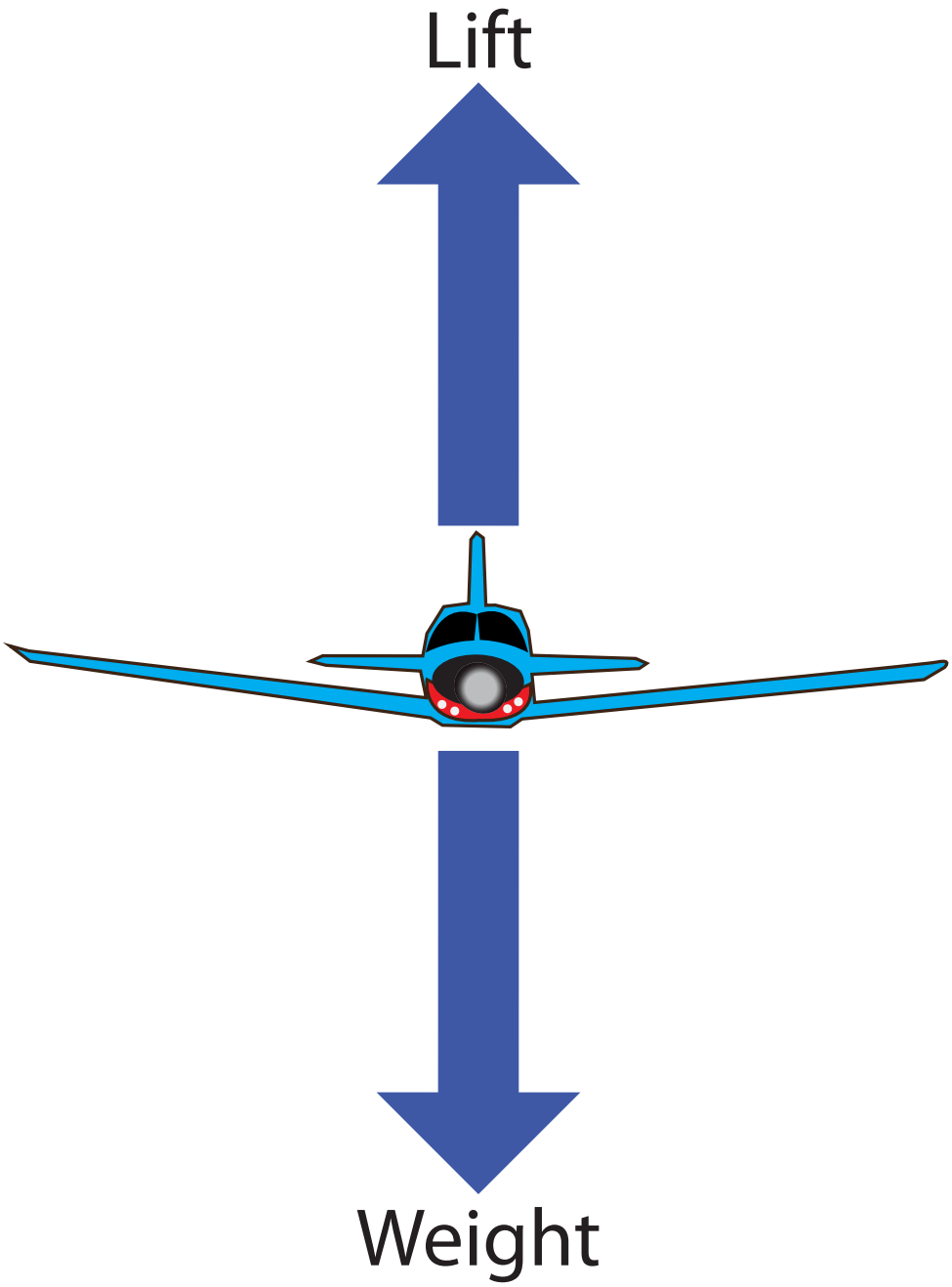


Fig. 3 Aircraft control surfaces

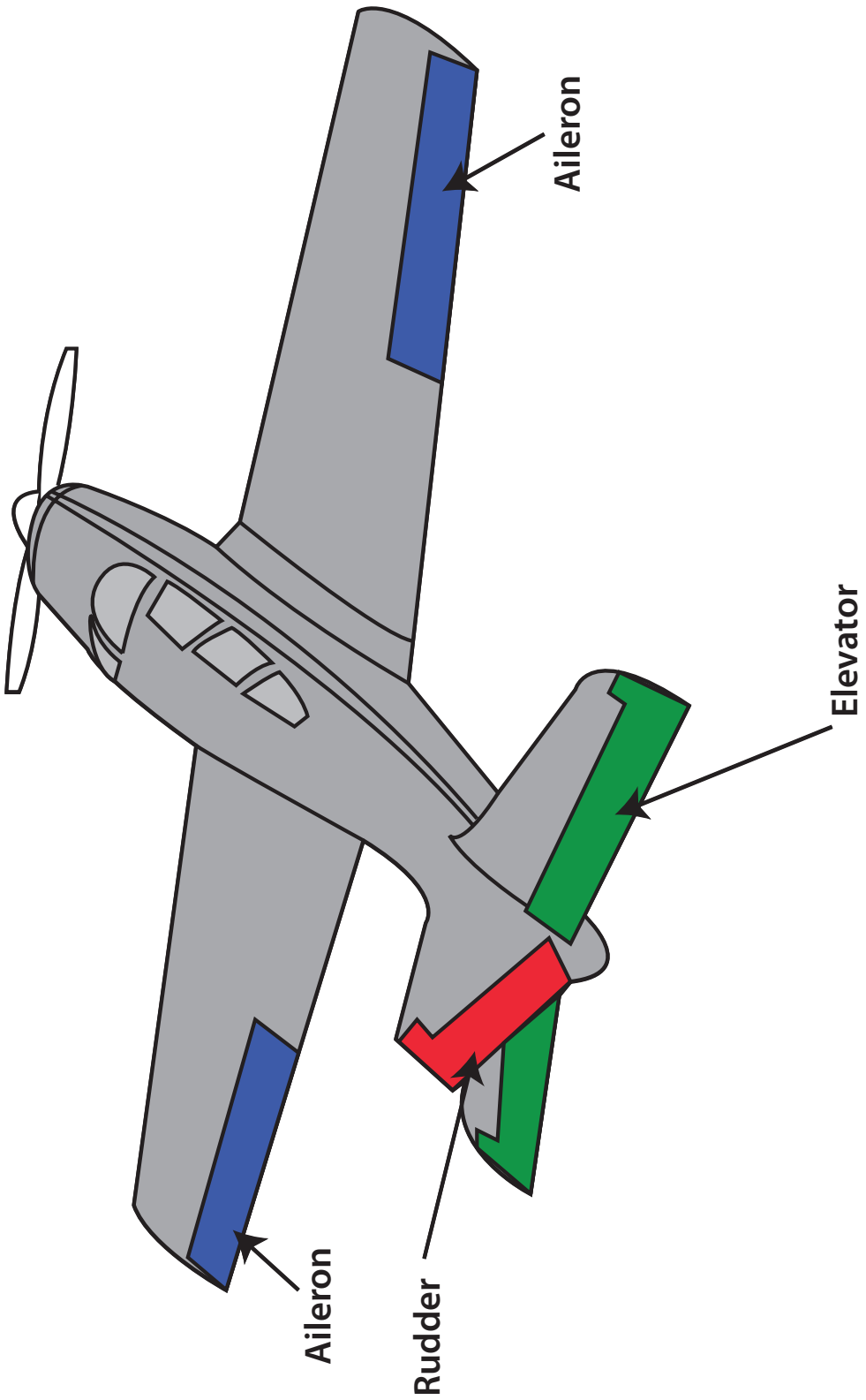


