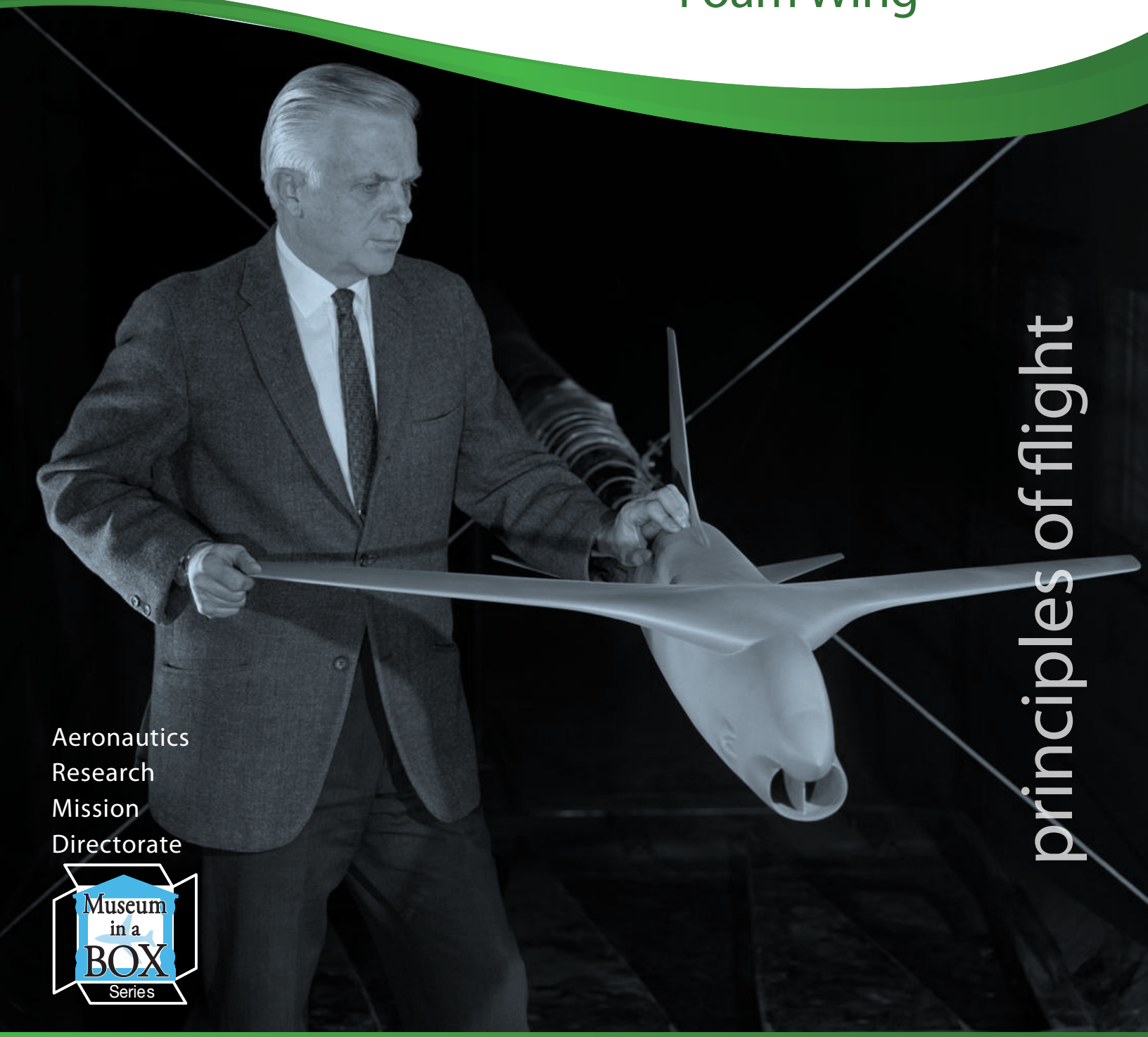
National Aeronautics and Space Administration

GRADES K-12

Foam Wing



principles of flight

Aeronautics
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Foam Wing

Lesson Overview

Participants in the foam wing activities will learn about motions and forces, and transfer of energy as they explore Bernoulli's Principle. They will also have the opportunity to wear a giant foam wing while standing before a simulated wind tunnel in order to experience the sensation of lift. The instructor will present information about airfoil design, lift, and the Bernoulli Principle for all participants, but those in the 5th – 12th grades may engage in a brief discussion about the Area Rule and the difference between laminar flow airfoils and conventional airfoils.

Objectives

Students will:

1. Identify the general design of an airfoil and relate the design to lift.
2. Explain how the Bernoulli Principle contributes to lift.
3. Explain how greater curvature on the top of an airfoil results in greater lift.
4. Experience the physical sensation of lift and drag during the foam wing simulation.
5. Explore NASA technologies including the Area Rule and fuel-efficient winglets.

Materials:

In the Box

Foam wing

Drinking straws

Fan

Provided by User

Paper

A quarter

GRADES **K-12** **Time Requirements:** 1 hour 10 minutes

Background

What causes an airplane to have lift? The 18th century Swiss physician and mathematician Daniel Bernoulli discovered that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure.

An airplane's wing has a special shape called an airfoil. The airfoil is shaped so that the air traveling over the top of the wing travels farther and faster than the air traveling below the wing. Thus, the faster moving air above the wing exerts less pressure than the slower moving air below the wing. According to the Bernoulli Principle, this pressure differential pushes the airplane upward, giving it lift.

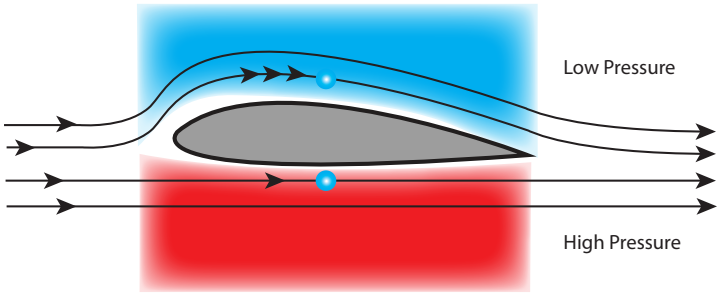


Fig. 1 Wing pressure areas

The Coanda Effect provides another important explanation for lift. While the shape of a wing (airfoil) is designed to create differences in air pressure, the Coanda Effect explains that a wing's trailing edge must be sharp, and it must be aimed diagonally downward if it is to create lift. Both the upper and lower surfaces of the wing act to deflect the air. The upper surface deflects air downwards because the airflow "sticks" to the wing surface and follows the tilted wing down. This phenomena is also called Flow Attachment. After the wing has passed through the air, the air must remain flowing downwards for the lifting force to work. The Coanda effect rarely occurs naturally but it can be produced on the wing of an aircraft to increase lift by a factor of 3. Vertical Takeoff and Landing (VTOL) aircraft as well as the C-17 Globemaster III utilize the Coanda effect. A method to produce the Coanda effect is to deflect a part of the exhaust from an aircraft engine over the wing of an aircraft in flight.

