

GRADES

9-12

# Principles of Flight in Action

principles of flight

Aeronautics  
Research  
Mission  
Directorate



# Principles of Flight in Action

## Lesson Overview

During this lesson students will have the opportunity to use interactive computer simulations in order to gain a better understanding of some of the factors that affect flight through the atmosphere. Students will also be introduced to some of the aerospace pioneers that led the way to begin our understanding of the principles of flight. Aeronautical terms associated with principles of flight will be defined to provide for better understanding of the data the students collect while completing the two simulations.

## Objectives

Students will:

1. Understand the importance of aeronautical research to design aircraft that can fly faster, farther, and higher.
2. By using AtmosModeler computer simulation software, students will demonstrate an understanding of density, pressure, and temperature in flight through the atmosphere
3. By using the FoilSim III computer simulation students will be able to understand the Lift/Drag ratio and its importance in designing aircraft with high lift ratios and low drag ratios and its implication in the design of aircraft.

## Materials:

### In the Box

CD with simulation applets necessary for lesson

Simulation applets can also be downloaded from the MIB website:

<http://www.aeronautics.nasa.gov/mib.htm>

### Provided by User

Copies of worksheets in lessons

**GRADES**

**9-12**

**Time Requirements:** 2 hours 30 minutes

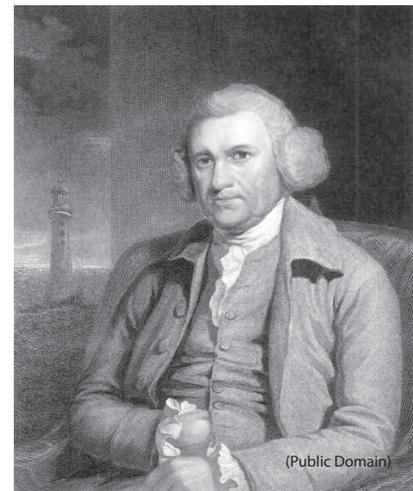
# Background

## Introduction to Aeronautical Research

For countless generations humankind dreamed of flying like the birds through the atmosphere. However, it would not be until the 18th century that the mystery of flight began to be understood. It takes a certain know-how to turn dreams into realities. The story of a heavier-than-air flight begins with a few individuals who began to study the properties of flight in new ways that enabled them to begin to identify the factors that influenced the behavior of the airplane. Space does not allow a detailed story of explaining the history of flight. For this brief introduction six individuals have been selected to start the story.

### John Smeaton

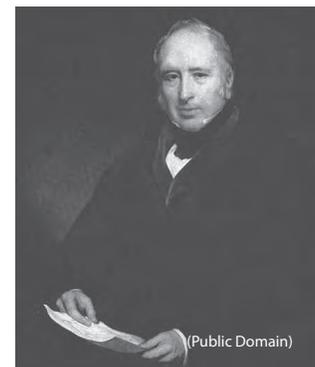
(1724-1792) In 1759, the British engineer John Smeaton published a paper that addressed the relationship between pressure and velocity for objects moving in water and air. Smeaton had used a whirling arm device to measure the drag exerted on a surface by moving air. From his work Smeaton created an equation to explain his observations. The equation is  $D = (C_D) kSV^2$ , where  $D$  is the drag,  $S$  is the surface area,  $V$  is the air velocity, and  $k$  is a pressure constant and  $C_D$  is a drag coefficient that depends on the shape, roughness, and inclination of the model to the flight direction. Smeaton's coefficient ( $k$ ) is the drag of a 1 square foot flat plate moving at one mile per hour. The value of  $k$  was determined experimentally and, by 1900, the accepted value was .005. The modern accepted value is .00326. (Note that this form of the drag equation is no longer used today. The  $k$  factor has been replaced by the density of the air to account for variations with altitude and weather conditions.)



**Img. 1** John Smeaton

### George Cayley

(1773-1857), of Yorkshire, England is considered the "Father of Aviation". In 1799, he set forth for the first time in history, the concept of the modern airplane. Cayley understood the basic principles of flight and constructed working models. Cayley had identified two very important factors related to flight. One is that the drag vector is parallel to the flow and the lift vector is perpendicular to the flow. Cayley identified for the first time that lift is generated by a region of low pressure on the upper surface of the wing. In addition, he demonstrated that cambered wings (curved surfaces) generate lift more efficiently than a flat surface.



**Img. 2** George Cayley

## Otto Lilienthal

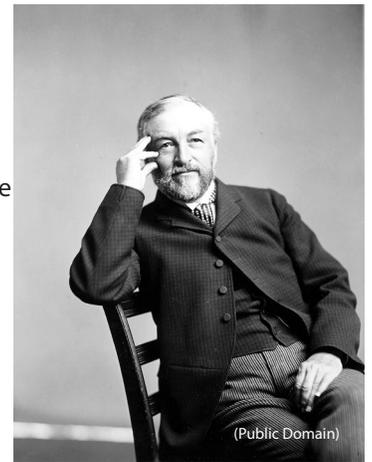
(1846-1896) Otto Lilienthal was a German engineer who became the first man to launch himself into the air, fly, and land safely. Lilienthal was an important source of inspiration and information for the Wright brothers. Unfortunately, on August 9, 1896, the glider he was piloting stalled and went into a nosedive. He died the next day of a broken spine. His last words were “Sacrifices must be made.” Lilienthal had a great impact on aviation. His writings were translated and distributed worldwide. The many photographs that authenticated his flights visually proved that a human could launch himself into the air and stay aloft. He showed the significance of identifying the principles that governed an experiment before proceeding, and his painstaking records of his research provided guidance for those that came after him.



**Img. 3** Otto Lilienthal

## Samuel Pierpont Langley

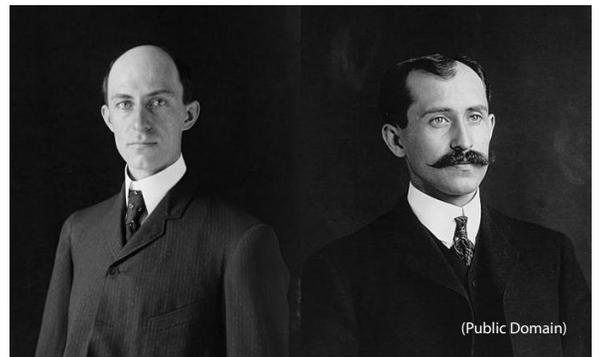
(1834-1906) Langley is remembered as one of the most unlucky trail blazers in flight history. Langley was highly-educated and served as Secretary of the Smithsonian Institution from 1887 to 1906. In 1896 one of his heavier-than-air machines, Aerodrome no. 6, became the first to achieve sustained unmanned flight. Aerodrome no. 6 flew 1280 meters (4,200 feet) at about 48 km/hr (30 mph) over the Potomac River in Washington, D.C. Langley received a government contract to build and fly a heavier-than-air machine with a pilot on board. However, his attempts to fly a manned aircraft were not so fortunate. The Great Aerodrome was built and was launched by catapult from a houseboat anchored in the Potomac River. The plane had to go from a dead stop to 96.5 km/hr (60 mph) in only 21.3 meters (70 feet). During the October 7, 1903, launch the catapult created more stress than the wood and fabric aircraft could stand and the front wing was badly damaged. Things went even worse during the second launch on December 9, 1903. The rear wing and tail completely collapsed during the launch. Charles Manley, the pilot, nearly drowned before he could be rescued from the wreckage in the ice-covered Potomac. After this near disaster, Langley did not attempt any further flights.



**Img. 4** Samuel Pierpont Langley

## Orville and Wilbur Wright

(Wilbur 1867-1912) (Orville 1871-1944) On December 17, 1903, the Wright Brothers changed the world forever. On that date at Kitty Hawk, North Carolina, the Wright Brothers flew the first powered, heavier-than-air machine to achieve controlled, sustained flight with a pilot aboard. There were several factors that led to the Wright Brothers' success. They invented a means for a pilot to steer the aircraft effectively to maintain three-axis control of roll, pitch, and yaw. They conducted flight experiments with kites and gliders for several years before the powered flight. By 1902, they were the most experienced glider pilots in the world. They built a wind tunnel and tested models of their aircraft in their bicycle shop in Dayton, Ohio. The data that they collected related to drag and lift were more accurate than any before.



**Img. 5** The Wright Brothers

This enabled them to design and build wings and propellers that were more efficient than any other at that time. Following the first flights at Kitty Hawk, the brothers continued to perfect their design with two more years of powered flight experiments at Huffman Prairie in Dayton. By late 1905, they had an aircraft that could maneuver in the air at the pilot's command until it ran out of gas.

These pioneers in aeronautical research paved the way for future flight. The demand for aircraft to fly faster, farther, and higher led to the creation of aeronautical research centers in the United States. From March 1915 until October 1, 1958, the National Advisory Committee for Aeronautics (NACA) provided advice and carried out much of the cutting-edge research in aeronautics in the United States.



**Img. 6** NASA's Aeronautical Research Centers

NACA created four aeronautical research centers that became a part of NASA on October 1, 1958. Note that some of the centers have been renamed since their beginning. The NASA aero centers are:

- Langley Research Center in Langley, Virginia
- Ames Research Center in Moffett Field, California
- Glenn Research Center in Cleveland, Ohio
- Dryden Flight Research Center at Edwards AFB, California

The research carried out at these four centers has greatly impacted flight. There is not an aircraft flying today that does not have some technology that was developed at one of these facilities. Aeronautical research does not stand still.

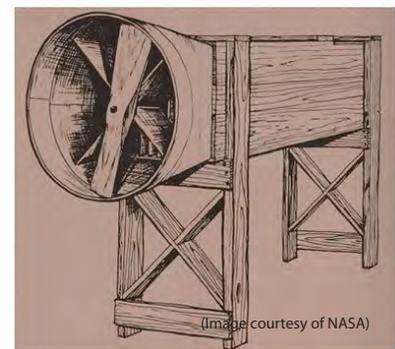


(Image courtesy of NASA)

**Img. 8** Big Fan in a Langley Research Center Tunnel

New test facilities are required to push the envelope in aeronautical research.

Wind tunnels have greatly increased research capabilities building on the model-testing techniques employed by the Wright Brothers. NASA has over 40 wind tunnels which enable researchers to 'fly' aircraft on the ground. Air speeds in NASA wind tunnels vary by wind tunnel.



(Image courtesy of NASA)

**Img. 7** Wright Brothers Wind Tunnel

Some tunnels accelerate air only to subsonic speeds which are slower than the speed of sound. Others reach transonic air speeds (slightly below, through and above the speed of sound), supersonic speeds (much faster than the speed of sound) and hypersonic speeds (more than five times the speed of sound).

Though powerful wind tunnels continue to be used as a research tool, supercomputing is reducing NASA's dependence on wind tunnels to conduct aeronautical research. The Pleiades is a part of NASA's state-of-the-art technology for meeting NASA's supercomputing requirements, enabling its scientists and engineers to conduct modeling and simulation for aeronautics. Note in Images 9 and 10 how supercomputing is reducing the need for wind tunnels and assisting in the design of advanced aircraft.

So in a sense we are back where we began. Today's scientists and engineers are studying the same factors that impact the principles of flight that were identified by the pioneers in aeronautical research—lift, drag, gravity, and thrust. There is still plenty of research to be done.

## Introduction to the Atmosphere

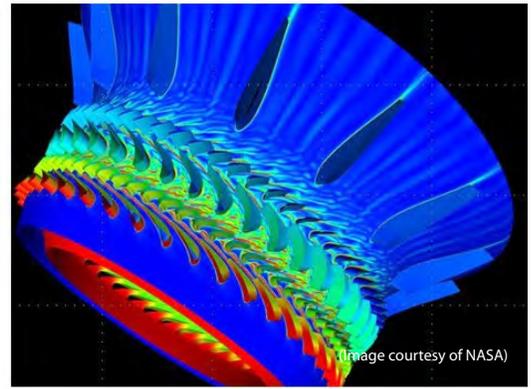
Since students will determine some of the effects of flying an aircraft at various altitudes in the atmosphere it is important that the students have some understanding of the atmosphere. From space one is able to view the atmosphere from a unique position. (See image 11)

As can be seen in this astronaut's photo of Earth, the atmosphere appears as a thin blue line stretching to the blackness of space. If an apple represented Earth, the red skin of the apple would approximate the thickness of the atmosphere.

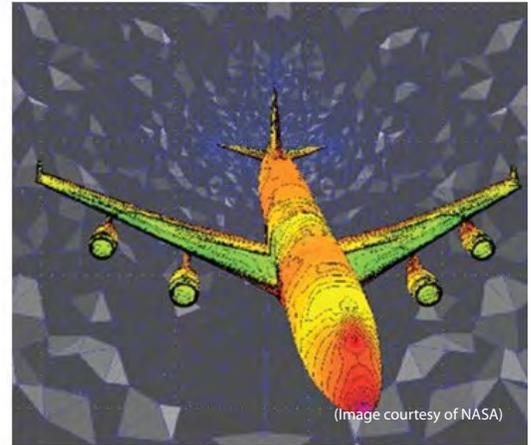


**Img. 11** Earth from space showing our thin atmosphere

(cirrus, cirrostratus, and cirrocumulus) can be found in the lower regions of the stratosphere.