Fig. 4 Elevator and pitch movement

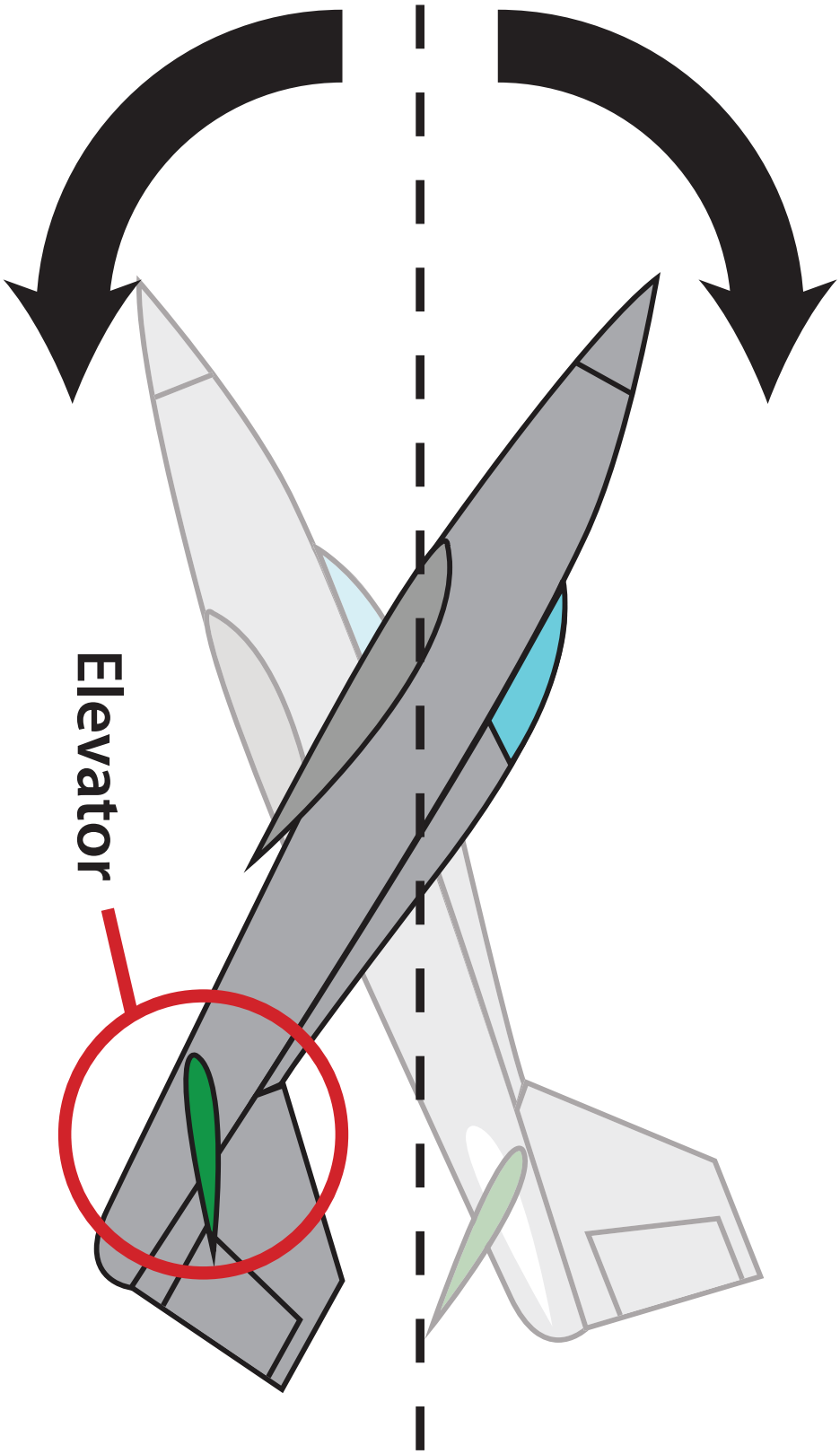