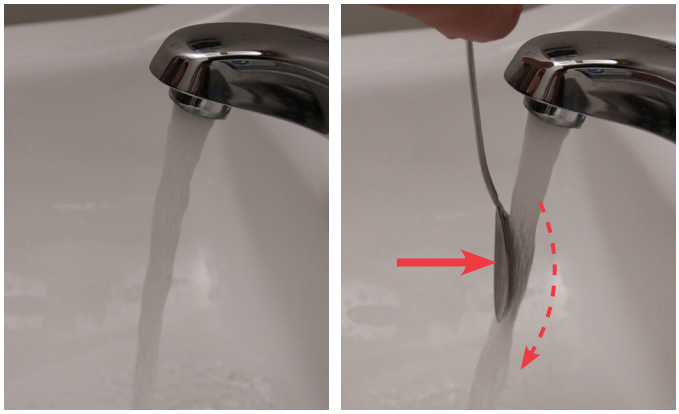


Fig. 2 Coanda effect

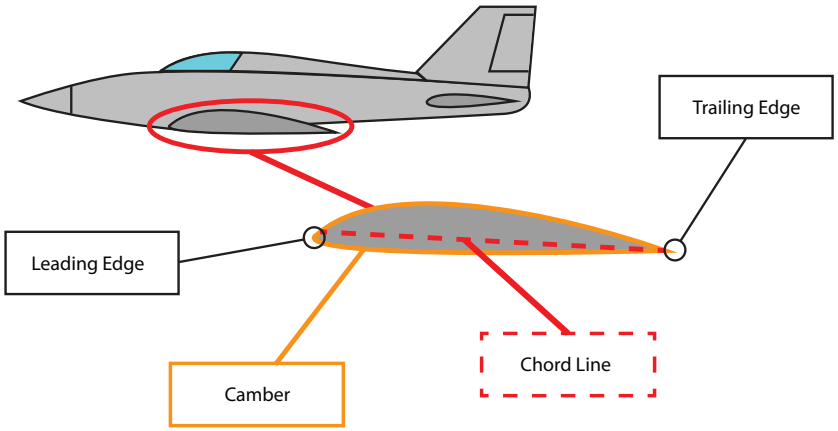


Fig. 3 Airfoil diagram

In general, the operation for which an airplane is designed determines the shape and design of its wings. If the airplane is designed for low-speed flight, a thick airfoil is most efficient, whereas a thin airfoil is more efficient for high-speed flight. There are generally two kinds of airfoils: laminar flow and conventional. Laminar flow airfoils were originally developed to make an airplane fly faster. The laminar flow wing is usually thinner than the conventional airfoil, the leading edge is also more pointed, and its upper and lower surfaces are nearly symmetrical. However, the most important difference between the airfoils is that the thickest part of a laminar flow wing occurs at 50% chord, while in the conventional design, the thickest part is at 25% chord (the distance from the leading to the trailing edges of a wing).

The laminar flow airfoil greatly reduces drag since it requires less energy to slice through the air. The pressure distribution on the laminar flow wing is more uniform since the camber of the wing from the leading edge to the point of maximum thickness is more gradual. The conventional airfoil is still preferred in commercial aircrafts though, because it is more resistant to stalling.

So what explains lift? Lift is explained in part by the Bernoulli Principle, the Coanda Effect, and Newton's Third Law of Motion.

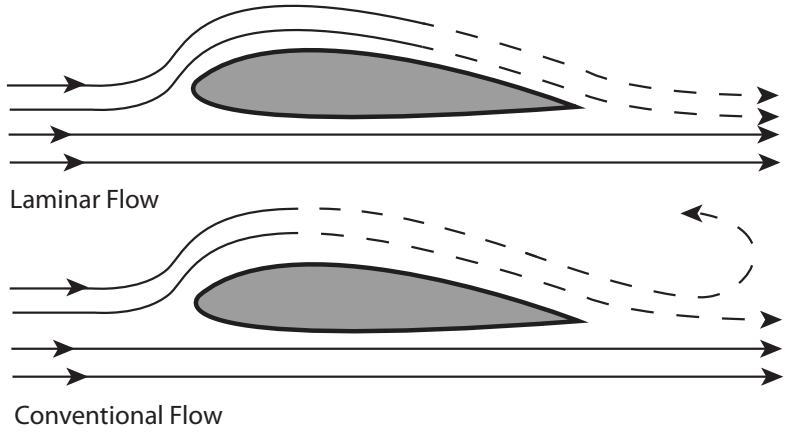


Fig. 4 Laminar vs conventional flow

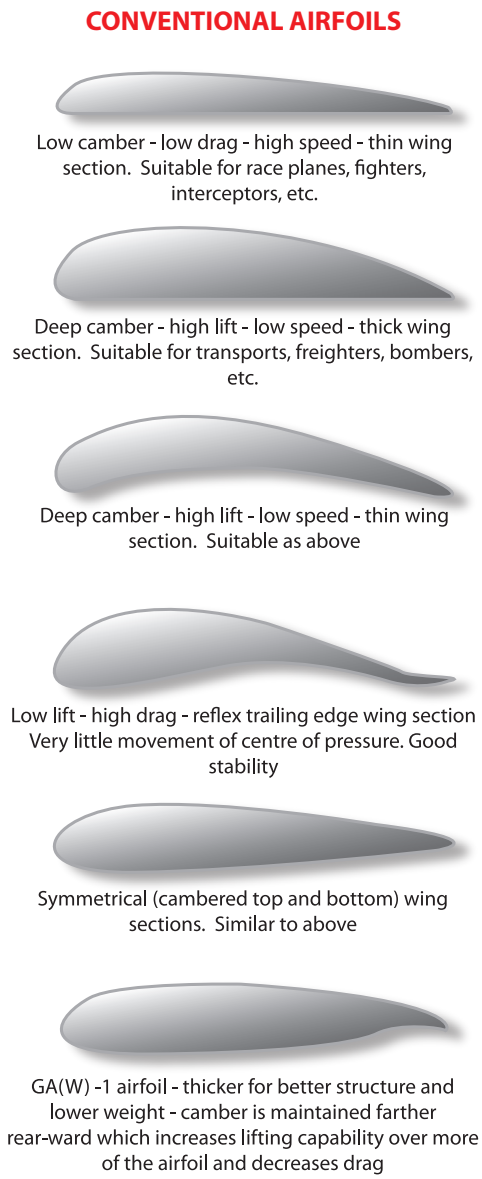


Fig. 5 Conventional airfoils

Activity 1 Paper Tent

GRADES K-12

Time Requirements: 10 minutes

Materials:

In the Box

A straight drinking straw

Provided by User

Paper

Worksheets

None

Reference Materials

None

Key Terms:

Air pressure
Bernoulli Principle
Camber
Chord
Lift
Newton's Third Law

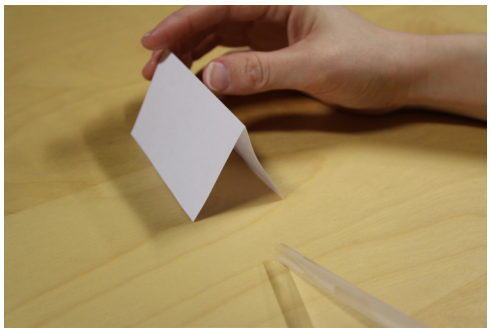
Objective:

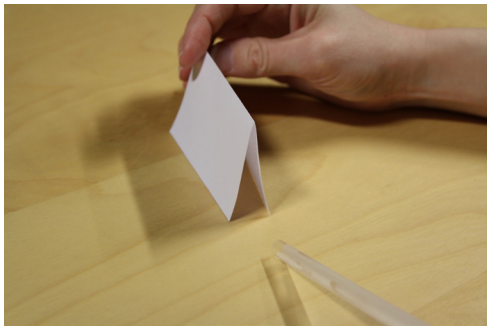
In this lesson .students will learn about motions and forces as they observe the Bernoulli Principle at work.

Activity Overview:

In this lesson students will experiment with the Bernoulli Principle using a straw and piece of paper.

Activity:





1. **Distribute a straw and piece of paper to each participant.**
2. **Participants should fold the paper in half to make a tent.**
3. **Have participants set the paper tent on a table and then predict what will happen if they blow air forcefully through the inside of the tent.**
4. **Once predictions have been made, have participants perform the activity.** Instruct students to blow forcefully but to keep the airflow steady (making sure not to just make a short, forceful burst). Participants will observe that when air is blown forcefully, but steadily, under the paper tent, the sides of the tent will pull together.
5. **Ask the participants: Why did the tent pull together?**
6. **Explain that the Bernoulli Principle states that the fast-moving air under the tent creates an area of low pressure in that location, and the resulting higher air pressure on the outside of the tent pushes the tent downward.**

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

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

PHYSICAL SCIENCE

- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

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

PHYSICAL SCIENCE

- Motions and forces

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

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

PHYSICAL SCIENCE

- Motions and forces
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2 Bernoulli Coin Experiment

GRADES K-12

Time Requirements: 15 minutes

Materials:

In the Box

1 straw per student

Provided by User

A Quarter (one per student)

One-inch squares of paper (one per student)

Paper

Worksheets

None

Reference Materials

None

Key Terms:

Lift

Objective:

In this lesson students will learn about motion and forces as they observe the Bernoulli Principle at work.

Activity Overview:

In this lesson students will experiment with the Bernoulli Principle using a quarter and small piece of paper.

Activity:

1. **Have participants place a 1-inch square of paper in the palm of their hands.**
2. **Instruct participants to hold a quarter, face up between their thumb and forefinger, about an inch above the paper square and ask:** ***How can you get the paper square to stick to the coin without touching the paper square?***
3. **Tell participants to blow a steady stream of air forcefully and directly on the upward facing surface of the coin.** This takes a little practice, but the paper square should rise toward the underside of the coin and "stick" there as long as the participants continue to blow. Participants may use a straw to blow on the quarter if desired.
4. **Ask:** ***What caused the paper to lift?*** Explain that the faster moving air above the coin creates an area of low pressure, and since the air pressure below the paper is greater, the high pressure pushes the paper square upward and against the coin. The paper appears to stick to the coin.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
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PHYSICAL SCIENCE

- Motions and forces

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
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NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

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

PHYSICAL SCIENCE

- Motions and forces

Activity 3 Foam Wing

GRADES K-12

Time Requirements: 40 minutes

Materials:

In the Box

Foam wing

Provided by User

A quarter
Paper

Worksheets

None

Reference Materials

Airfoil diagram (figure 3)
Conventional airfoils (figure 4)
Winglets (image 2)

Key Terms:

Air foil
Air pressure
Air resistance
Area Rule
Bernoulli Principle
Camber
Chord
Coanda Effect
Drag
Laminar flow
Mach Number
Supersonic
Transonic

Objective:

In this lesson students will learn about motions and forces as they:

1. Examine a giant foam wing and discuss the shape of the wing and airfoil, relating how the wing is shaped to create lift.
2. Experience the potential of lift while wearing a giant foam wing and standing in a stream of air from a fan that is meant to simulate a wind tunnel.

Activity Overview:

In this activity, participants will have the opportunity to wear an arm-sized foam wing and stand in a simulated wind tunnel in order to experience the potential of lift.

Activity:

1. **Show participants the giant foam wing.** Ask them to make a few preliminary observations about the wing.
2. **Direct participants to examine the shape of one of the wing's airfoils, which you will define as the cross-section of the wing.** Ask participants to describe the shape of the airfoil. They will probably recognize that the upper surface of the airfoil is curved while the underside is relatively flat.
3. **Show students the diagram of the airfoil.** Discuss the locations and definitions of: camber, chord, leading edge, and trailing edge.
4. **Ask participants to identify the leading edge, trailing edge, camber, and chord of the foam wing**.

5. **Explain how air traveling over the curved upper surface of the wing moves faster than air moving under the wing.** The faster air flowing over the top of the wing creates lower pressure than the slower moving air under the wing. Lift is partially achieved because high-pressure air pushes toward low-pressure air, pulling the airplane upward.

6. **Show the participants the diagram of conventional airfoil shapes.** Discuss how the shape of an airfoil will depend on the function of the airplane.

7. **Select a participant to wear the giant foam wing.** Have that participant stand in the simulated wind tunnel (the stream of air coming from the fan) in order to simulate a "lift" experience. Make sure the participant directs the leading edge of the wing into the wind while holding on to the internal handgrips in order to maintain control of the wing's position.