**Img. 9** Super computer image of a fan



**Img. 10** Super computer image of an airplane

Most aircraft flights occur in the lowest part of the atmosphere, which is called the troposphere. The troposphere extends from the Earth's surface to an altitude of about 17 kilometers (11 miles). The weather and clouds can be found in the troposphere.

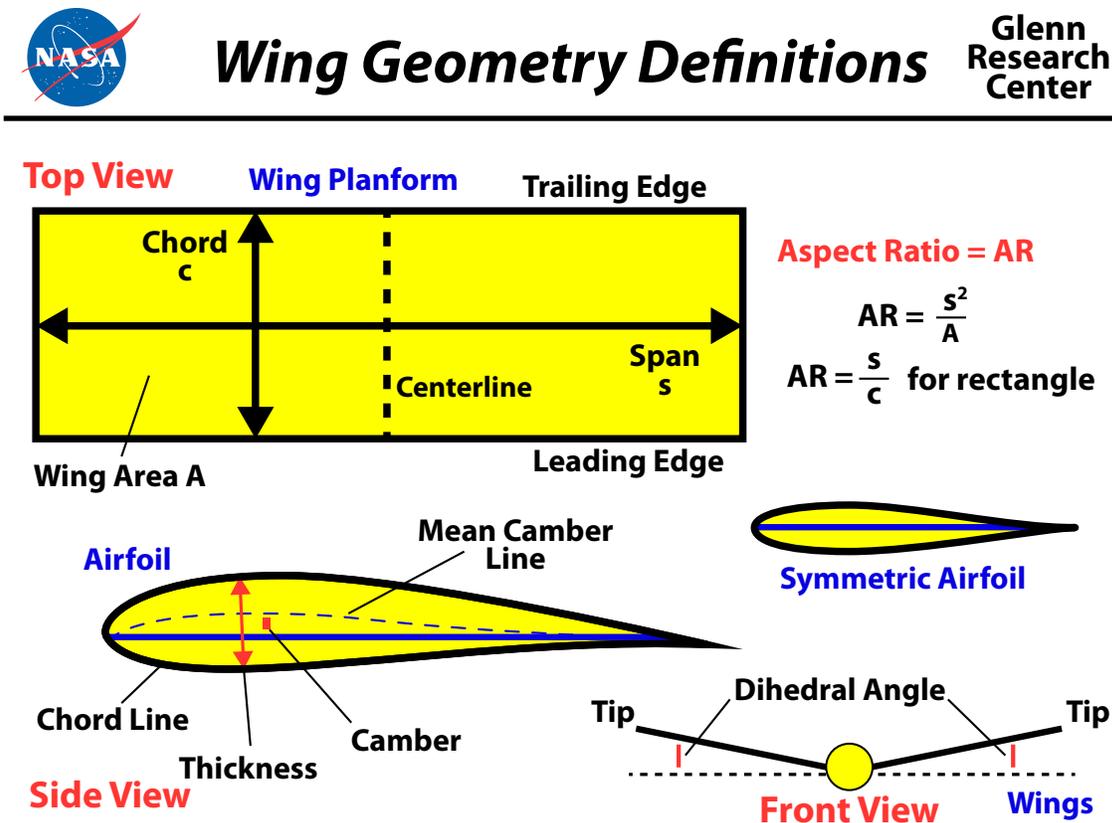
Beyond the troposphere is the stratosphere. The stratosphere extends from the troposphere upwards to about 50 kilometers (31 miles). The ozone layer can be found in the stratosphere. The ozone layer protects living things on Earth from the biologically lethal ultraviolet rays. Only the highest clouds

At Earth's surface the pressure of air per square inch is about 100 kilo Pascals (14.7 pounds per square inch). However, as one gets to higher altitudes the air pressure is much less than 100 kilo Pascals. In addition, temperature's value also changes with a change in altitude. As a result of doing the activities in this lesson students will find that a change in temperature can affect the speed of sound.

## Selected Definition Illustrations Included in the Activities

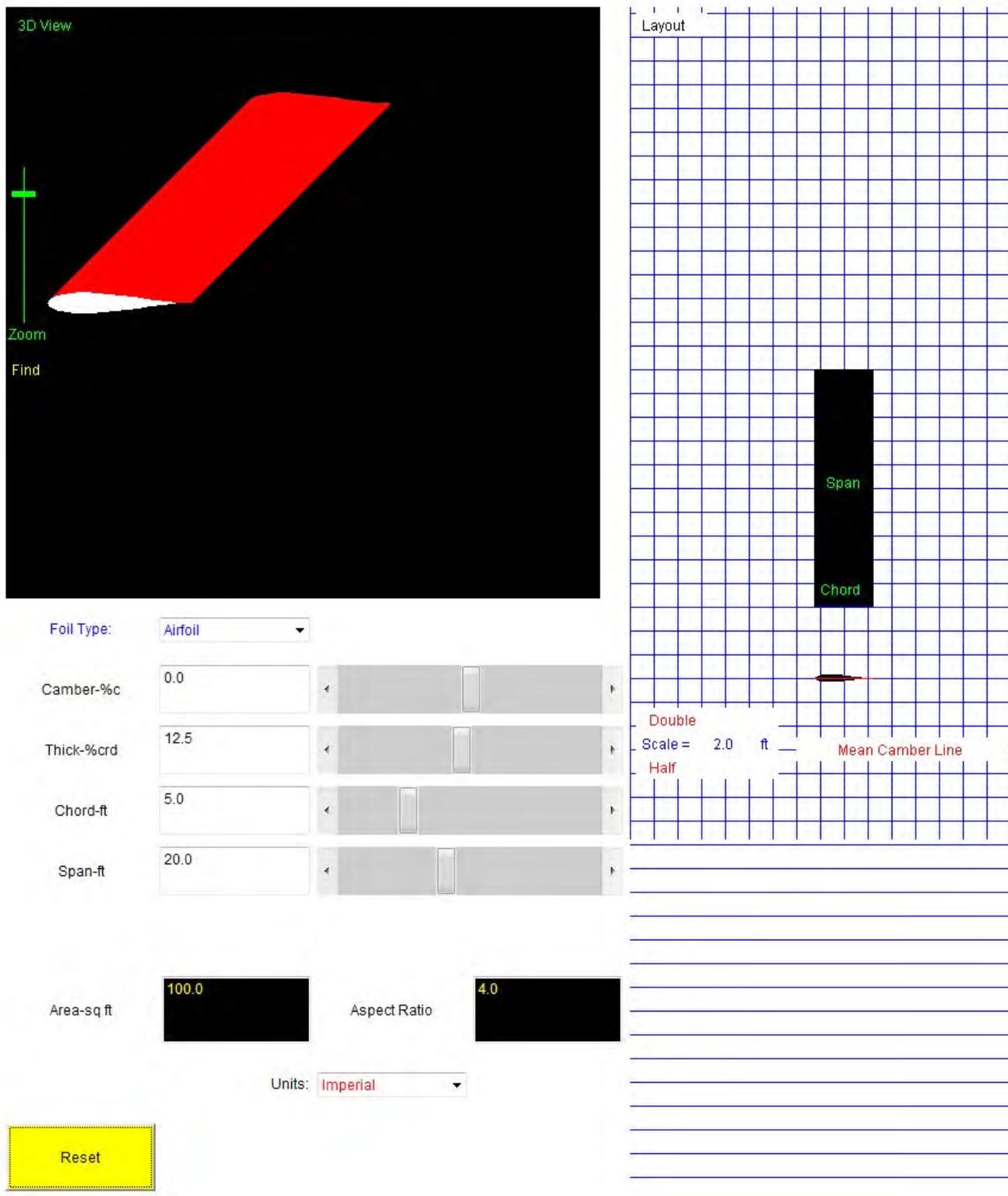
The Beginner's Guide to Aeronautics is an excellent resource to use to gain an overview of many aeronautics terms. The Beginner's Guide can be accessed at the following website: <http://www.grc.nasa.gov/WWW/K-12/airplane/index.html>. This website was created by Tom Benson at the NASA Glenn Research Center in Cleveland, Ohio. The following illustrations and information were taken from the Beginner's Guide.

The wing's geometry is a major factor affecting an aircraft's lift and drag.



**Fig. 1** Wing Geometry Definitions (<http://www.grc.nasa.gov/WWW.k-12/airplane/geom.html>)  
Beginner's Guide to Aeronautics, NASA

The illustration in Figure 1 highlights the definitions for wing geometry. You may want to have students use the Wing Design Interactive on the MIB web page to get a better understanding of wing shapes. The Wing Design Interactive is shown on the next page.



**Fig. 2** Computer Wing Geometry Simulation (<http://www.grc.nasa.gov/WWW/k-12/airplane/geom.html>) Beginner's Guide to Aeronautics, NASA—Applet can be downloaded at MIB website: <http://www.aeronautics.nasa.gov/mib.htm>.

By moving the various sliders different wing configurations can be created.

## Dynamic Pressure

In fluid mechanics, dynamic pressure depends on the density and velocity of the fluid. In flight, the fluid is air. The following equation is used to solve for dynamic pressure.

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

Dynamic pressure is a pressure term associated with the velocity of the flow of air.

Assume an aircraft is flying at an altitude of 5000 meters and is traveling at a speed of 1029 km/hour. Determine the dynamic pressure. The density at 5,000 m is .74 kg/m<sup>3</sup>. Students will solve for density for the atmosphere in Activity 1. Use this number for the density in the Dynamic Pressure equation.

### Sample Problem

An aircraft is traveling at a speed of 1029 km/hr. This number needs to be converted to meters/sec. Do the following:

1. Convert km/hr to meters/hr (1029 km/hr x 1000 m/km) = 1,029,000 meters/hr.
2. Next convert meters/hr to meters/sec. There are 3,600 seconds in one hour. To convert meters/hr to meters/sec divide the meters/hr by 3,600 secs

$$\text{Meters/sec} = \frac{1,029,000 \text{ m/hr}}{3,600 \text{ sec/hr}} = 285.8 \text{ m/sec}$$

Now the Dynamic Pressure can be calculated.

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

$$q = \frac{.74 \text{ kg/m}^3 (285.8 \text{ m/sec})^2}{2} = 30.2 \text{ kilo Pascals}$$

## Speed of Sound

The speed of sound through a gas is determined by the type of molecules in the gas and the temperature of the gas. Air is composed of 78% nitrogen, 21% oxygen, and traces of other molecules. There is a unique value of the gas constant that can be used when computing the speed of sound in air. When air heats up it has more kinetic energy and the molecules move faster and collide more often with other molecules. Since the molecules are moving faster at higher temperatures, sound waves travel more quickly.

The following equation can be used to find the speed of sound in air as follows:

$$\text{speed of sound} = a = \text{square root} [ 400.4 \text{ (m}^2/\text{s}^2 / \text{k)} \times T \text{ (k)} ]$$

a = speed of sound

T is the absolute temperature of the air; the temperature relative to absolute 0.

In the metric system of units, T is expressed in kelvin. T kelvin = T Celsius + 273.15

One thing to keep in mind is that this equation finds the average speed of sound for any given temperature. The temperature is affected by several factors such as altitude and weather conditions. Assume that you are at an altitude of 2,000 meters, what is the speed of sound? The air temperature at 2,000 meters is 2° Celsius.

$$a = \text{square root} [ 400.4 \times T (k) ]$$

$$a = \text{square root} [ 400.4 \times ( 273.15 + 2^\circ ) ]$$

$$a = \text{square root} [ 400.4 \times 275.15 ] = \text{square root} [ 110170.06 ]$$

$$V = 331.91 \text{ m/s}$$

To convert velocity in m/s to km/hr do the following:

1. Multiply the velocity in meters/sec x 3600 sec/hr. In the example 331.91 m/s x 3600sec/hr = 1,194,907 meters/hour
2. To convert to km/hr divide the number of meters by 1000 m/km. In the example, 1,194,907 meters/hour /1000 m/km = 1194.9 km/hr (the speed of sound at an altitude of 2,000 meters)

Why are engineers interested in the speed of sound? Near and above the speed of sound, the drag of the aircraft increases because of the formation of shock waves in the air around the aircraft. Shock waves are extremely small regions where the pressure and temperature increase by a large amount, while the velocity decreases by large amount. The change in pressure creates a sonic boom.

## Static Temperature

The static temperature is the temperature of the gas if it had no ordered motion and was not flowing. Temperature decreases to an altitude of about 20,000 meters. The sea level temperature is 15° C. By the time an aircraft climbs to 5000 meters the outside temperature is -17.5° C.

## Static Pressure

The air pressure at different altitudes is referred to as static pressure. For an altitude of 2000 meters the static pressure is 80 kPa.

## Mach Number

The Mach number is a ratio of the speed of the aircraft to the speed of sound. The following equation can be used to determine the Mach number. To be accurate the speed of sound for any given altitude should be used to determine the Mach number.