Fig. 5 Ailerons and roll movement

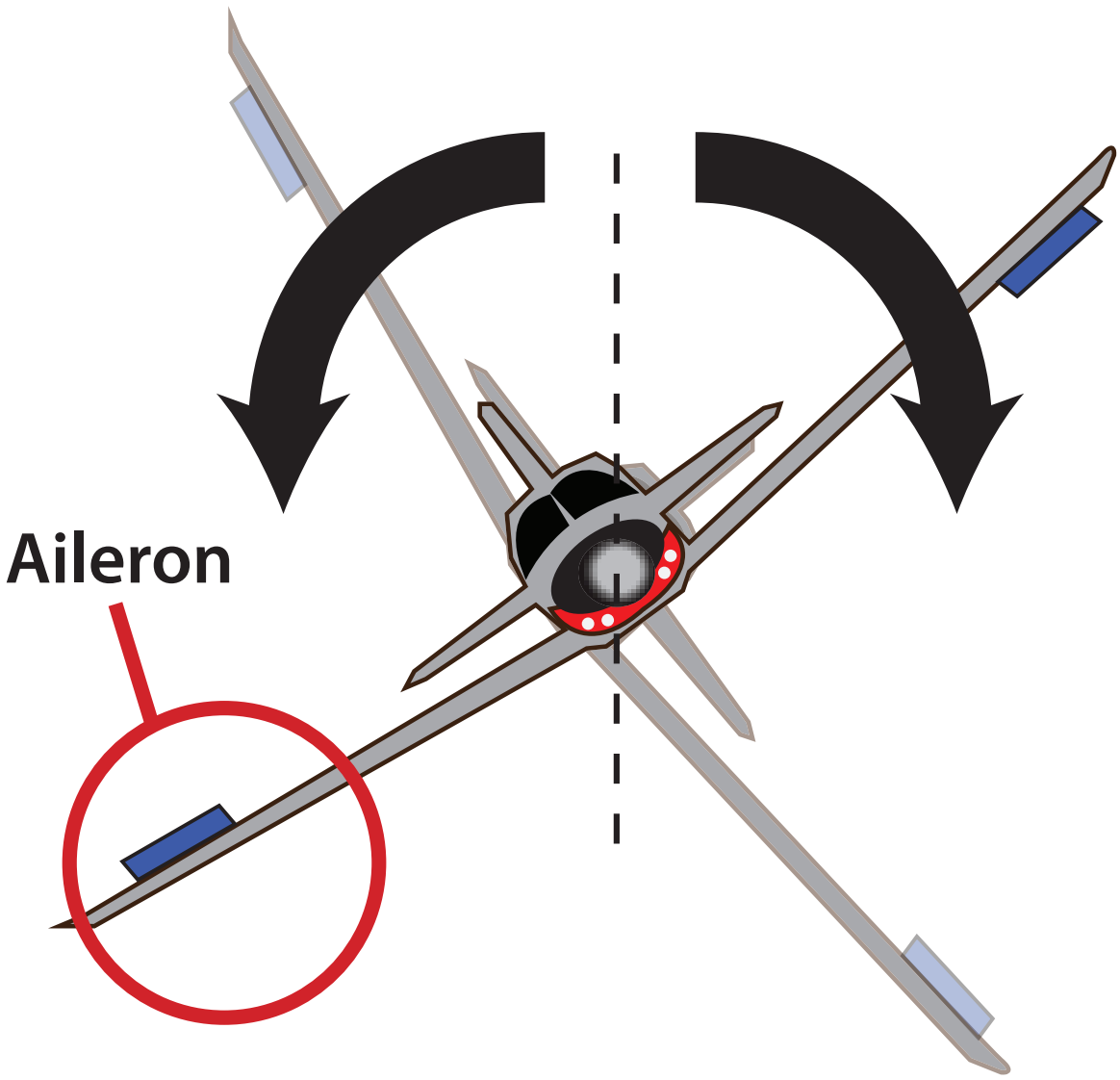


Fig. 6 Rudder and yaw movement