8. **Ask:** ***If our wing wearer were to flap the wing, would he/she be able to achieve lift?*** Participants will likely answer that lift would not be possible because the mass of the person wearing the wing is too great compared to the size of the wing. In addition, lift needs thrust (Newton's third law). Because there is no thrust, it is not possible for a person wearing the wing to fly."

9. **Ask the wing-wearing participant:** "So while you cannot actually fly with the giant foam wing, can you feel the potential of lift?"
   Students should be able to feel the lift potential.

10. **Now have the wing-wearing participant tilt the wing's leading edge upward.**

11. **Ask:** "What do you feel now?"
    Students should be able to feel resistance or drag.

12. **Elaborate on the participant's response by introducing the terms: drag, air resistance, air pressure, Coanda Effect, the Bernoulli Principle and Newton's Third Law.** Determine how complex your explanations may need to be based on the ages and experiences of your audience.

13. **Next, have the participant wearing the wings pivot those wings so that the leading edge is angled slightly downward.**

14. **Ask:** "What do you feel now?"
    Students should be able to feel more pressure on the top of the wing than they did with the wing tilted in the other direction.

15. **Have the participant compare and describe the feeling of different wing angles.**

16. **Allow other participants to wear the wings.** Have each participant experiment with other movements, such as quickly changing from an upward to a downward tilt and back again. Try flapping or pivoting the wings so the tip of the wing is facing the wind (fan).

17. **Ask the participants to verbalize the physical feelings they experience and make connections to what they have learned about drag and lift.**

18. **After allowing students to experience lift in the simulated wind tunnel, explain that NASA engineers and scientists continue to test different airplane models in wind tunnels and simulate flight on computers in order to advance their understanding of flight.** Through their research, NASA researchers and engineers are able to design and build safer, quieter, and more fuel-efficient airplanes.

19. **At this point older participants may be introduced to the Area Rule, a theory introduced in the 1950s by NASA scientist Richard Whitcomb.** In 1952, Richard Whitcomb discovered an important aeronautical design process while working at the NASA Langley Research Center in Langley, Virginia. His design process is most often referred to as the Area Rule (Fig 6.). What Whitcomb discovered was that by narrowing the fuselage of an airplane, the drag of an aircraft could be reduced while at the same time provide an increase of aircraft speed without the addition of power. The fuselage is the body of the airplane that holds together all parts of an aircraft. Airplanes that employ the Area Rule have a fuselage resembling an old fashion "Coke bottle."

Img. 1 Richard Whitcomb

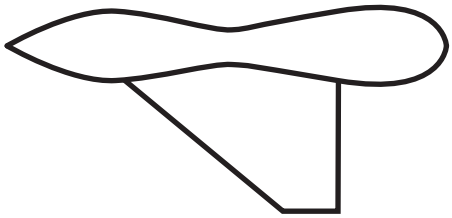

Fig. 6 Area rule

Since 1952, aircraft designers have been utilizing Whitcomb's Area Rule to design aircraft that fly higher, faster, and farther (Fig. 7).

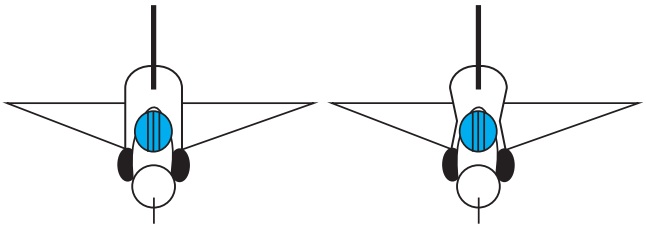

Fig. 7 Before and after area ruling

20. **Explain that in addition to Whitcomb's Area Rule, winglets are one of the most successful examples of a NASA aeronautical innovation that is presently being utilized all around the world on all types of aircraft.**

Img. 2 Winglets

When the price of aircraft fuel was increasing in the 1970s, aircraft designers began to look for additional ways to improve fuel efficiency. During that time, Richard Whitcomb advanced the concept for winglets through wind tunnel tests and computer studies at the NASA Langley Research Center. Winglets (Img. 2) are vertical extensions on wingtips that improve an aircraft's fuel efficiency and cruising range. Designed as small airfoils, winglets reduce the aerodynamic drag associated with vortices that develop at the wingtips as the airplane moves through the air. Vortices are tubes of rotating air that are left behind a wing as it produces lift.

Img. 3 A Boeing B-1B Lancer over the Pacific ocean

Through his research, Whitcomb concluded that winglets produced twice the benefit of a wingtip extension with the equivalent area. As a result, winglets imposed much less weight and drag penalty than increased wingspan. By reducing wingtip drag, fuel consumption goes down and range is extended.

Aircraft of various types and sizes can have winglets, from single-seat hang gliders and ultra-lights all the way up to jumbo jets.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
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SCIENCE AND TECHNOLOGY

- Abilities of technological design
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NATIONAL SCIENCE STANDARDS 5-8

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NATIONAL SCIENCE STANDARDS 9-12

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- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

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- Understanding about science and technology

Reference Materials

Glossary

Airfoil:
The cross-section of an airplane wing

Air pressure:
The force exerted on objects by the weight of tiny particles of air (air molecules)

Air resistance:
Also known as drag

Area Rule:
Developed by Richard Whitcomb, the Whitcomb Area Rule is also known as the Transonic Area Rule; the Area Rule is used in the design of an aircraft to reduce its drag at transonic and supersonic speeds, particularly between Mach 0.75 and 1.2

Bernoulli Principle:
A physical phenomenon named after the Swiss scientist Daniel Bernoulli who lived during the eighteenth century; the principle states that "the pressure of a fluid [liquid or gas] decreases as the speed of the fluid increases"

Camber:
The asymmetry between the top and the bottom surfaces of an airfoil; an airfoil that is not cambered is called a symmetric airfoil

Chord / Chord Line:
The distance from the leading to the trailing edges of a wing

Coanda Effect:
A phenomenon in which a stream of air or liquid attaches itself to a nearby surface

Drag:
The aerodynamic force that opposes an aircraft's motion through the air; drag is a mechanical force generated by the contact of a solid body with a fluid (liquid or gas)

Laminar Flow:
A non-turbulent flow that occurs when a fluid flows in parallel layers with no disruption between the layers

Leading Edge:
The part of the wing that first contacts the air; alternatively it is the front edge of a wing

Lift:
The force that directly opposes the weight of an airplane and helps keep the airplane in the air

Mach number:
The Mach number is given as a ratio to the speed of sound; for example an aircraft flying at 1.5 times the speed of sound is traveling at Mach 1.5

Newton's Third Law:

A physical law that states that for every action of motion there is an equal and opposite reaction

Supersonic:

A speed greater than the speed of sound in a given medium, especially air; M (Mach) = 1.2 to 5.0 supersonic

Trailing edge

The rear edge of the wing; where the airflow separated by the leading edge rejoins

Transonic:

Speeds close to the speed of sound; M (Mach) = 0.8 to 1.2

Fig. 1 Wing pressure areas

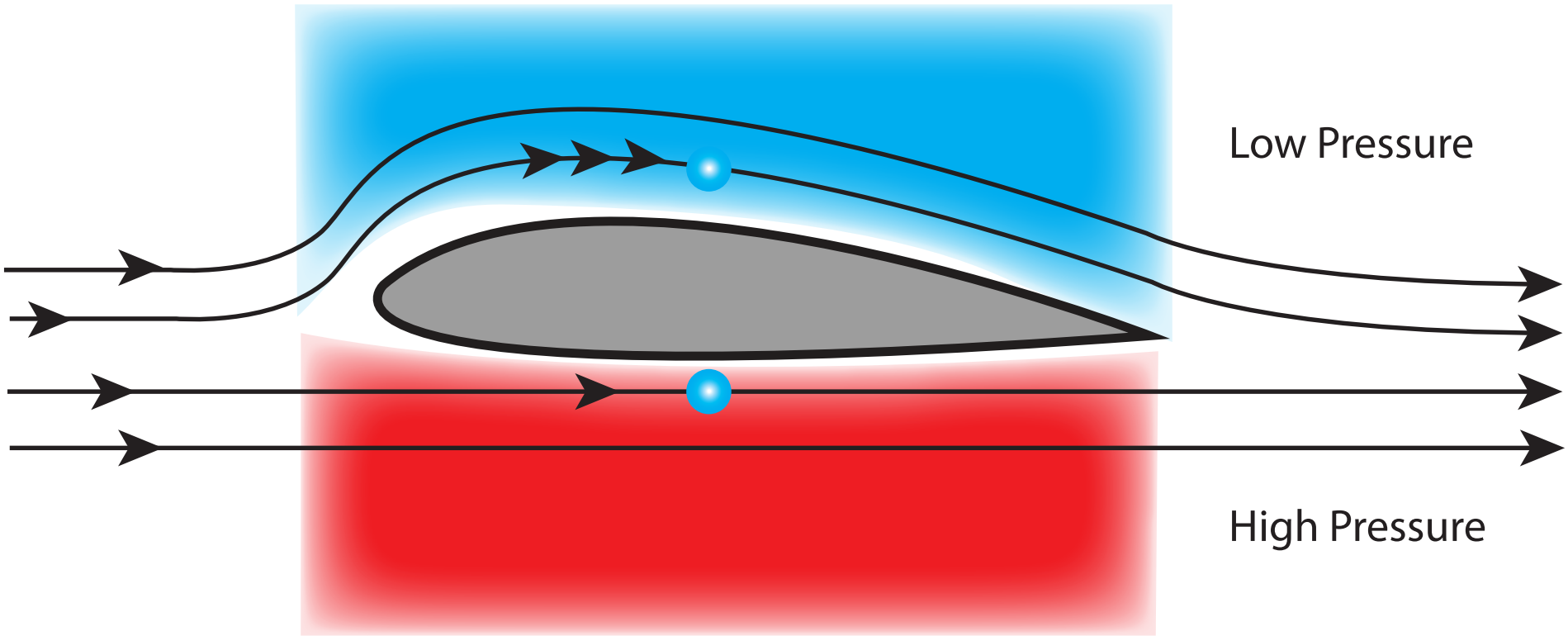


Fig. 2 Coanda effect

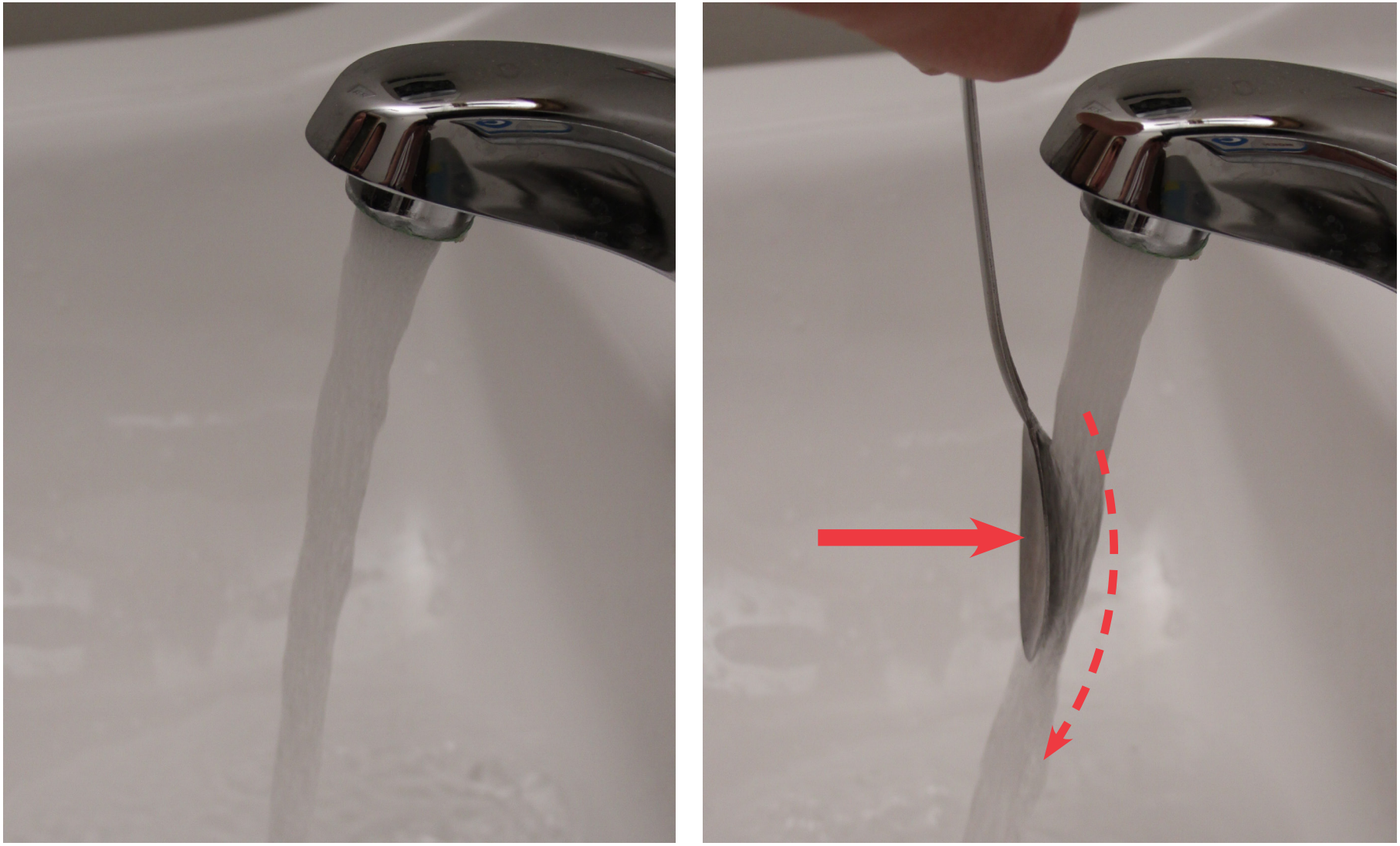


Fig. 3 Airfoil diagram

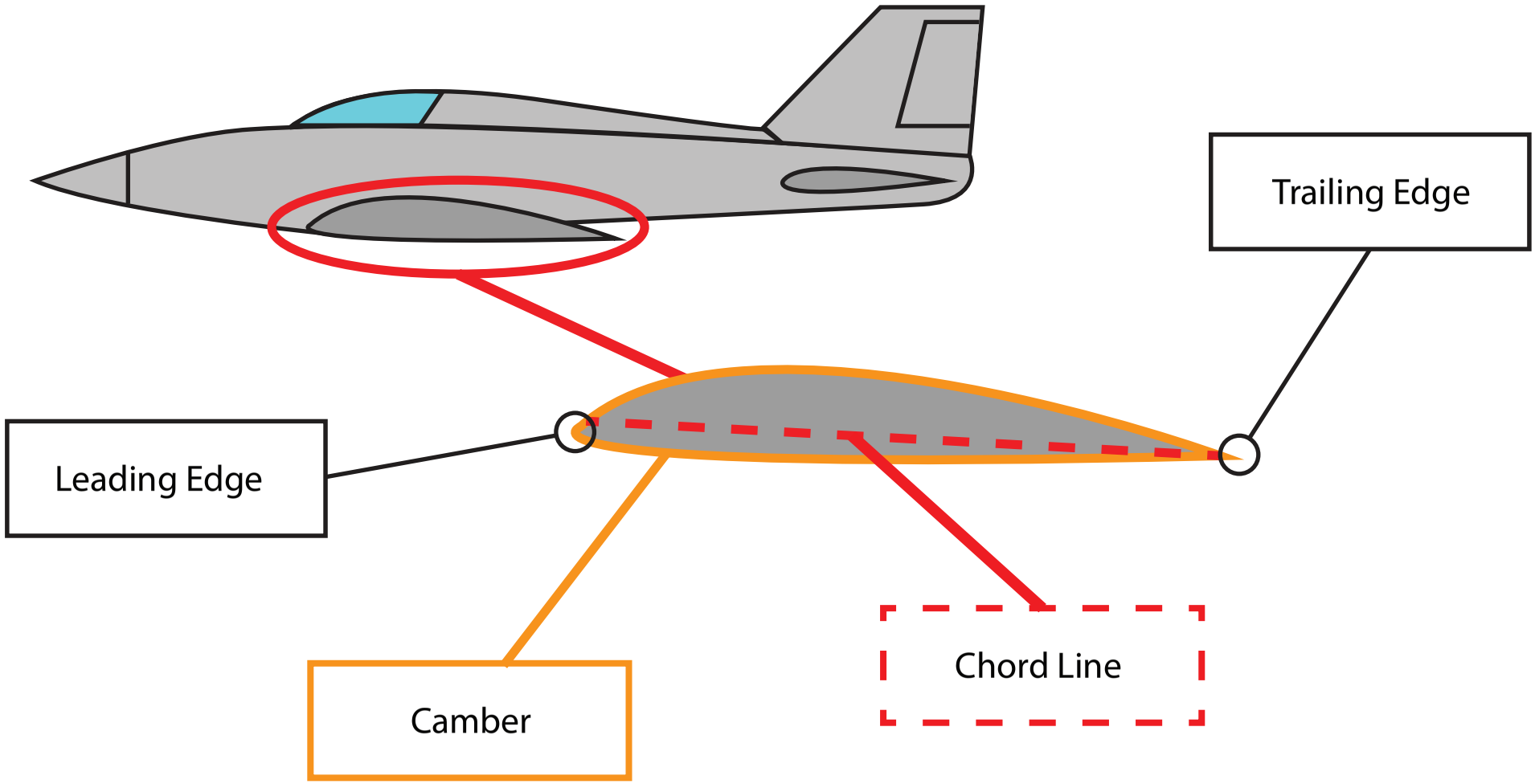