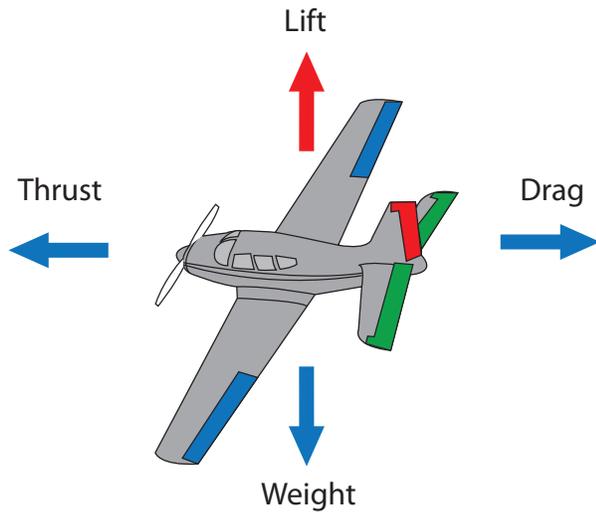
$$\text{Mach number} = \frac{\text{Speed of Aircraft}}{\text{Speed of Sound}}$$

An aircraft is traveling at a speed of 223 m/sec at a 2000 meter altitude, what is its Mach number? The speed of sound at 2000 meters is 332 m/sec.

$$\text{Mach number} = \frac{223 \text{ m/sec}}{332 \text{ m/sec}} = .67$$

## Lift

Lift is a mechanical force. It is created when a solid object moves through a fluid. For an aircraft, lift is the force that directly opposes the weight of the aircraft and keeps the aircraft in the air. Most of the lift on an aircraft is produced by its wings. The amount of lift produced by a wing will vary depending on its shape and size. In addition, the



**Fig. 3** Four forces of flight

fuselage of an aircraft can also produce lift if it is inclined to the air flow.

Notice the red arrow in Figure 3. The red arrow represents lift and is pointing straight up, while the blue arrow for weight is pointing straight down.

There are two requirements necessary to create lift. The first is that the aircraft must be in contact with a fluid and for an aircraft, the fluid is the air in our atmosphere. If there is no air, the aircraft will not fly. Lift also depends on the properties of air. For example, lift is affected by the density of the atmosphere. At a constant speed, lift decreases with an increase in altitude.

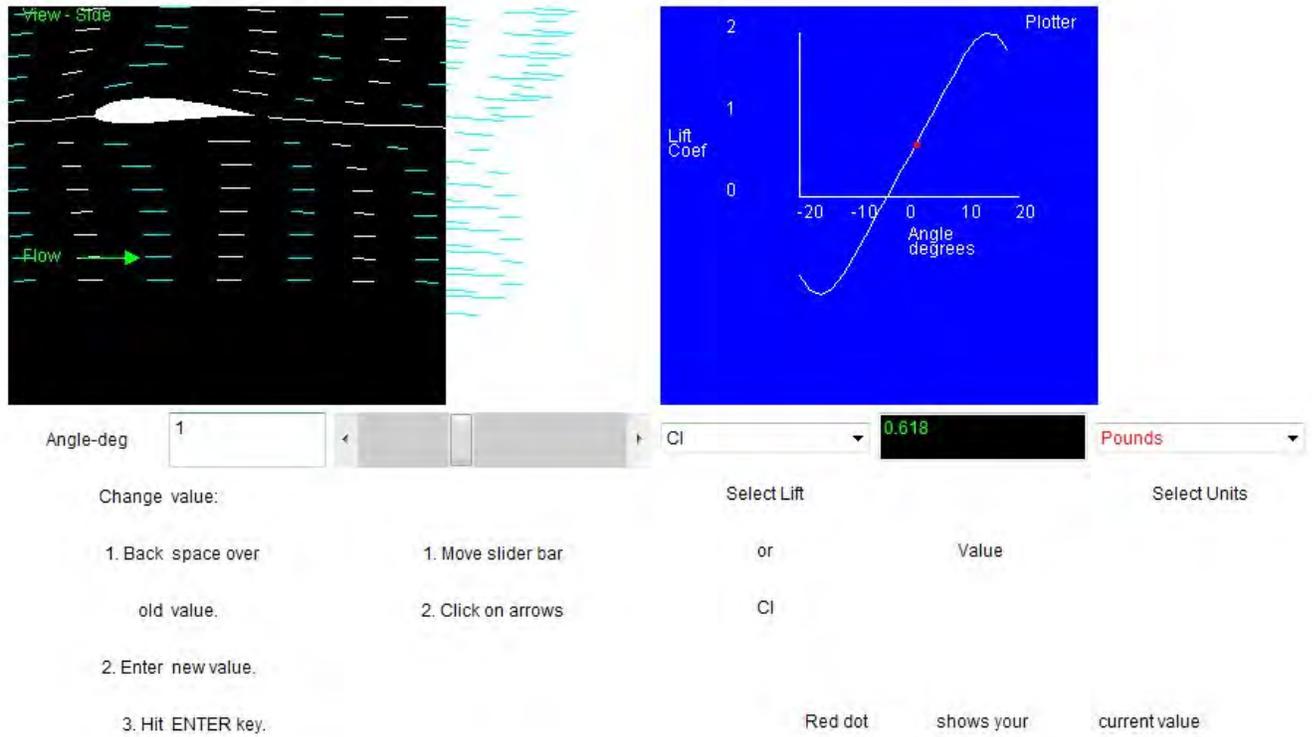
The second requirement deals with motion. There must be a motion between the aircraft and the air. With no motion there is no lift. Lift acts perpendicular to the flow of air. The amount of lift produced will depend on the speed of the aircraft and how it is inclined to the flow.

The most common explanation for lift provided to students is that lift is generated by a pressure differences across a wing. The air passing over the top of a lifting wing passes across the wing at a faster velocity than the air passing on the underside of the wing. Therefore, according to Bernoulli's principle the pressure on the top of the wing is less than the pressure below the wing. The difference in pressure produces the lift. Though this explanation is easy to understand, the real details for how an aircraft generates lift are complex. For additional background refer to NASA's Beginners Guide to Aeronautics.

The following equation can be used to solve for lift:

$$\text{Lift} = \frac{\text{coefficient of lift (C}_l\text{)} \times \text{density} \times \text{velocity squared} \times \text{wing area}}{2}$$

It should be noted that the Coefficient of Lift and the Coefficient of Drag include all of the complex dependencies on design parameters such as shape, surface roughness, sonic conditions, and angle of attack. The value of the coefficients changes with variations of the design parameters. The value of the coefficients is usually determined by wind tunnel experiments. For some simple designs, the value of the coefficients can be determined by numerical calculations. Here is a computer simulation program to allow students to study the effects of angle of attack on the lift of a wing.



**Fig. 4** Angle of Attack and Coefficient of Lift Interactive from the Beginner's Guide to Aeronautics, (<http://www.grc.nasa.gov/WWW/K-12/airplane/incline.html>) Beginners Guide to Aeronautics, NASA. Applet can be downloaded at MIB website <http://www.aeronautics.nasa.gov/mib.htm>.

Note in Figure 4 that an aircraft flying at a 1° angle of attack has a coefficient of lift of 0.618. You can use the slider or type in the angle of attack to determine the coefficient of lift at some other angle of attack.

Air Density is specified in kilogram/m<sup>3</sup> or slug/ft<sup>3</sup>

Velocity measured in Meters/sec or ft/sec

Wing area measured in square meters or square feet.

#### Lift Sample Problem

A Boeing 747 is flying at an altitude of 12,192 meters and has a velocity of 265.5 m/s. The aircraft has a wing area of 510.97 m<sup>2</sup>. The coefficient of lift is 0.52 and the density of air at 12,192 meters is approximately 0.30267 kg/m<sup>3</sup>. The weight of the 747 is 2,833,500 N (637,000 pounds). Solve for lift.

$$\text{Lift} = \frac{\text{coefficient of lift (C}_L\text{)} \times \text{density} \times \text{velocity squared} \times \text{wing area}}{2}$$

$$\text{Lift} = \frac{(0.52) \times 0.30267 \times (265.5\text{m/s})^2 \times 510.97 \text{ m}^2}{2}$$

$$\text{Lift} = 2,834,439 \text{ Newtons}$$

To convert Newtons to pounds divide the number of Newtons by 4.448. This is the number of Newtons in one pound.

$$\frac{2,834,439 \text{ Newtons}}{.448 \text{ Newtons/pound}} = 637,238 \text{ pounds of lift}$$

Notice the lift in Newtons and pounds matches within a few pounds the weight of the Boeing 747. The aircraft has enough lift to fly.

## Angle of Attack

The angle of attack is the angle that the wing or airfoil is inclined into the air flow. A small angle of attack is adequate to achieve lift at a low speed. If the wing is moving at a constant speed, a larger angle of attack will generate more lift. However, if the angle of attack is too high, its ability to create lift is greatly reduced. This is called a “stall”. As the angle increases, it also causes more drag

## Drag

As an aircraft moves through air, it contends with a form of resistance called drag. Every part of an aircraft affects drag. The amount of drag produced depends on the aircraft’s size and shape. A large aircraft will produce more drag than a thin, streamlined one. Drag in flight is of two basic types: parasite drag and induced drag. The first is called parasite because it in no way functions to aid flight. For example, the shape of the aircraft or the smoothness of the skin of the aircraft impact parasite drag. The second type of drag is created as a result of the wing developing lift. Drag acts in a direction that is opposite the forward motion of the aircraft. Thrust from the engines is used to overcome drag. Drag reduces the efficiency of an aircraft in flight. Drag increases with the square of velocity and also increases with increasing air density.

## Lift to Drag Ratio

For an aircraft, the lift-to-drag ratio, or L/D ratio is the amount of lift the wing generates, compared to the drag it creates by moving through the air. A higher L/D ratio is one of the major goals in wing design. A particular aircraft’s needed lift does not change. Producing that lift with lower drag leads directly to better fuel economy. The lift to drag ratio is used to describe the relationship between lift and drag. The L/D ratio is obtained by dividing the lift coefficient by the drag coefficient,  $C_L / C_D$ . The speed of an aircraft affects lift and drag. Both lift and drag increase with the square of the speed. If the speed of an aircraft is doubled, the drag or lift will be quadrupled. Remember in the equation for lift that the velocity is squared. In contrast the relationship between lift or drag and air density is a direct relationship. An increase or decrease in air density will cause an increase or decrease in both drag and lift.

A high lift to drag ratio can occur when an aircraft produces a large amount of lift or a small amount of drag. An aircraft with a large lift value can carry a larger payload. When the drag is low for an aircraft, it will not burn as much fuel during its flight and will be able to fly for longer distances.

L/D ratio

High Lift, High Drag—crop duster

Low Lift, Low Drag—jet fighter

Moderate Lift, Moderate Drag—light aircraft

Moderate Lift, Low Drag—aerobatic aircraft

## Air Density

Air density is the mass per volume of Earth's atmosphere, and is a useful value in aeronautics. In the International System of Units air density is measured as the number of kilograms of air in a cubic meter. With a temperature of 20° C as sea level, a cubic meter of dry air has a mass of approximately 1.2 kg. At sea level and at 20° C dry air has a density of approximately 1.2 kg/m<sup>3</sup>.

## Activity 1

## Effect of Altitude on the Temperature, Density, Pressure, and Speed of Sound in Flight

**GRADES****9-12****Time Requirements:** 60 minutes**Materials:**In the Box

CD with simulation applets necessary for lesson

Simulation applets can also be downloaded from the MIB website: <http://www.aeronautics.nasa.gov/mib.htm>.

Provided by User

None

Worksheets

How Does Altitude Relate to Temperature, Density, Pressure and the Speed of Sound Worksheet (worksheet 1)

Reference Materials

None

**Key Terms:**

Static Temperature

Static Pressure

Air Density

Speed of Sound

Mach Number

Dynamic Pressure

**Objective:**

Students will learn about motions and forces as they determine how a change in altitude affects temperature, pressure, density and the speed of sound through the use of the AtmosModeler Interactive Simulator. Students will also solve a problem related to dynamic pressure and the Mach number.

**Activity Overview:**

By completing this activity students will learn how the properties of the atmosphere change with altitude through the use of the AtmosModeler Simulator. Students will investigate changes in the atmosphere and its effects on aerodynamic variables. In this activity temperature, pressure, density, and speed of sound will be investigated. Students will create graphs to observe trends and draw conclusions on the effects of the atmosphere on the aerodynamics of flight. Students will also use data provided to solve for the dynamic pressure on an aircraft as well as the Mach number.