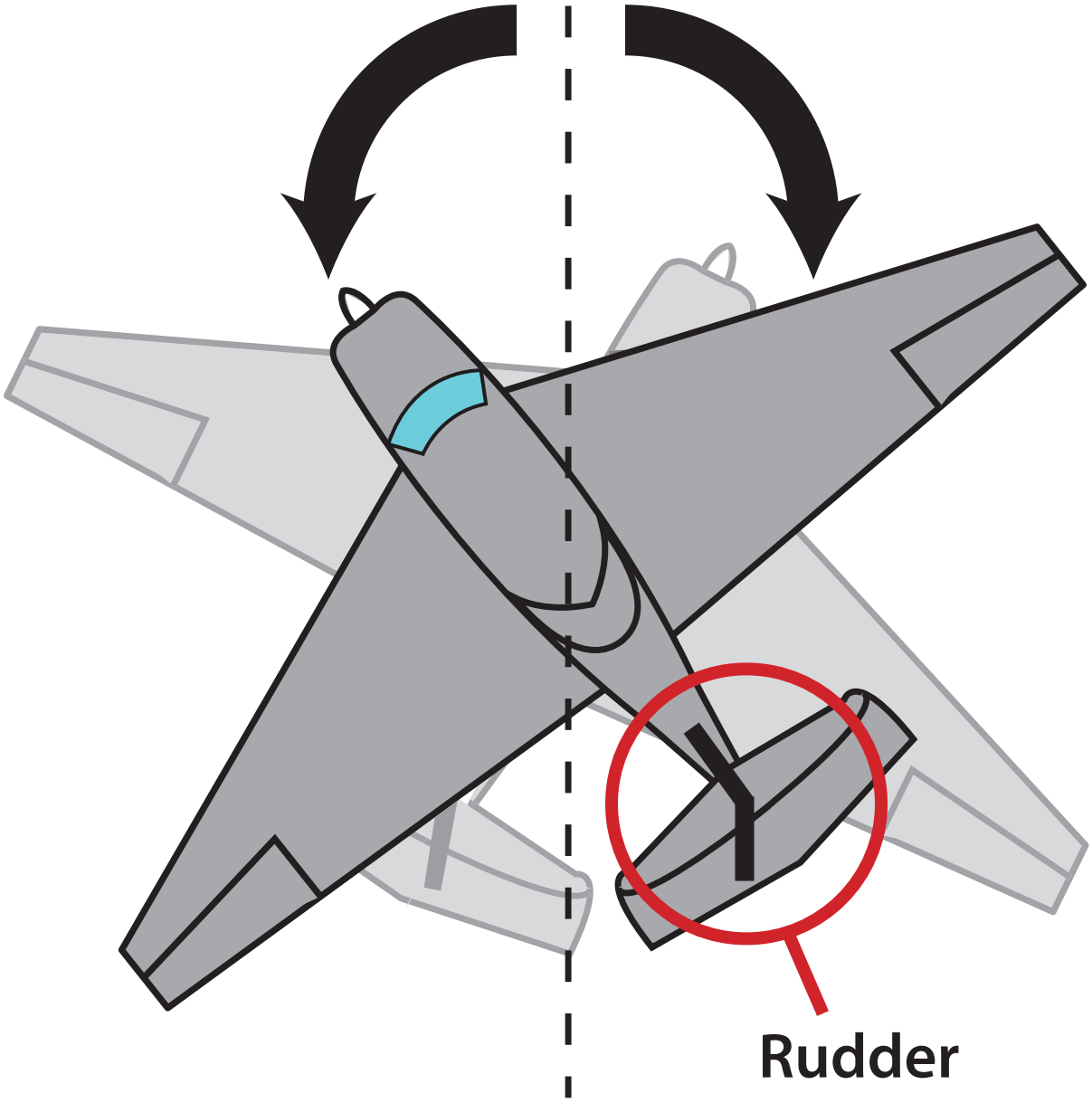


Fig. 7 The lateral axis

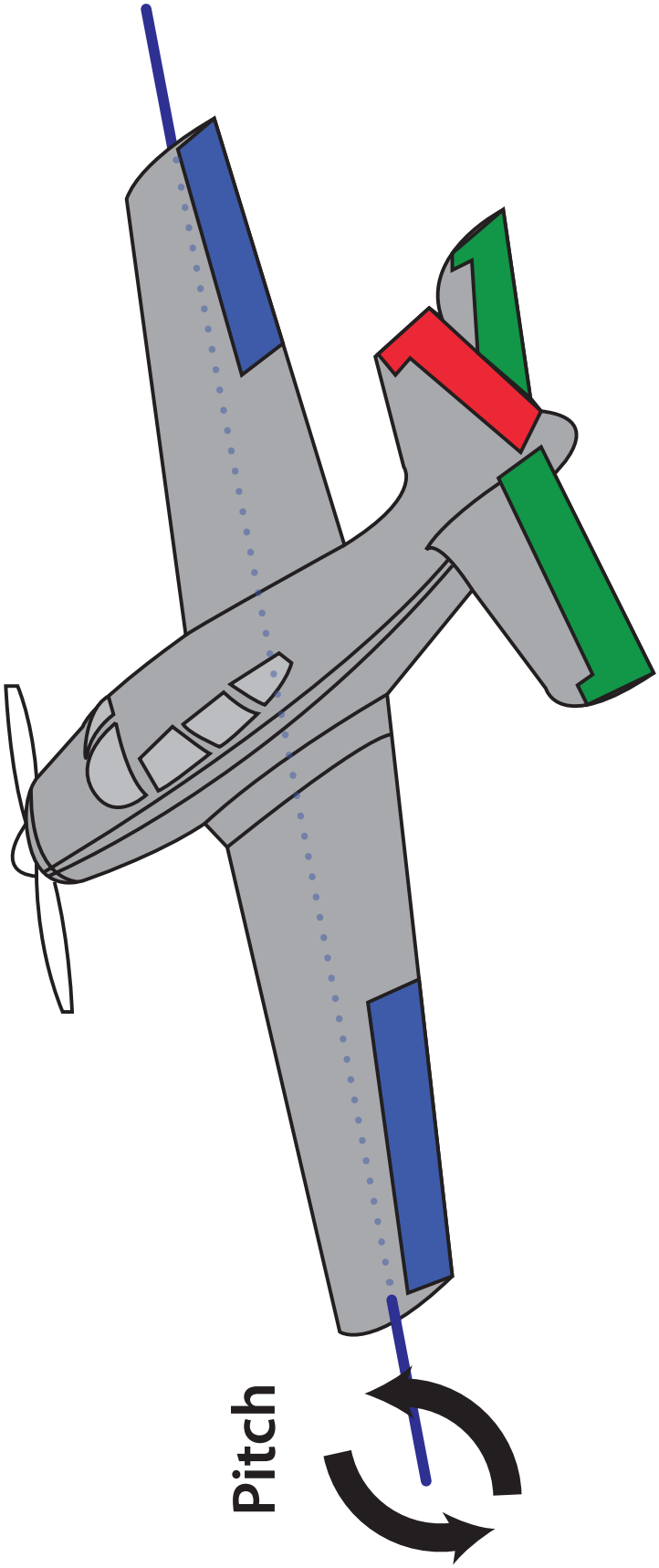