Fig. 4 Laminar vs conventional flows

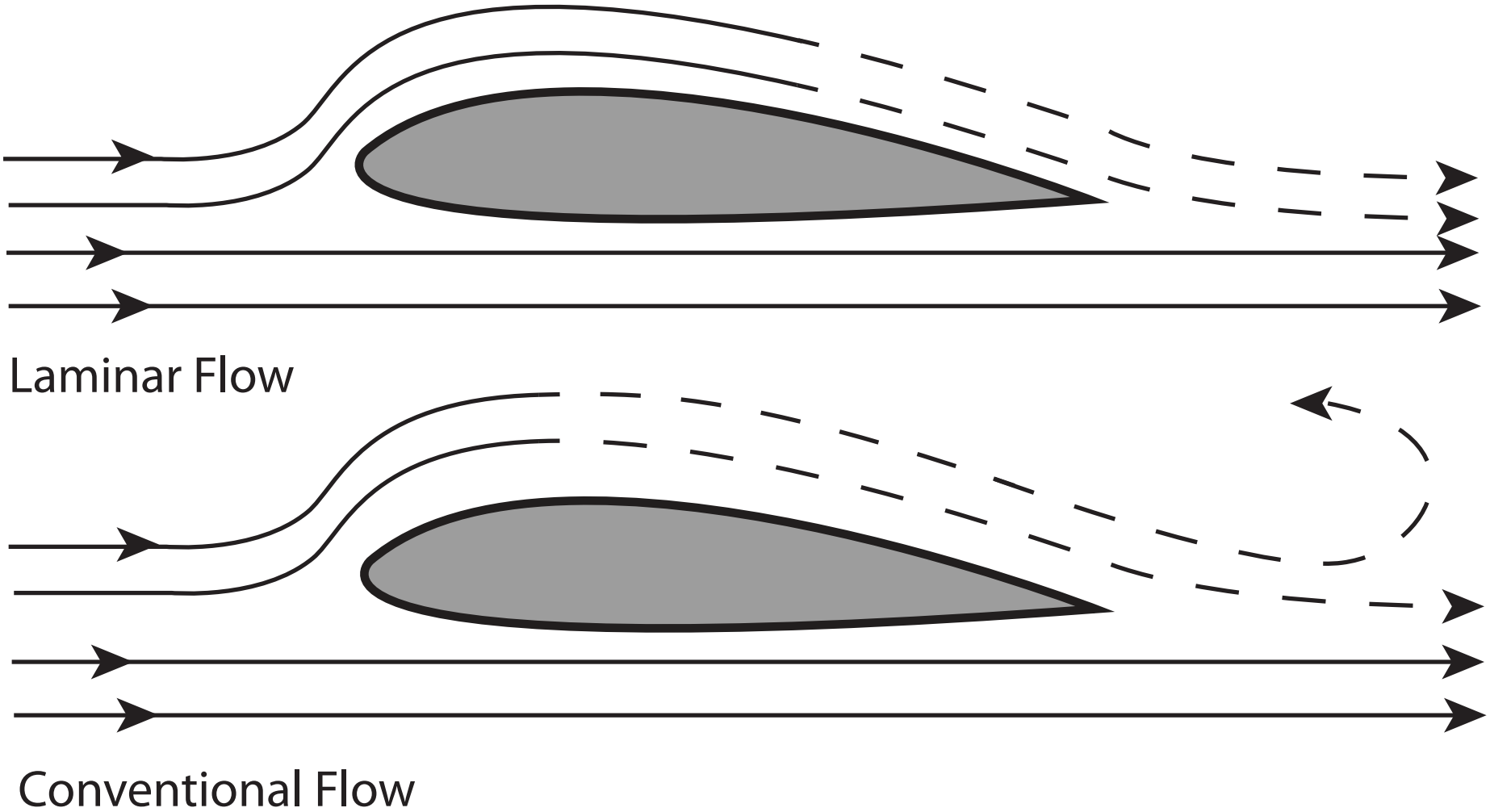


Fig. 5 Conventional airfoils

CONVENTIONAL AIRFOILS

Low camber - low drag - high speed - thin wing section. Suitable for race planes, fighters, interceptors, etc.

Deep camber - high lift - low speed - thick wing section. Suitable for transports, freighters, bombers, etc.

Deep camber - high lift - low speed - thin wing section. Suitable as above