**Activity:**

1. **Introduce the lesson by reviewing some of the great research performed by the aeronautical pioneers included in the background.**
2. **Explain to the students that in this activity they will determine how changes in altitude affect the temperature, pressure, density, and the speed of sound of an aircraft flying at constant speed at the different altitudes using the AtmosModeler Simulator.** As the students change the height within the atmosphere, the software calculates the different outputs. For this activity, the students will be collecting data related to the static temperature, standard pressure, density, and the speed of sound.
3. **Have the students working as individuals, pairs or teams of 4.**

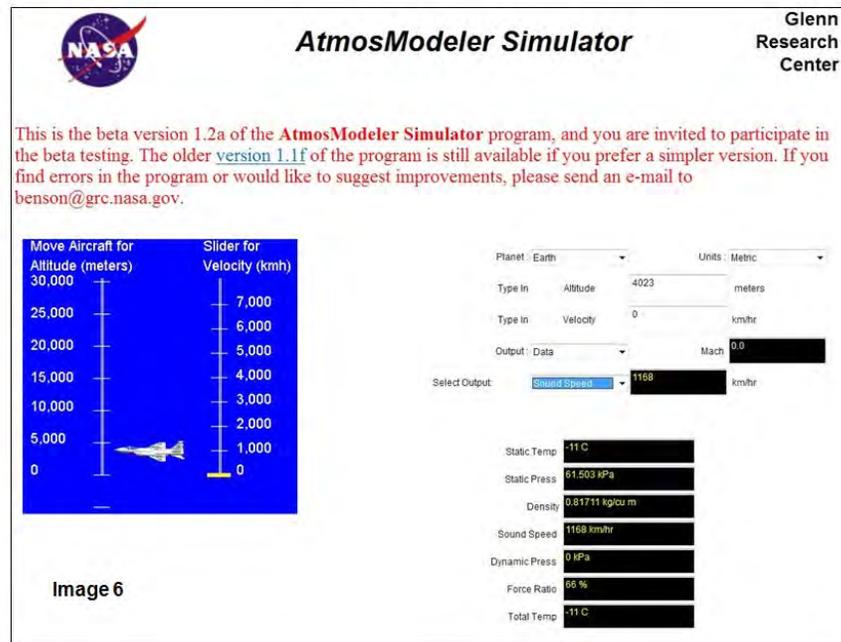


Image 6

**Fig. 5** Beginner's Guide to Aeronautics, NASA  
<http://www.grc.nasa.gov/WWW/K-12/airplane/atmosi.html>

4. **Show the students Figure 5.** Identify the various parts of the Atmospheric Simulator. Explain to them that in this activity they are to leave the aircraft speed at 0. Have the students use metric units. Show them on Figure 5 where the unit selection is located. Also remind them to select Earth as the planet. The students should also select to display their output in the data format as shown in Figure 5.
5. **Have the students open the AtmosModeler Simulator.**
6. **Allow the student a few minutes to familiarize themselves with the simulator.**
7. **Have the students set the aircraft speed to 0.** Explain to the students that by doing this they will be measuring the effect of only one variable, the altitude, on pressure, temperature, density and the speed of sound. It is important for this activity to have the students keep the speed of their aircraft at 0 for each measurement.
8. **Distribute the How Does Altitude Relate to Temperature, Density, Pressure and the Speed of Sound Worksheet.**
9. **Walk the students through the worksheet and highlight the instructions.** Remind the students that it is very important to follow the directions on the worksheet.
10. **Upon completion of the worksheet review the discussion points with the students.**

## Discussion Points:

1. **How has aeronautical research changed over the years?**

*Research has changed from when individuals or small groups of individuals studied flight. (Refer to Background Information) to today where we have research facilities that provide for many types of aeronautical research by teams of individuals including NASA centers, universities, or aerospace companies. In addition, today's aeronautical research centers have state of the art equipment. Modern super computers are enabling research that no longer requires the use of a wind tunnel to get accurate results.*

2. **What is the effect of altitude on the speed of sound? What does your data tell you?**

*The speed of sound decreases with increasing altitude. The speed of sound at sea level is approximately 341 m/s (1116 feet/sec). Expressed in kilometers per hour, the speed of sound is 1224 kilometers/hr. (761 mph) The speed of sound at 9.144 km (30,000 feet) is 300 m/s (994 feet/sec).*

3. **What is the effect of altitude on static temperature? What does your data tell you?**

*The atmospheric temperature decreases with increasing altitude. At sea level the standard temperature is 14.4° C (58° F). The temperature at 9.144 km (30,000 feet) is -43.8° C (-47° F).*

4. **What is the effect of altitude on static pressure? What does your data tell you?**

*The atmospheric pressure decreases with increasing altitude. At sea level the atmospheric pressure is 101.32 KPa (14.695 pounds/square inch - psi), while at 9.144 km (30,000 feet) the air pressure is reduced to 30.15 KPa (4.373 psi).*

5. **What is the effect of altitude on atmospheric density? What does your data tell you?**

*The density of the air through which an aircraft is flying is perhaps the most important factor affecting the performance of the aircraft in flight. For example, the flow of less dense air over a wing produces less lift for an aircraft flying at a constant speed. As evidenced through the use of the simulator, the density of air decreases with altitude. At sea level the density is 1.221 kilograms/cubic meter (.064 slugs/cu yard). At 9.144 km (30,000 feet) the density of air is .459 kilograms/cubic meter (.024 slugs/ cubic yard).*

6. **How does the altitude affect the Mach number when flying at a constant speed?**

*The Mach number increases with increasing altitude for an aircraft. An aircraft traveling at 500 mph would be traveling at Mach .736 while at 30,000 feet. With the same speed the aircraft would be traveling at Mach .656 at sea level. From question 1 above you can see that the speed of sound is lower at altitude than at sea level. Therefore traveling at a constant speed would increase the Mach number (dividing by a smaller number). This is an important result for airplane designers because the drag coefficient increases with Mach number as the aircraft approaches Mach 1. At altitude, one needs more thrust to overcome the increased drag to maintain the same speed as at sea level.*

## NATIONAL SCIENCE STANDARDS 9-12

### SCIENCE AS INQUIRY

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

### SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

- Science and technology in local, national, and global challenges

### HISTORY AND NATURE OF SCIENCE

- Science as human endeavor
- Nature of scientific knowledge
- Historical perspectives

## NATIONAL MATH STANDARDS 9-12

### NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

### ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

### MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

### DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

### PROCESS

- Problem Solving
- Communication
- Connections
- Representation

## Activity 2

## Relationship of Lift and Drag in Flight

**GRADES** 9-12

**Time Requirements:** 90 minutes

### Materials:

#### In the Box

CD with simulation applets necessary for lesson

Simulation applets can also be downloaded from the MIB website: <http://www.aeronautics.nasa.gov/mib.htm>.

#### Provided by User

None

#### Worksheets

Relationship of Lift and Drag in Flight (worksheet 2)

#### Reference Materials

Beginner's Guide to Aeronautics Website

### Key Terms:

Lift  
 Drag  
 Lift to Drag Ration  
 Coefficient of Lift  
 Coefficient of Drag  
 Angle of Attack

### Objective:

Through the use of the FoilSim III simulation students will learn how lift and drag are influenced by the angle of attack and how the Lift to Drag ratio can provide useful information about an aircraft such as whether it can lift a large payload or fly extended flights.

### Activity Overview:

Through the first part of Activity 2 students will utilize the FoilSim III simulator to determine how the Coefficient of Lift and Drag are related by changing the angle of attack. During the second part of the activity students will change input for the size of the wing. All other inputs will remain the same. With the new input students will once again determine the Coefficient of Lift and Drag by changing the angle of attack. Results from the two simulations will enable the students to determine if the Coefficients of Drag and Lift are constant and if the lift and drag are also the same as they were during the first part of Activity 2. Students will analyze data from tables, graphs, and equations to gain a better understanding of the relationship of lift and drag and its effects on an aircraft's flight.

### Activity:

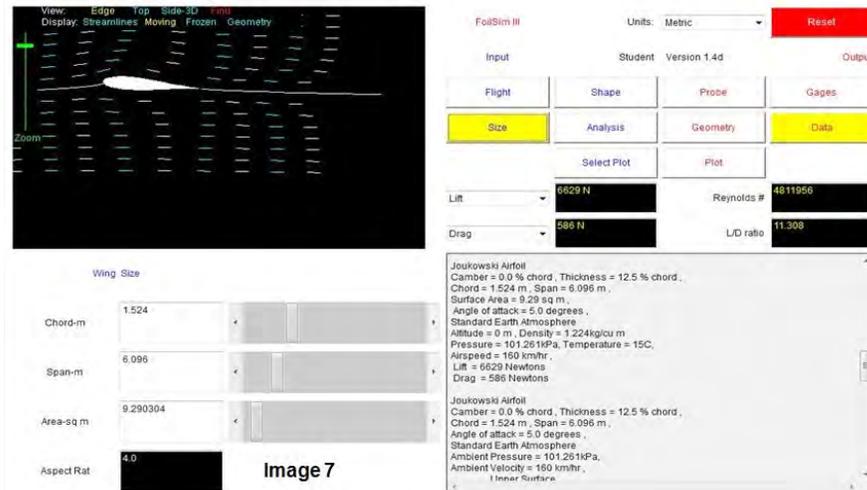
1. **Introduce this activity by highlighting some of aeronautic concepts included in the lesson background such angle of attack, lift, drag and the lift to drag ratio.**
2. **Inform the students that in this activity they will be using the FoilSim III Student Version 1.4d software that was developed at the NASA Glenn Research Center.** Highlight for the students that this software will enable them to determine how changes in the angle of attack of an aircraft wing influence the lift and drag of the aircraft. For this activity students will collect data from the FoilSim III Student Version 1.4d interactive and record it on the data collection forms for them to analyze.



FoilSim III Student Version 1.4d

Glenn  
Research  
Center

This is a beta 1.4d student version of the FoilSim III program, and you are invited to participate in the beta testing. If you find errors in the program or would like to suggest improvements, please send an e-mail to [Thomas.J.Benson@nasa.gov](mailto:Thomas.J.Benson@nasa.gov). FoilSim III is still available if you prefer the older version.



**Fig. 6** Beginner's Guide to Aeronautics, NASA  
<http://www.grc.nasa.gov/WWW/K-12/airplane/foil3.html>

3. Have the students working as individuals, pairs or teams of 4. Show the students Figure 6. Highlight the parts of the FoilSim III interactive.
4. Explain to them that in this activity they are to enter the data as called for in the Relationship of Lift and Drag in Flight Worksheet.
5. Have the students open the FoilSim III Student Version 1.4d software.
6. Allow the student a few minutes to familiarize themselves with the software.
7. Remind the students that they are to set the data for the simulation as required in the worksheet.
8. Distribute the Relationship of Lift and Drag in Flight Worksheet.
9. Walk through the students through the worksheet by highlighting the instructions.
10. Upon completion of the worksheet review the discussion points with the students.

## Discussion Points:

1. **From your use of the FoilSim III simulator what factors influences how any aircraft will fly?**

*Some possible answers include the speed of the aircraft, its altitude, the size of the wing, its shape, its span and thickness, the camber of the wing and the angle of attack.*

2. **How does the angle of attack influence the Coefficient of Lift and Drag?**

*From the coefficient of lift graph it can be noted that there is positive lift from an angle of attack greater than  $0^\circ$  and less than  $15^\circ$ . As angle of attack increases, the lift increases up to about  $15^\circ$ . An angle of attack greater than  $15^\circ$  will create a stall condition for the aircraft and the lift decreases. Drag also increases with angle of attack up to the stall angle.*

3. **What angle of attack produced the maximum lift to drag?**

*From the Lift to Drag graph an angle of attack between  $2^\circ$  and  $6^\circ$  produces the maximum lift to drag?*

4. **During the activity you had to change the area on the wing leaving all of the other data the same? Were the coefficient of lift and drag the same in both flights?**

*In the first flight with a wing area of 30 sq m the coefficient of lift was .0573 and the coefficient of drag was .054. The lift to drag ratio was 10.518. When the wing surface was increased to 54 sq m leaving all other variables the same the coefficient of lift was 0.578 and the coefficient of drag was .054. The lift to drag ratio was 10.625. The angle of attack for all measurements was  $5^\circ$ .*

5. **How can the Lift to Drag ratio be used in the design of an aircraft?**

*High Lift, High Drag aircraft often limited to flying slow and for short distances. A good example of a high lift, high drag aircraft is a crop duster.*

*Low lift, Low Drag aircraft are fast moving, like jets. Their thin shaped airfoil generates very little drag and little lift so the jet must fly very fast to generate enough lift to stay aloft.*

*Moderate Lift, Moderate Drag aircraft produce moderate lift and at the same time do not generate a lot of drag. Many small light planes like a Cessna 172 fall in this category.*

*Moderate Lift, Low Drag aircraft are used in aerobatics. The wing is symmetrical in aerobatic planes. That means that the curvature on the top of the wing is the same as the bottom of the wing.*

6. **During the activity you were asked to design a wing that would generate a lift of 25,000 N. Share your results. Did all of the wings that were designed have the same measurements? So what can we say are ways to produce the 25,000 N of lift?**

*There are many possible answers to this question—changing the angle of attack will impact lift; increasing the size of the wing will impact lift; changing the wing's camber will also impact lift. The lift to drag ratios will also be different.*

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### ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

### MEASUREMENT

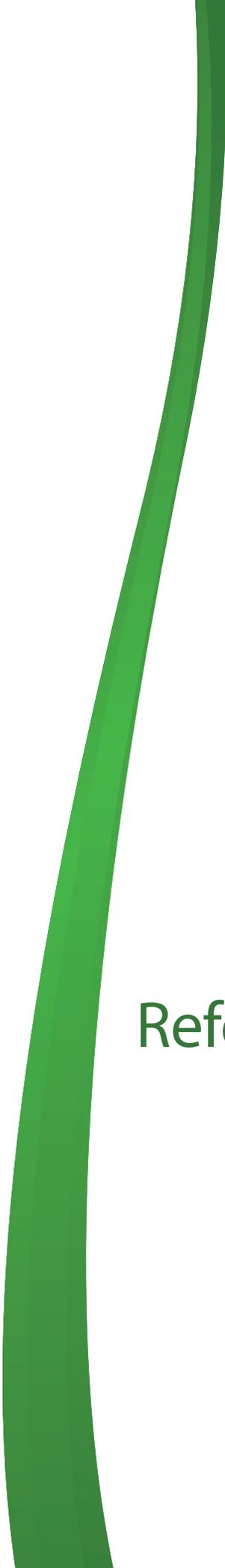
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- Apply appropriate techniques, tools, and formulas to determine measurements.

### DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

### PROCESS

- Problem Solving
- Communication
- Connections
- Representation



Reference Materials

# Glossary

**Air Density:**

Is measured, in the International System of Units, as the number of kilograms of air in a cubic meter. With a temperature of 20° C as sea level, a cubic meter of dry air has a mass of approximately 1.2 kg.

**Angle of Attack:**

The angle that the wing is inclined into the air flow

**Coefficient of Drag:**

Determined experimentally and provides a value that is constant or predictable and is used in the calculation of drag

**Coefficient of Lift:**

Determined experimentally and provides a value that is constant or predictable and is used in the calculation of lift

**Drag:**

Acts in a direction that is opposite the forward motion (thrust) of the aircraft. Drag reduces the efficiency of an aircraft flight

**Dynamic Pressure:**

A pressure term associated with the velocity of the flow of air. The following equation is used to solve for dynamic pressure

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

**Hypersonic Speed:**

The speed of an aircraft that is traveling at a speed of greater than Mach 5. At these speeds, the high energy and temperature of the flow cause the molecules of the air to rotate, vibrate, and finally to dissociate (break chemical bonds and strip off electrons)

**Lift:**

The force that directly opposes the weight of the aircraft and keeps the aircraft in the air

**Lift to Drag Ratio:**

The amount of lift the wing generates, compared to the drag it creates by moving through the air. A higher L/D ratio is one of the major goals in wing design

**Mach Number:**

The ratio of the speed of the aircraft to the speed of sound. An aircraft flying twice the speed of sound for that altitude has a Mach number of 2

**Speed of Sound:**

The velocity of sound in the atmosphere. Its speed varies with temperature and therefore by altitude. At sea level the speed of sound is 341 m/sec

**Static Pressure:**

Air pressure at different altitudes

**Static Temperature:**

The temperature of the gas if it had no ordered motion and was not flowing

**Stall:**

A condition in aerodynamics where the lift of a wing decreases as the angle of attack increases. Stall is caused by the separation of a thin layer of flow near the surface of the wing, called the boundary layer. The angle at which stall occurs is called the *critical angle of attack*

**Subsonic Speed:**

The speed of an aircraft that is traveling less than Mach 1

**Supersonic Speed:**

The speed of an aircraft that is traveling faster than Mach 1

**Total Temperature:**

The temperature of the airflow at the leading edge of the wing on an aircraft or about the nose of the aircraft

**Transonic Speed:**

The speed of an aircraft that is traveling near Mach 1

**WEBSITES TO VISIT:**

*Beginner's Guide to Aeronautics* (Thomas J. Benson, Author, NASA Glenn Research Center)

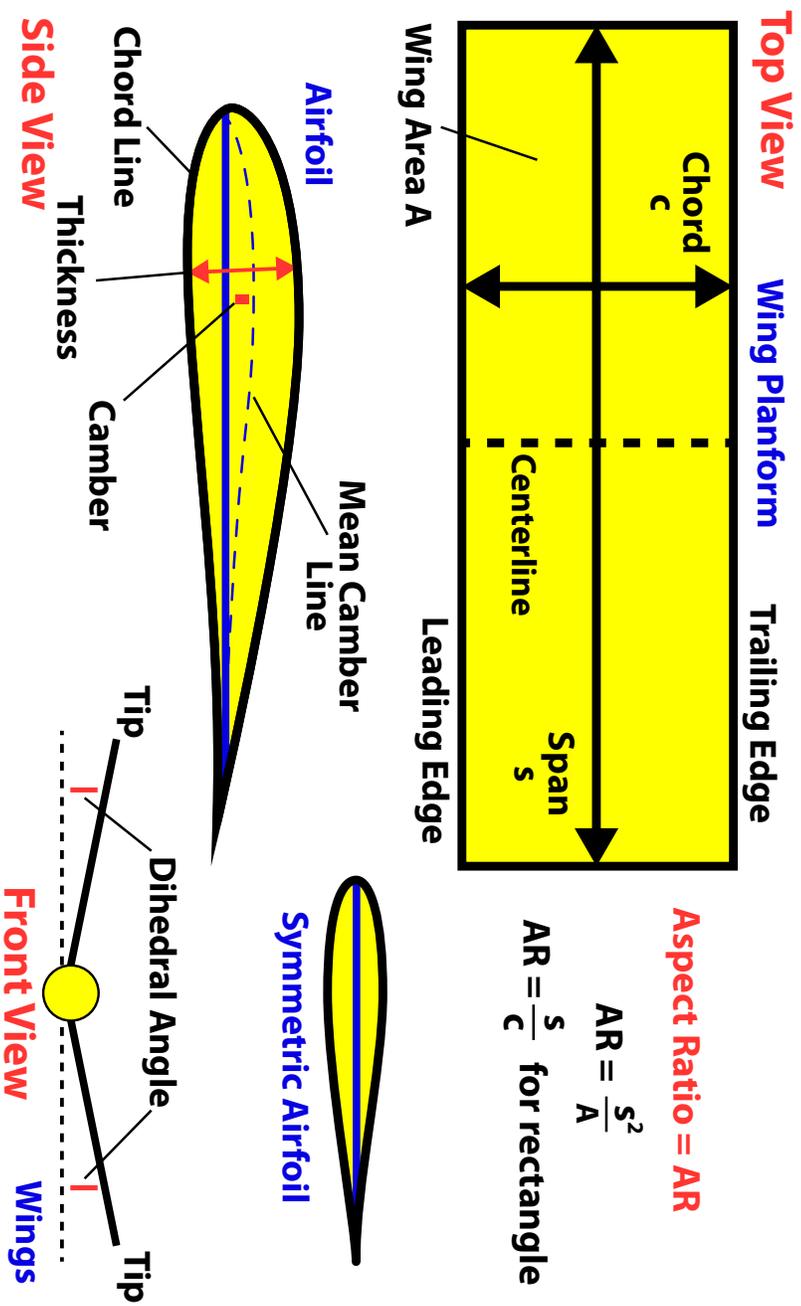
<http://www.grc.nasa.gov/WWW/K-12/airplane/index.html>

Fig. 1 Wing Geometry Definitions

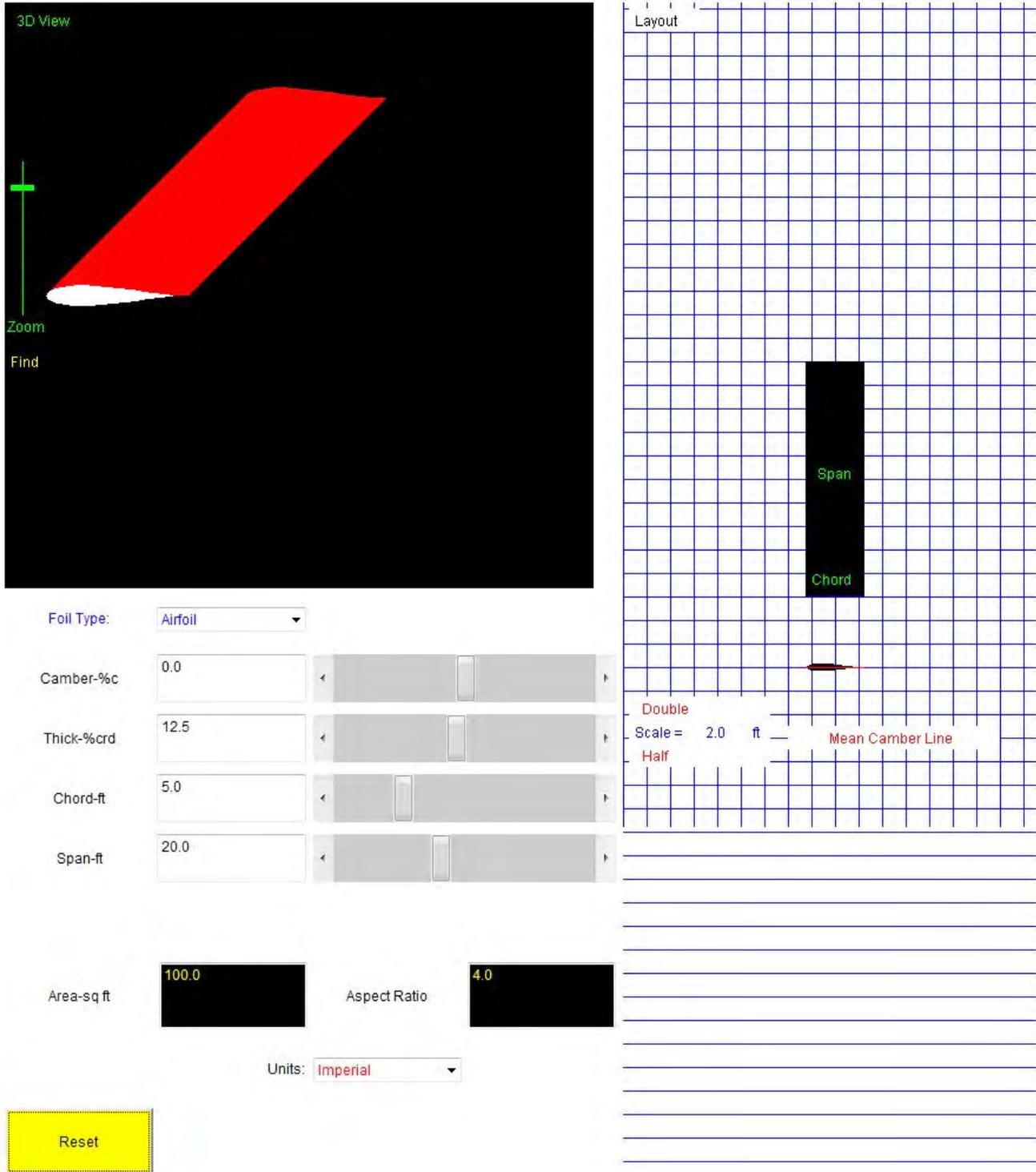


# Wing Geometry Definitions

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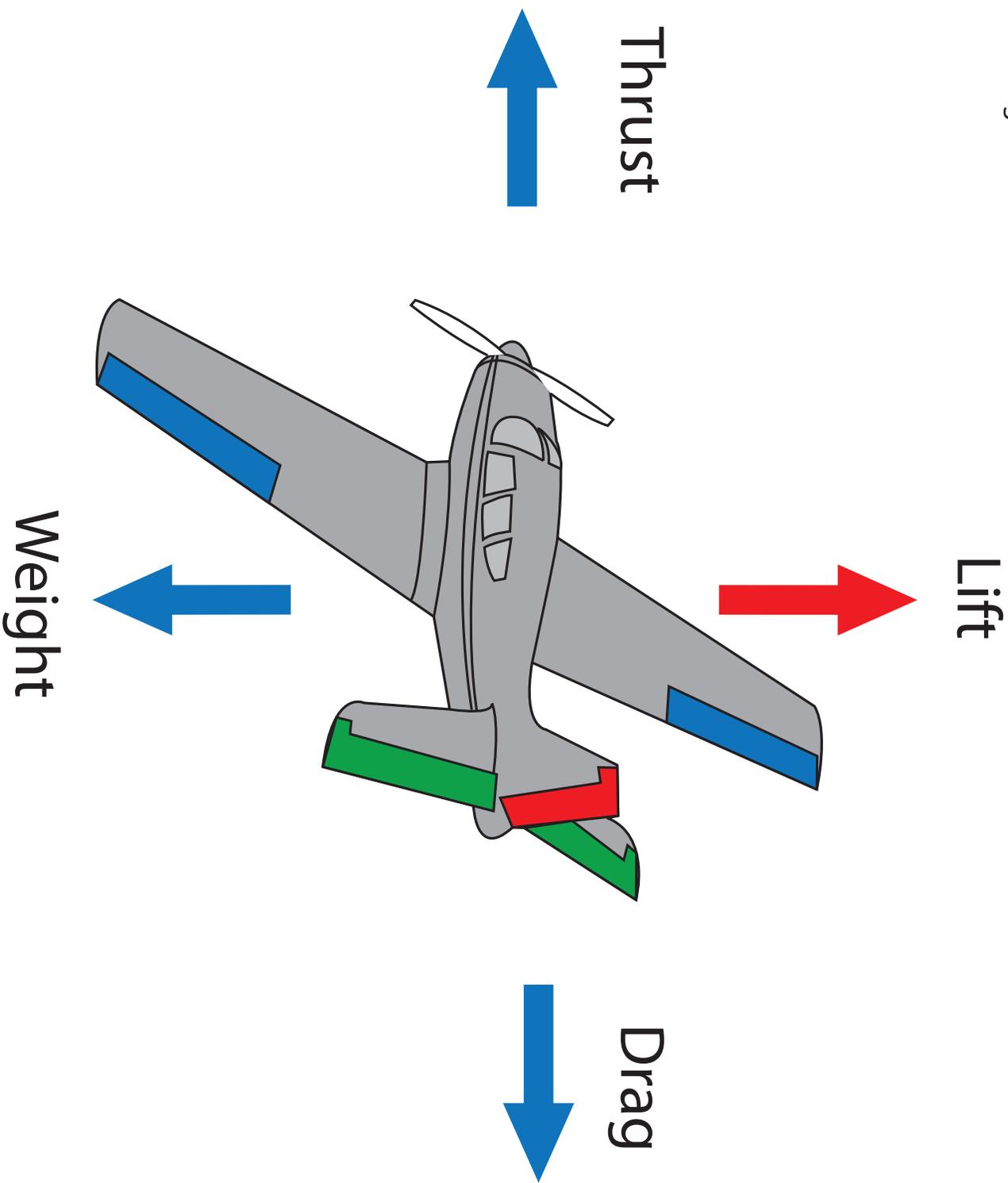