Fig. 8 The longitudinal axis

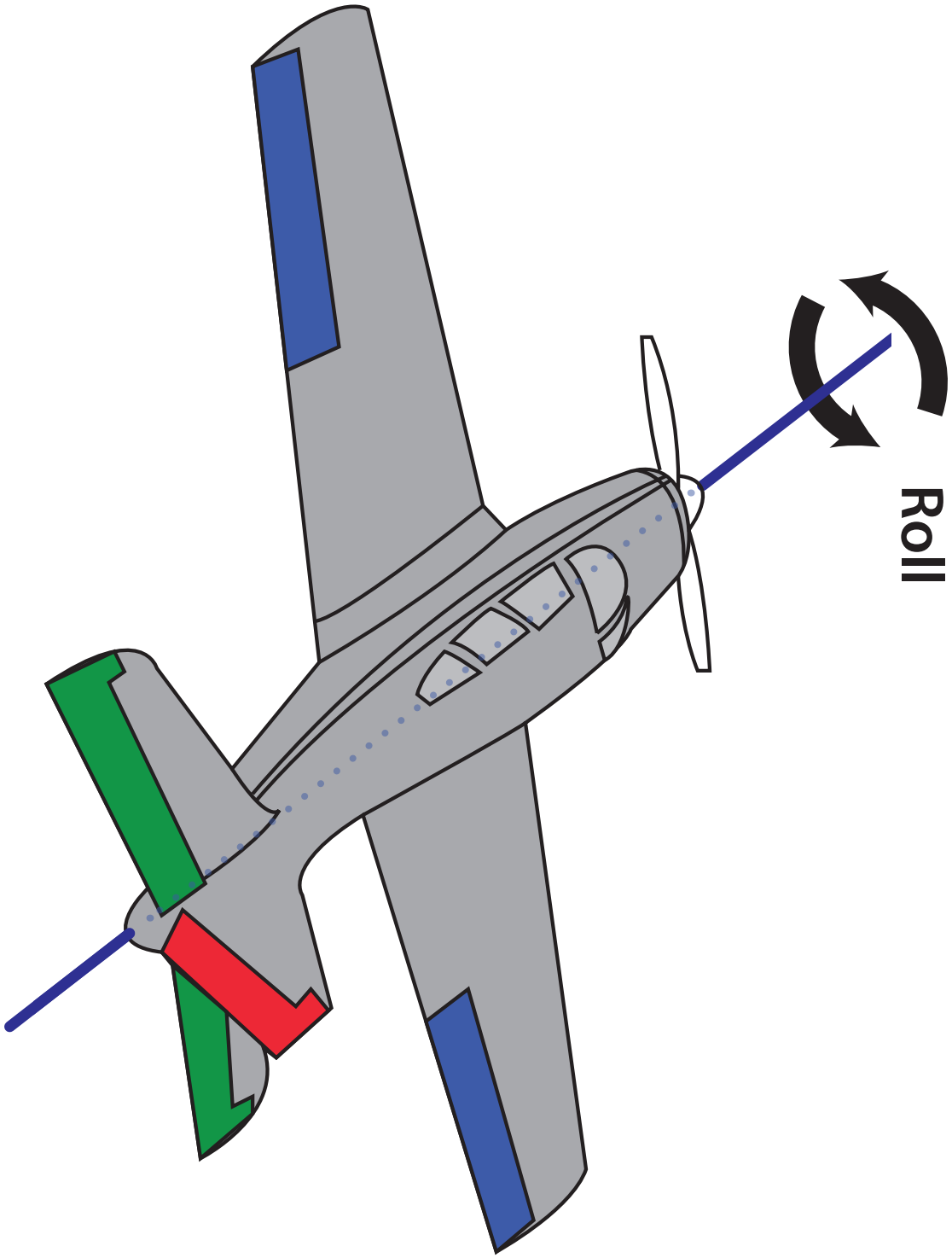