Low lift - high drag - reflex trailing edge wing section Very little movement of centre of pressure. Good stability

Symmetrical (cambered top and bottom) wing sections. Similar to above

GA(W) -1 airfoil - thicker for better structure and lower weight - camber is maintained farther rear-ward which increases lifting capability over more of the airfoil and decreases drag

Fig. 6 Area Rule

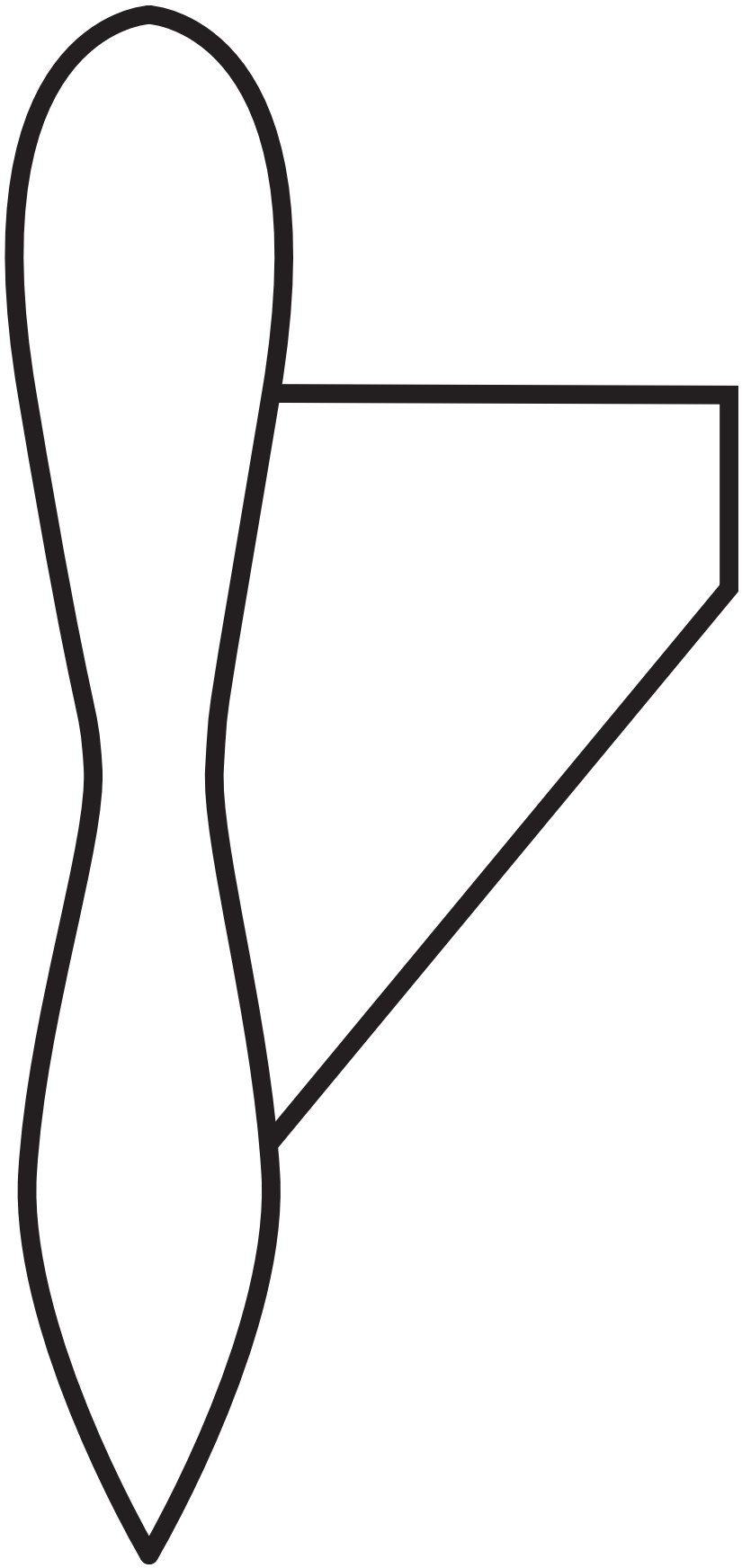
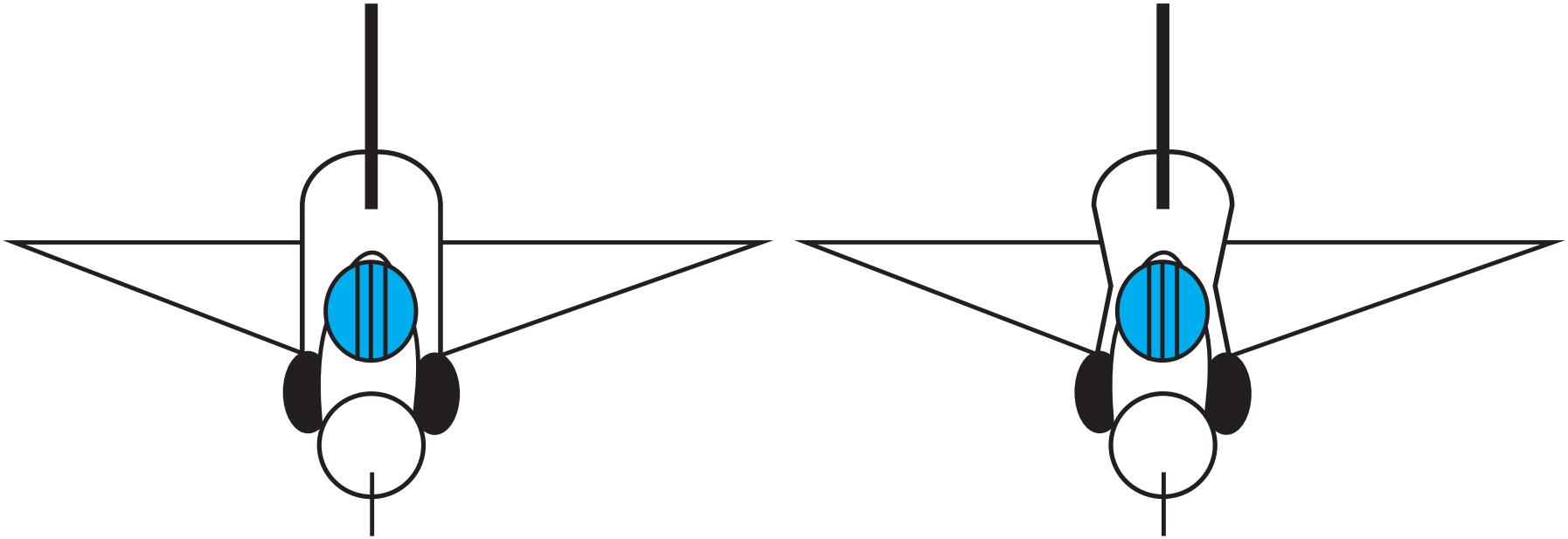