**Fig. 2** Computer Wing Geometry Simulation

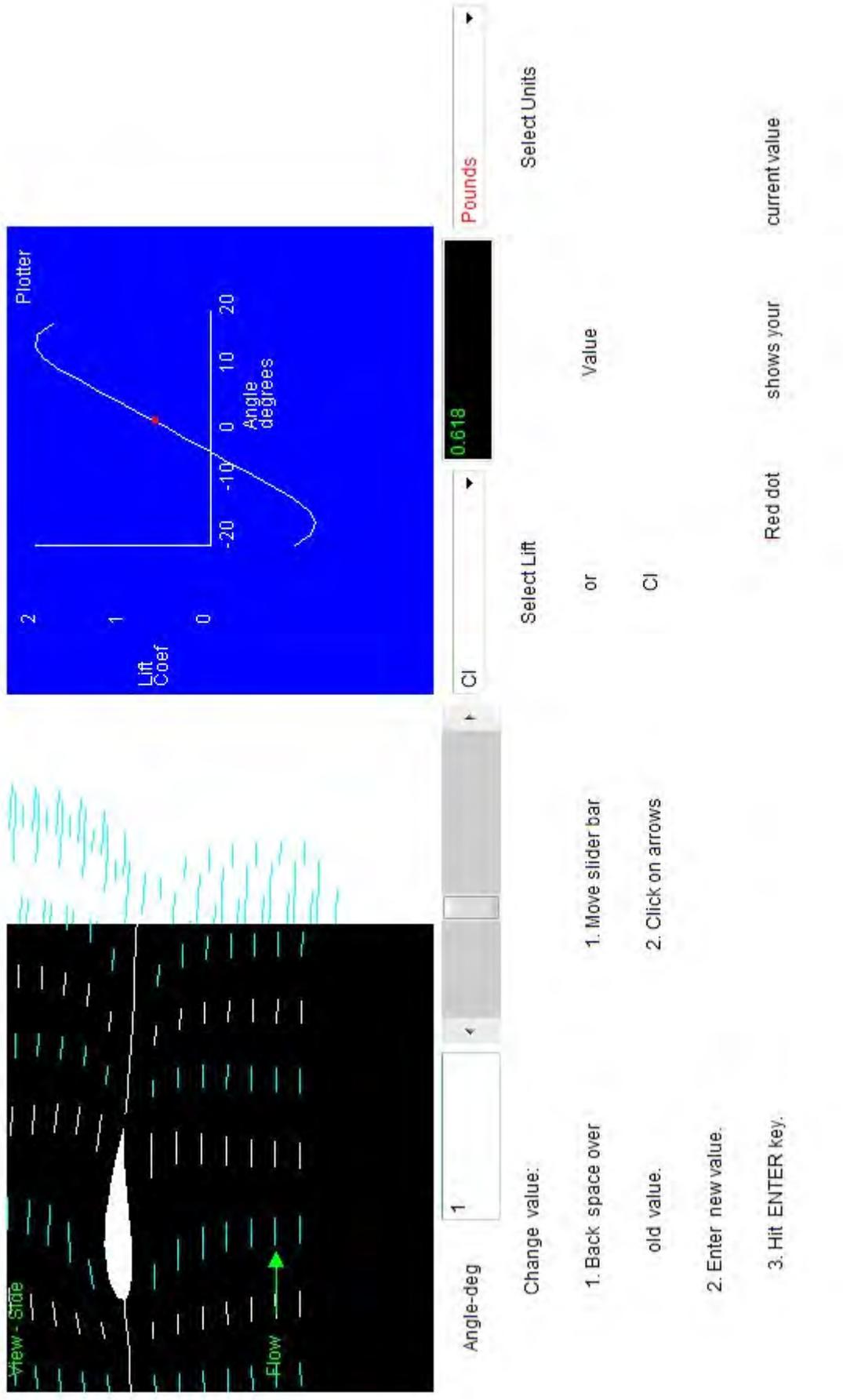


<http://www.grc.nasa.gov/WWW/k-12/airplane/geom.html> - Beginner's Guide to Aeronautics, NASA Applet can be downloaded at MIB website: <http://www.aeronautics.nasa.gov/mib.htm>.

**Fig. 3** Four Forces of Flight



**Fig. 4** Angle of Attack and Coefficient of Lift





# AtmosModeler Simulator

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This is the beta version 1.2a of the **AtmosModeler Simulator** program, and you are invited to participate in the beta testing. The older **version 1.1f** of the program is still available if you prefer a simpler version. If you find errors in the program or would like to suggest improvements, please send an e-mail to [benson@grc.nasa.gov](mailto:benson@grc.nasa.gov).

**Move Aircraft for**

Altitude (meters)

30,000  
25,000  
20,000  
15,000  
10,000  
5,000  
0



**Slider for**

Velocity (kmh)

7,000  
6,000  
5,000  
4,000  
3,000  
2,000  
1,000  
0



Planet: Earth

Type In: Altitude 4023 meters

Type In: Velocity 0 km/hr

Output: Data

Mach 0.0

Selected Output: **Sound Speed** 1168 km/hr

Static Temp	-11 C
Static Press	61,503 kPa
Density	0.81711 kg/cu m
Sound Speed	1168 km/hr
Dynamic Press	0 kPa
Force Ratio	68 %
Total Temp	-11 C

Units: Metric

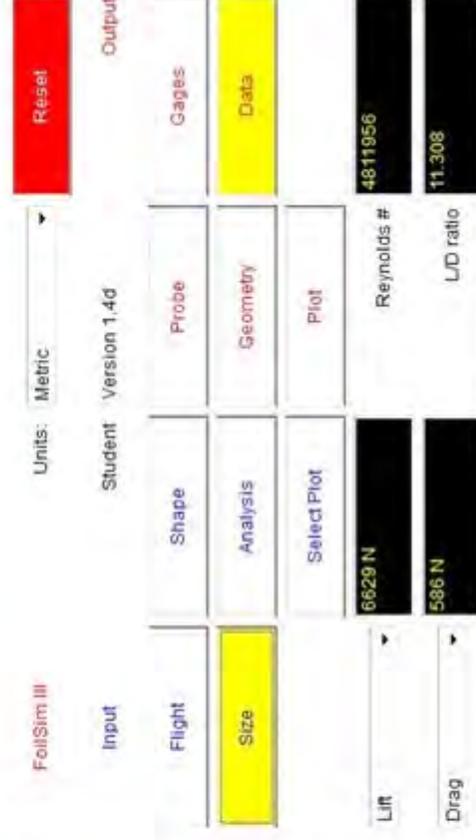
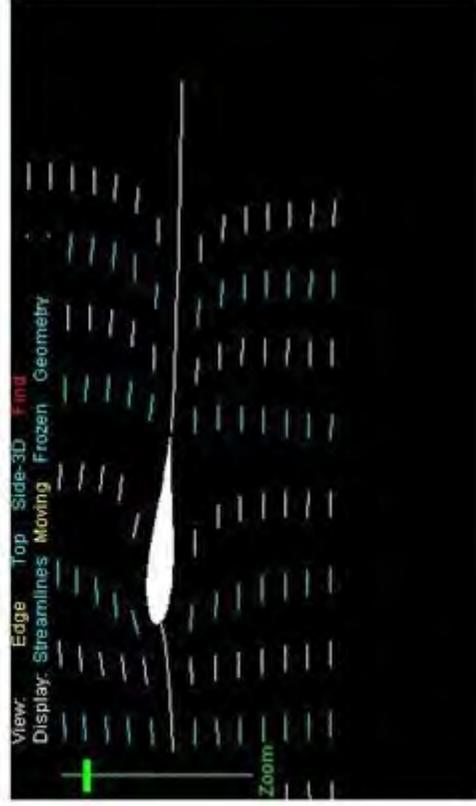
Fig. 6 Beginner's Guide to Aeronautics, NASA



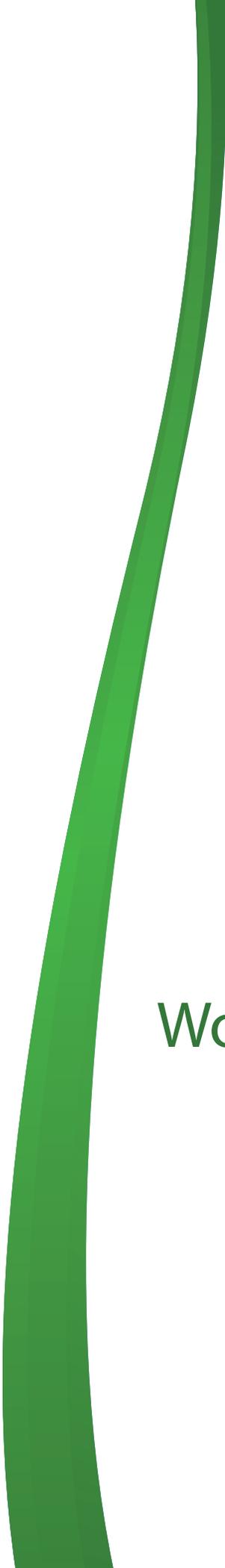
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## Foilsim III Student Version 1.4d

This is a beta 1.4d student version of the **Foilsim III** program, and you are invited to participate in the beta testing. If you find errors in the program or would like to suggest improvements, please send an e-mail to [Thomas.J.Benson@nasa.gov](mailto:Thomas.J.Benson@nasa.gov). [Foilsim III](http://www.nasa.gov/WWW/K-12/airplane/foil3.html) is still available if you prefer the older version.







Worksheets

# Worksheet 1

## How Does Altitude Relate to Temperature, Density, and Pressure

1. Open AtmosModeler Simulator
2. Familiarize yourself with the AtmosModeler Simulator
3. Make sure Planet Earth is selected, Units are in Metric and the Output is data.
4. On the simulator enter 0 for velocity and 0 meters, click enter and record the data.
5. Record the static temperature, static density, pressure, and speed of sound on the How Does Temperature, Density, and Pressure Vary with Altitude? form below.

How Does Temperature, Density, and Pressure Vary with Altitude?					
Altitude	Temperature C°	Density Kg/m <sup>3</sup>	Pressure KPa	Speed of Sound km/h	Speed of Sound mph
0 - Sea Level					
5,000 meters					
10,000 meters					
15,000 meters					
20,000 meters					
25,000 meters					
30,000 meters					

# Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

How Does Temperature Vary with Altitude?								-60
								-50
								-40
								-30
								-20
								-10
								0
								10
								20
	Alt	30,000 m	25,000 m	20,000 m	15,000 m	10,000m	5,000 m	0 m

# Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

Alt	How Does Density Vary with Altitude?																										
30,000 m																											
25,000 m																											
20,000 m																											
15,000 m																											
10,000 m																											
5,000 m																											
0 m																											
Density Kg/m <sup>3</sup>	1.3	1.25	1.2	1.15	1.1	1.05	1.0	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00

Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

How Does Pressure Vary with Altitude?								0
								10
								20
								30
								40
								50
								60
								70
								80
								90
								100
								110
Alt	30,000 m	25,000 m	20,000 m	15,000 m	10,000 m	5,000 m	0 m	Pressure KPa

# Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

Alt	How Does Speed of Sound Vary with Altitude?						
30,000 m							
25,000 m							
20,000 m							
15,000 m							
10,000 m							
5,000 m							
0 m							
Speed of Sound in m/sec	350	340	330	320	310	300	290

# Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

## Dynamic Pressure

Next solve for the dynamic pressure for an aircraft traveling at 1,500 km/hr at 8,000 meters.

The formula for the dynamic pressure on the aircraft =

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

Use the AtmosModeler Simulator to determine the density of the atmosphere at 8,000 meters.

Density of atmosphere at 8,000 meters = \_\_\_\_\_

The aircraft is traveling at 1,500 km/hr

Next convert speed in km/hr to m/sec.

To do this:

1. Convert km/hr to m/s
  - a. Multiply km/hr x 1000 m/km (1,500,000 m/hr)
2. Convert m/hr to m/sec
  - a. Divide m/hr by 3,600 sec/hr  $\frac{(1,500,000 \text{ m/hr})}{3,600 \text{ sec/hr}} = \text{_____ m/sec}$
3. Now solve for Dynamic Pressure

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

Dynamic Pressure = \_\_\_\_\_ Pascals

To convert Pascals to Kilo Pascals divide the number of Pascals found for the Dynamic Pressure by 1,000 Pascal/kilo Pascal.

Dynamic Pressure = \_\_\_\_\_ Kilo Pascals

## Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

### Mach Number

For the aircraft traveling at 1,500 km/hr, determine its Mach number. Use the speed in m/sec that was solved for in the Dynamic Pressure question as the speed of the aircraft. From the graph you created for the Speed of Sound estimate the speed of sound at 8,000 meters.