Fig. 9 The vertical axis

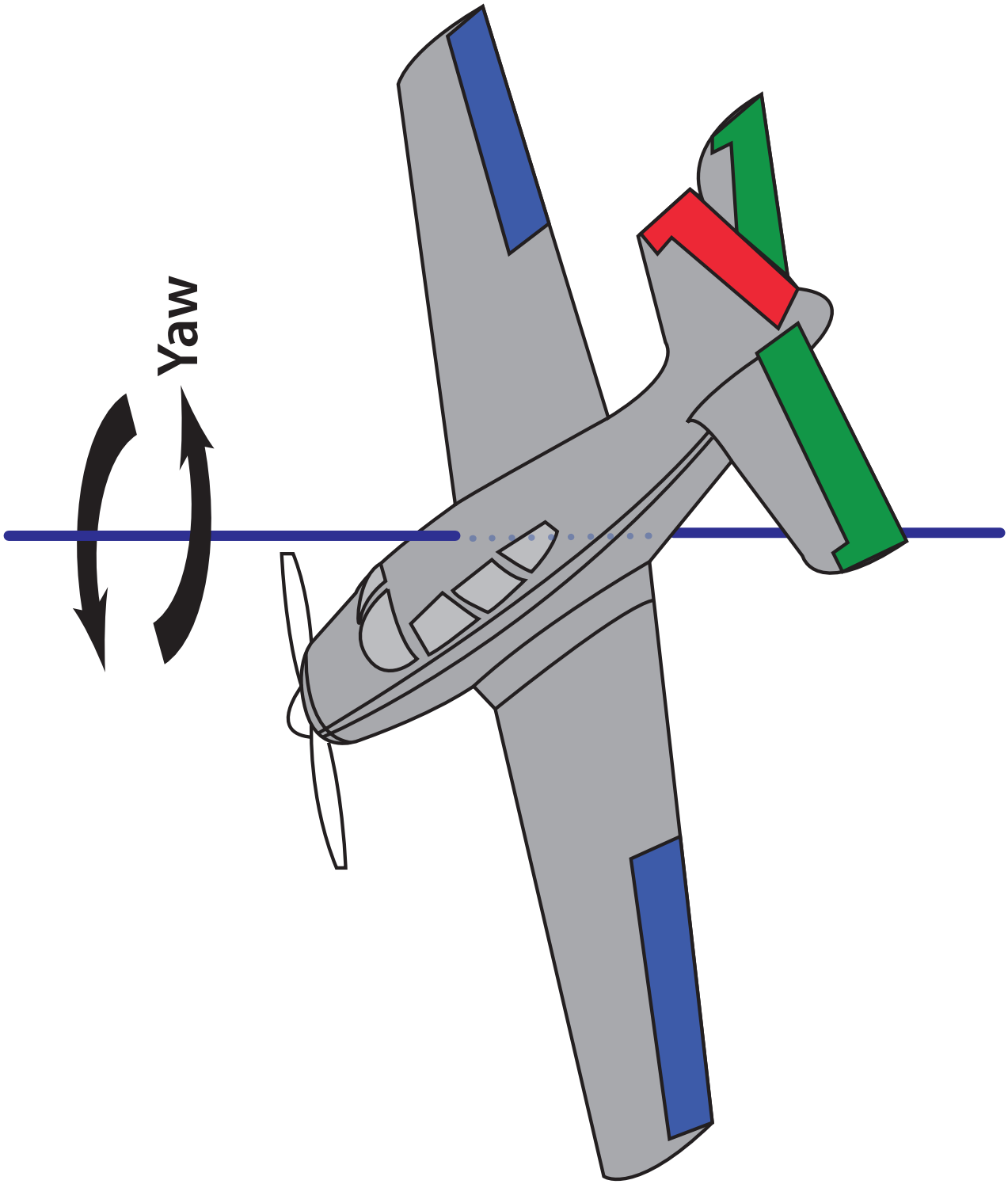
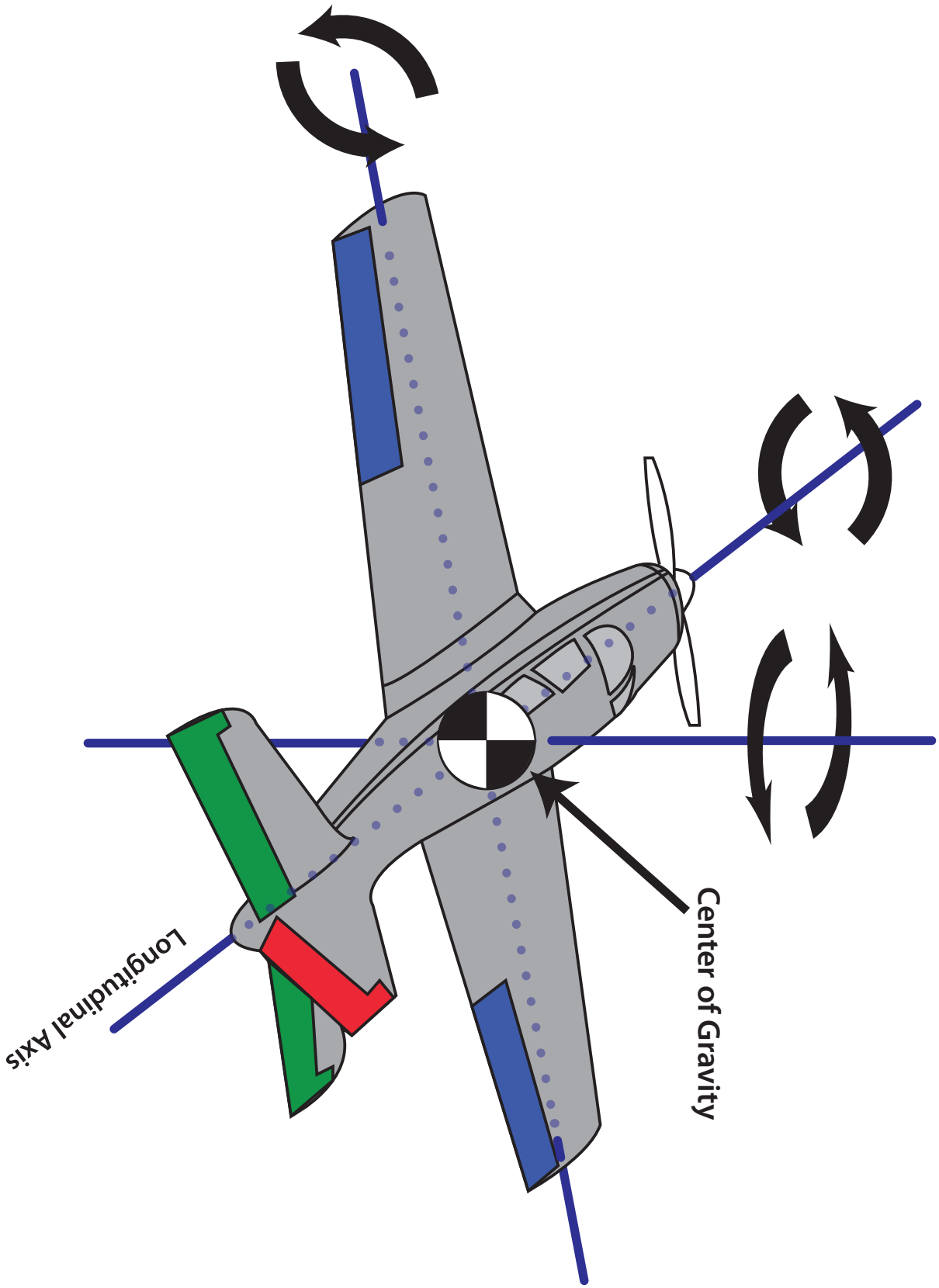