Fig. 7 Before and after area ruling



Images

Img. 1 Richard Whitcomb

(Photo courtesy of NASA)

Img. 2 Winglets

(Photo courtesy of NASA)

Img. 3 A Boeing B-1B Lancer over the Pacific ocean

(Photo courtesy of the United States Air Force)

Aeronautics
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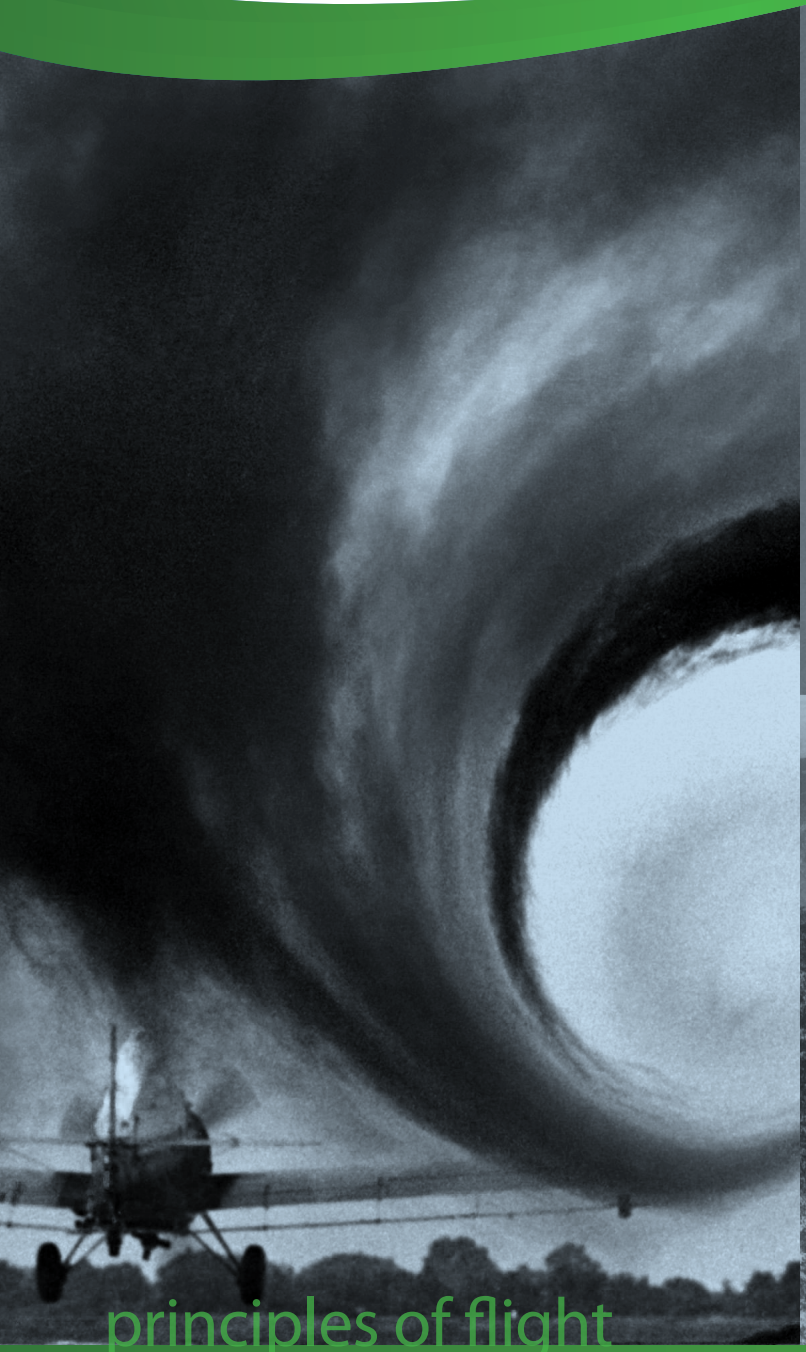
Museum in a BOX Series



principles of flight

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