From the graph it appears that the speed of sound at 8,000 m is approximately \_\_\_\_\_ m/sec. Use this speed in solving for the Mach number.

$$\text{Mach number} = \frac{\text{Speed of Aircraft}}{\text{Speed of Sound}}$$

Mach Number = \_\_\_\_\_

### Solve for Temperature

For an altitude < 11,000 meters (troposphere) atmospheric temperature in Celsius can be estimated using the formula:

$$T = 15.04 - .00649h \text{ (altitude in meters)}$$

Solve for the temperature at an altitude of 9,000 meters.

The formula to use to solve for temperature in the troposphere is

$$T = 15.04 - .00649^\circ/\text{m} \text{ (altitude)}$$

Answer: \_\_\_\_\_

### Solve for Pressure

Solve for the air pressure at 9,000 meters.

To determine pressure in the troposphere use the formula:

$$P = 101.29 \times \left[ \frac{T + 273.1^\circ}{288.08} \right]^{5.256}$$

-273.16° is the temperature of absolute zero

Use the temperature calculated in the Solve for Temperature problem.

The pressure will be in kilo Pascals (KPa)

Answer \_\_\_\_\_ kilo Pascals

1. Open FoilSim III Student Version 1.4d
2. Familiarize yourself with the FoilSim III interactive.
3. Select metric units
4. Enter the following data for Flight, Size, and Shape

A. Data for FoilSim III to Determine Lift, Drag, $C_L$ , $C_D$ and L/D ratio	
Flight	
Speed - km/h	300 km/h
Altitude - m	2000m
Size	
Chord - m	3 m
Span - m	10 m
Area - sq m	30 sq m
Shape	
Angle - deg	To be entered for each attack angle
Camber - %c	0.0
Thick - %crd	12.5

5. Once the inputs have been completed, reopen the Size Tab. Now enter, one at a time, the angle of attack for each of the angles in the left column of the Form. For each angle record the data in the proper column on the Form. As an example, the data for an angle of attack  $-3^\circ$  is listed.

## Worksheet 2 (cont.) Relationship of Lift and Drag in Flight

A. Effect of Angle of Attack on Lift and Drag Recording Form					
Angle of Attack	Lift	Drag	$C_L$	$C_D$	L/D ratio
-3°	-37340 N	2750 N	-0.354	0.026	-13.577
-2°					
-1°					
0					
1°					
2°					
3°					
4°					
5°					
6°					
7°					
8°					
9°					
10°					
11°					
12°					
13°					
14°					
15°					
16°					
17°					
18°					
19°					

6. Using the same procedure as above collect the required data for the parameters given in B. Entry Data for FoilSim III to Determine Lift, Drag,  $C_L$ ,  $C_D$ , and L/D ratio.

B. Entry Data for FoilSim III to Determine Lift, Drag, $C_L$ , $C_D$ and L/D ratio	
Flight	
Speed - km/h	300 km/h
Altitude - m	2000m
Size	
Chord - m	4.106
Span - m	13.21 m
Area - sq m	54.2 m
Shape	
Angle - deg	To be entered for each attack angle
Camber - %c	0.0
Thick - %crd	12.5

# Worksheet 2 (cont.) Relationship of Lift and Drag in Flight

B. Effect of Angle of Attack on Lift and Drag Recording Form					
Angle of Attack	Lift	Drag	$C_L$	$C_D$	L/D Ratio
2°					
5°					
10°					
15°					
19°					

During the activity you had to change the area on the wing leaving all of the other data the same? Were the coefficient of lift and drag the same in both flights?

Answer: \_\_\_\_\_

7. Use the data that you recorded in the A. Effect of Angle of Attack on Lift and Drag Recording Form to produce a line graph for the Lift to Drag Graph with Angle of Attack. The Y axis is L/D and the X axis the angle of attack.

Lift to Drag Graph with Angle of Attack											
L/D											
12											
11											
10											
9											
8											
7											
6											
5											
4											
3											
2											
1											
0											
Angle of Attack	0	2	4	6	8	10	12	14	16	18	20

From the graph between what angles do you get the maximum lift to drag?  
 Answer: \_\_\_\_\_

## Worksheet 2 (cont.) Relationship of Lift and Drag in Flight

8. Use the data that you recorded in the A. Effect of Angle of Attack on Lift and Drag Recording Form to produce a line graph on the Coefficient of Lift as a Function of Angle of Attack Graph. The Y axis is the CL and the X axis the angle of attack.

Coefficient of Lift as a Function of Angle of Attack											
C <sub>L</sub>											
1.3											
1.2											
1.1											
1.0											
0.9											
0.8											
0.7											
0.6											
0.5											
0.4											
0.3											
0.2											
0.1											
0.0											
Angle of Attack	0	2	4	6	8	10	12	14	16	18	20

Look at the graph and decide what is the stall angle? Answer: \_\_\_\_\_

**Lift to Drag Problem**

Assume the aircraft in this problem is the one that data has been gathered as part of Activity 2. This aircraft has a weight of 25184 Newtons. The aircraft’s velocity is 300 km/hr and the angle of attack is 2°. From the data the Coefficient of Lift (CL) for a 2° angle of attack is approximately 0.239. For this problem Lift can be equal to the weight of the aircraft in Newtons otherwise the aircraft would not fly.

A simple formula for solving lift: **Lift = K \* velocity squared \* CL**

First solve for K (K is a constant value made up of the air density and the wing area).

Can assume the lift is equal to the weight in Newtons (25184 Newtons) since the lift must equal the weight in order for the aircraft to fly, so it must be 25184 Newtons.

$$\text{Lift} = K \times V^2 \times C_L$$

K =

**L/D CURVE** The ratio of Lift to Drag is a very important parameter for any airplane. Determine the speed to fly this aircraft at the most favorable lift for the amount of drag being created for this aircraft with a 6° angle of attack. The resultant speed is the most favorable lift for the amount of drag being created. This would be the speed to fly the aircraft for the maximum distance either gliding or under power.

$$\text{Lift} = K \times (v)^2 \times C_L$$

Given:

K = Answer from above

Lift = 25,184 Newtons

CL for 6° angle of attack from data = .0685

Solve for speed (velocity)

$$(V^2) = \frac{L}{C_L}$$

Answer: \_\_\_\_\_

Explain your answer:

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## Worksheet 2 (cont.) Relationship of Lift and Drag in Flight

### Design a Wing

Given the following constraints, use FoilSim III to design an aircraft wing that generates 25,000 N of lift. Use the table shown below to record your answers.

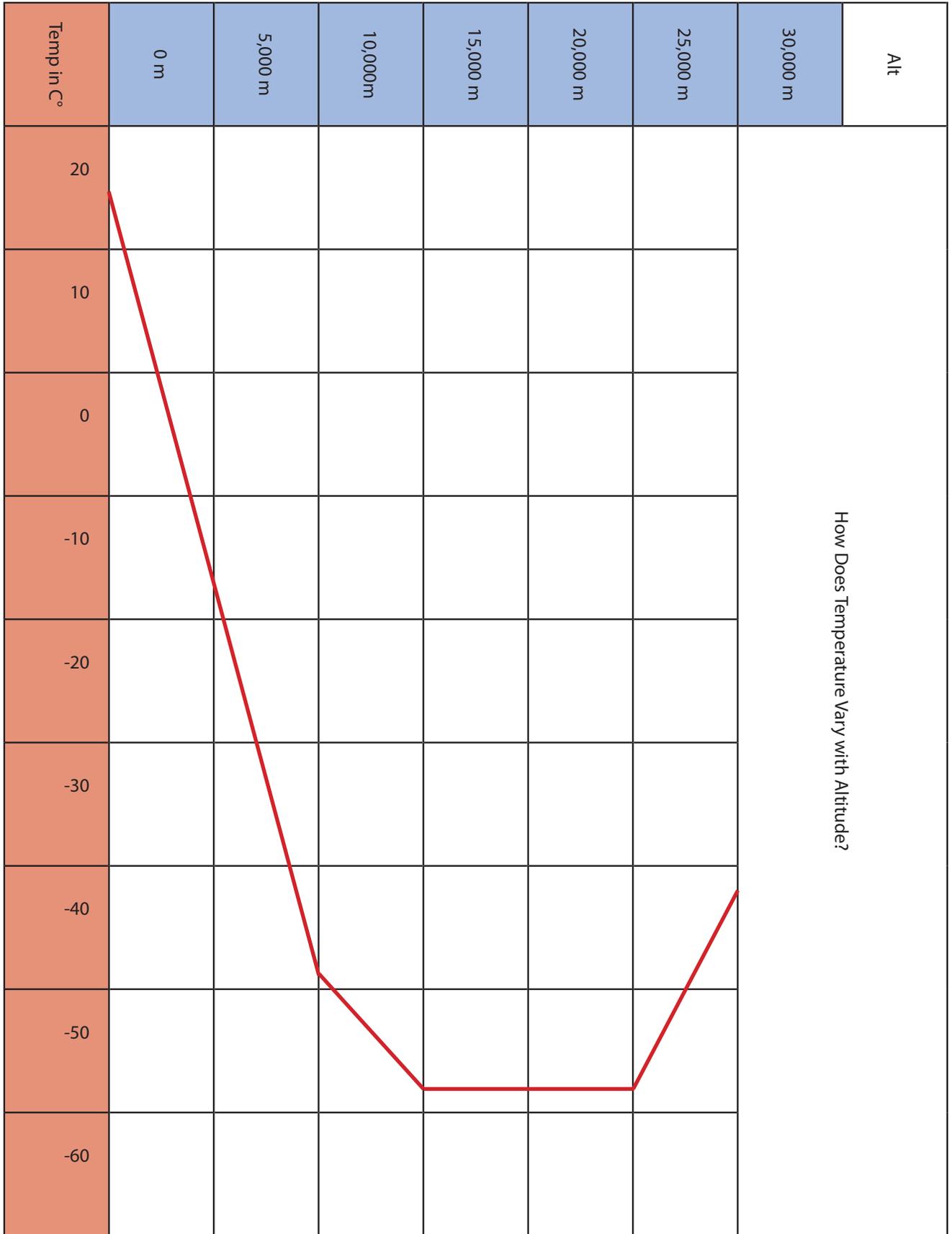
1. The maximum airspeed of the plane is 250 km/hr.
2. The airplane must be able to fly at an altitude of 7000 meters.
3. Lift = 25,000 N
4. Record your values.

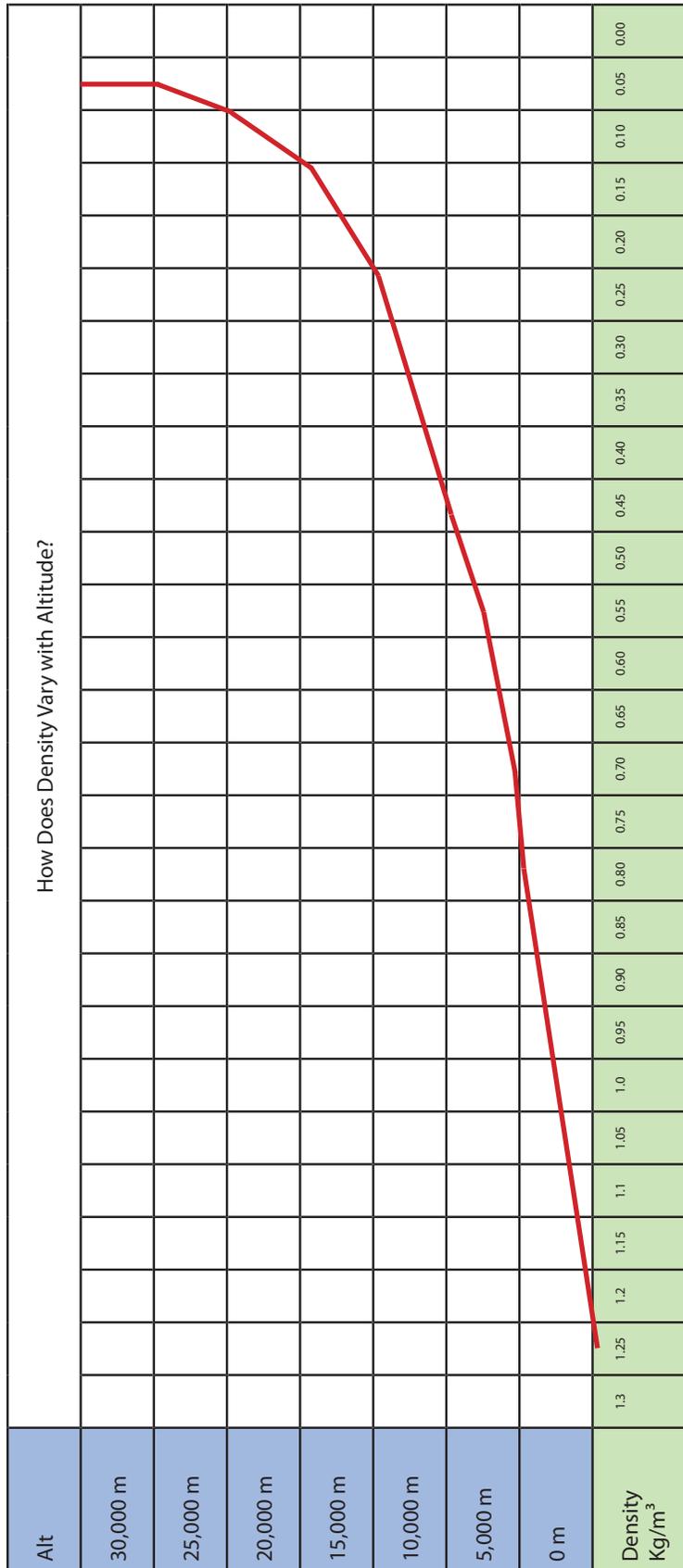
Design a Wing	
<u>Variable</u>	<u>Actual Value</u>
Airspeed:	250 km
Altitude:	7000 m
Angle:	
Chord:	
Span	
Camber %chord	0
Area:	
Lift:	25,000 N
Lift/Drag ratio	