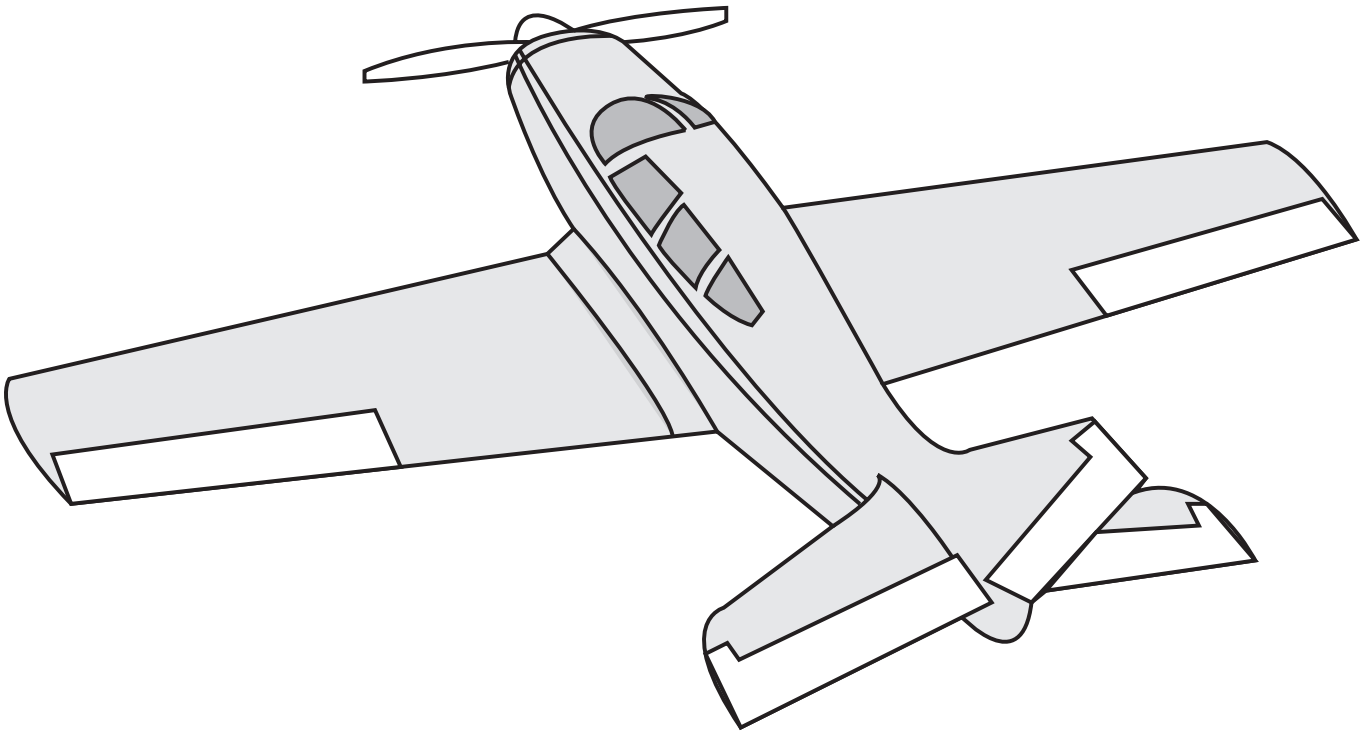
Fig. 10 Center of gravity



Worksheets

Worksheet 1 Parts of an airplane

Color code each of the airplane's control surfaces.



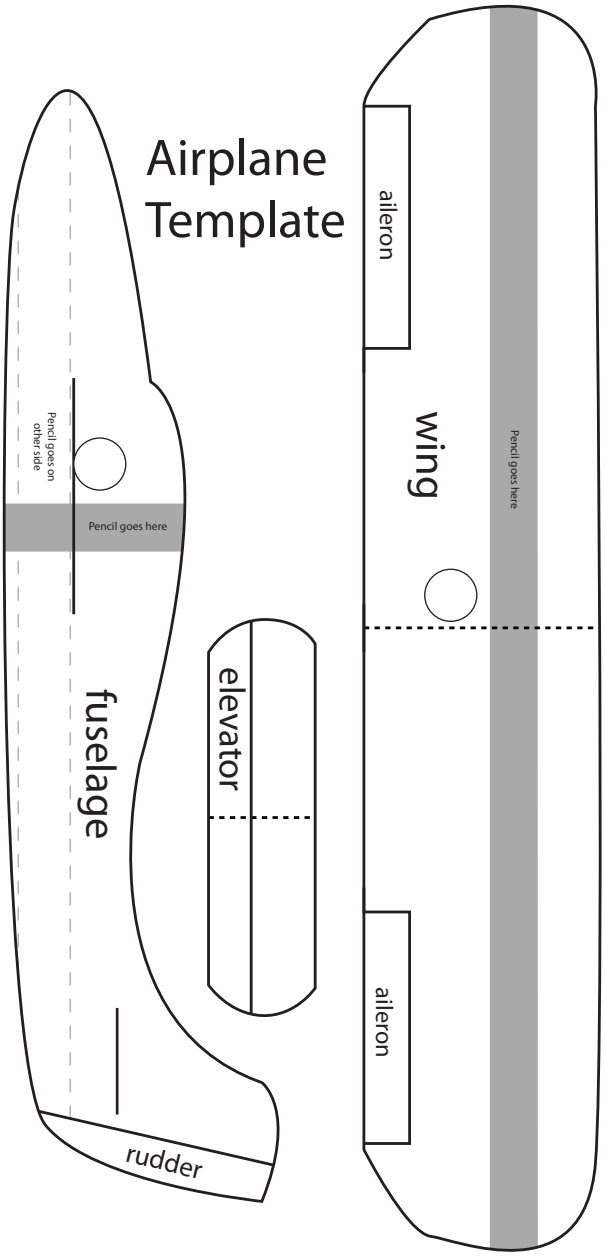
Aileron

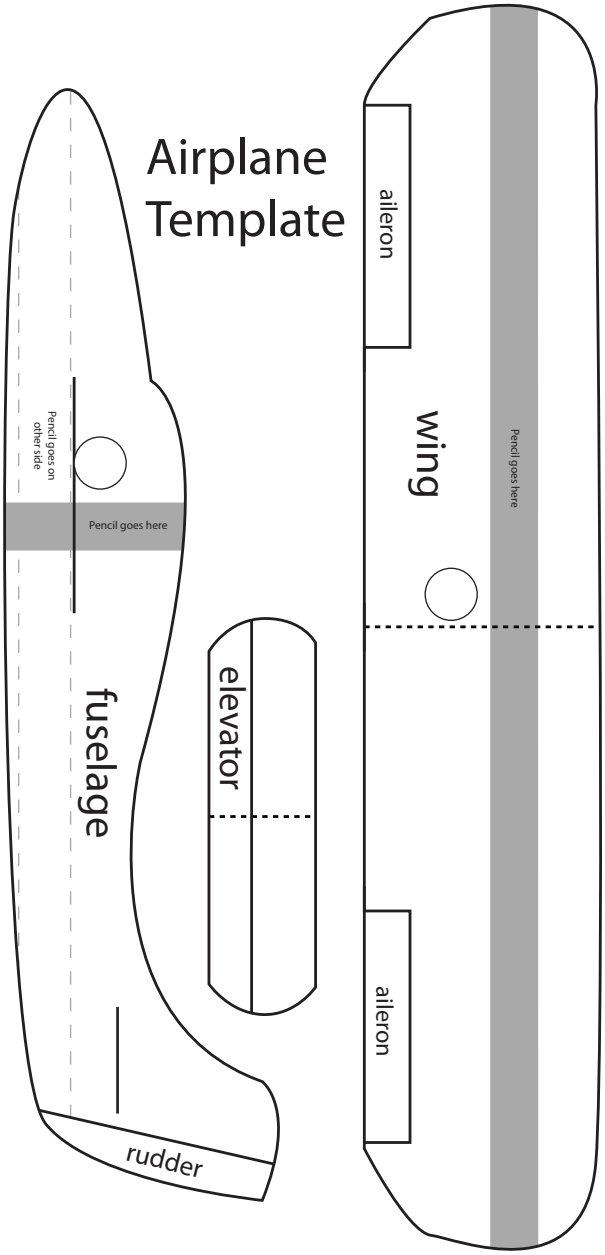
Rudder

Elevator

Worksheet 2

Airplane Template (2 per page)





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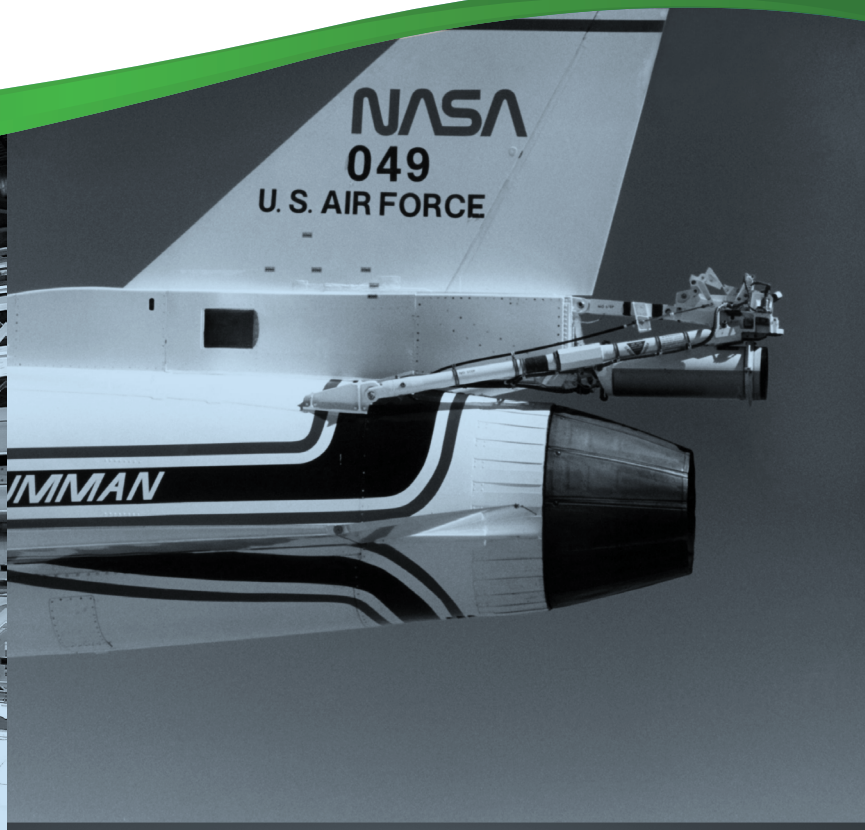

principles of flight

EP-2010-12-470-HQ