How Does Temperature, Density, and Pressure Vary with Altitude?					
Altitude	Temperature C°	Density Kg/m <sup>3</sup>	Pressure KPa	Speed of Sound km/h	Speed of Sound mph
0 - Sea Level	15	1.224	101.324	1225	340.3
5,000 meters	-17	0.736	54.085	1154	320.6
10,000 meters	-49	0.413	26.51	1078	299.4
15,000 meters	-56	0.193	12.012	1062	295
20,000 meters	-56	0.08774	5.461	1062	295
25,000 meters	-56	0.03989	2.483	1062	295
30,000 meters	-41	0.01775	1.179	1098	305

Worksheet 1

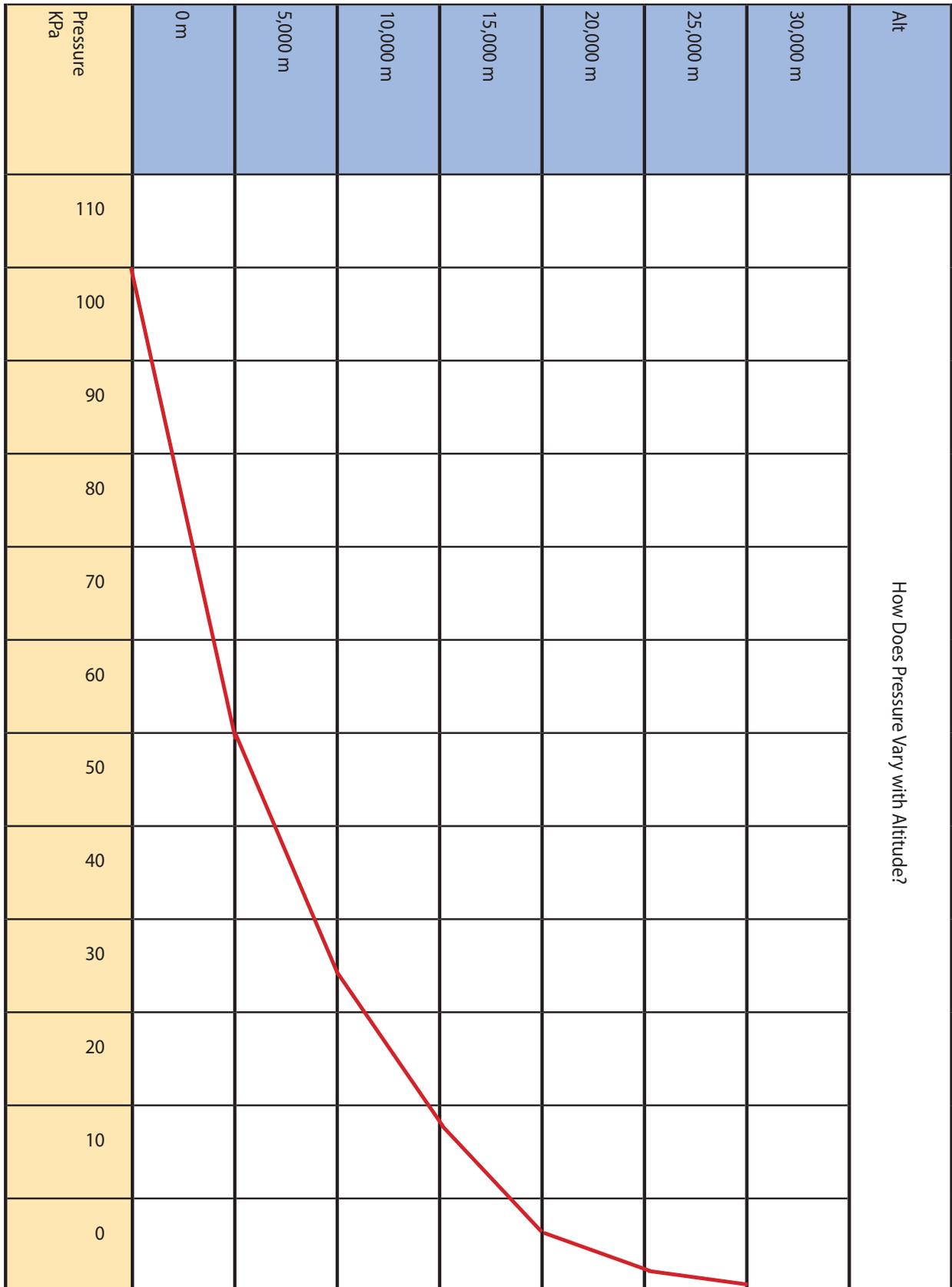
How Does Altitude Relate to Temperature, Density, and Pressure (Teacher Version)

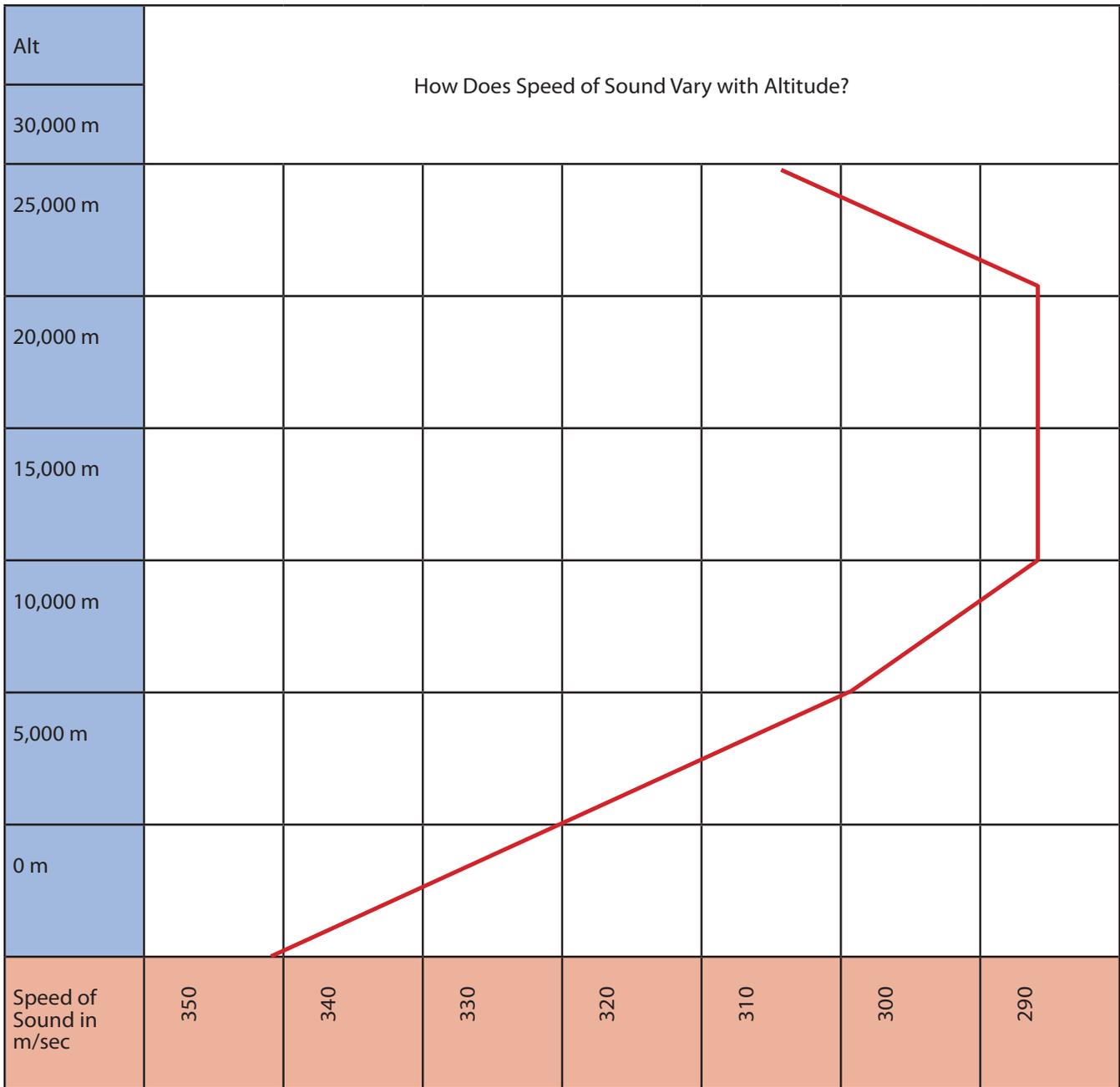




Worksheet 1

How Does Altitude Relate to Temperature, Density, and Pressure (Teacher Version)





## Worksheet 1      How Does Altitude Relate to Temperature, Density, and Pressure (Teacher Version)

### Dynamic Pressure

The formula for the dynamic pressure on the aircraft =

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

Density of the atmosphere at 8,000 meters is .552 kg/cubic m

The aircraft is traveling at 1,500 km/hr

1. Convert km/hr to m/s
  - a. Multiply km/hr x 1000 m/km (1,500,000 m/hr)
2. Convert m/hr to m/sec
  - a. Divide m/hr by 3,600 sec/hr  $\frac{(1,500,000 \text{ m/hr})}{3,600 \text{ sec/hr}} = 416 \text{ m/sec}$
3. Now solve for Dynamic Pressure

$$\text{Dynamic Pressure (q)} = \frac{.552 \text{ kg/cubic meter } (416 \text{ m/sec})^2}{2}$$

$$\text{Dynamic Pressure (q)} = \frac{95526.9}{2}$$

$$\text{Dynamic Pressure (q)} = 47,763.5 \text{ Pascals}$$

To convert to Kilo Pascals divide the number of Pascals found for the Dynamic Pressure by 1000 Pascal/kilo Pascal

**Answer is 47.7 Pascals is the Dynamic Pressure**

## Mach Number

From the graph the students drew for the Speed of Sound they are to estimate the speed of sound at 8,000 meters. From the graph it appears that the speed of sound is approximately 305 m/sec at 8,000 meters. In this problem the aircraft has a velocity of 416 m/sec. Students are to use this speed in solving for the Mach number.

$$\text{Mach number} = \frac{\text{Speed of Aircraft}}{\text{Speed of Sound}}$$

$$\text{Mach Number} = \frac{416 \text{ m/sec}}{305 \text{ m/sec}}$$

$$\text{Mach Number} = 1.36$$

## Solving for Temperature

For an altitude <11,000 meters (troposphere) atmospheric temperature in Celsius can be estimated using the formula:

$$T = 15.04 - .00649h \text{ (altitude in meters)}$$

$$\text{For an altitude of 8,000 m } T = 15.04 - .00649^\circ/\text{m} (9,000 \text{ m}) = 15.04 - 51.92$$

$$\text{Answer: } -36.88^\circ = -37^\circ$$

## Solving for Pressure

To determine pressure in the troposphere use the formula:

-273.16° is the temperature of absolute zero

The pressure will be in kilo Pascals (KPa)

$$P = 101.29 \times \left[ \frac{T + 273.1^\circ}{288.08} \right]^{5.256}$$

$$P = 101.29 \times \left[ \frac{-37 + 273.1^\circ}{288.08} \right]^{5.256}$$

$$P = 101.29 \times [273]^{5.256}$$

$$P = 101.29 \times [.8196]^{5.256}$$

$$P = 101.29 \times .3514$$

$$P = 35.6 \text{ KPa}$$

## Worksheet 2

## Relationship of Lift and Drag in Flight (Teacher Version)

1. Open FoilSim III Student Version 1.4d
2. Familiarize yourself with the FoilSim III interactive.
3. Select metric units
4. Enter the following data for Flight, Size, and Shape

A. Data for FoilSim III to Determine Lift, Drag, $C_L$ , $C_D$ and L/D ratio	
Flight	
Speed - km/h	300 km/h
Altitude - m	2000m
Size	
Chord - m	3 m
Span - m	10 m
Area - sq m	30 sq m
Shape	
Angle - deg	To be entered for each attack angle
Camber - %c	0.0
Thick - %crd	12.5

5. Once the inputs have been completed, reopen the Size Tab. Now enter, one at a time, the angle of attack for each of the angles in the left column of the Form. For each angle record the data in the proper column on the Form. As an example, the data for an angle of attack  $-3^\circ$  is listed.

A. Effect of Angle of Attack on Lift and Drag Recording Form					
Angle of Attack	Lift	Drag	$C_L$	$C_D$	L/D ratio
-3°	-37340 N	2750 N	-0.354	0.026	-13.577
-2°	-25184 N	2029 N	-0.239	0.019	-12.41
-1°	-12739 N	1629 N	-0.121	0.015	-7.817
0	0.0 N	1557 N	0.0	0.014	0.0
1°	12739 N	1817 N	0.121	0.017	7.008
2°	25184 N	2388 N	0.239	0.022	10.542
3°	37340 N	3248 N	0.354	0.03	11.493
4°	49214 N	4383 N	0.467	0.041	11.228
5°	60811 N	5784 N	0.578	0.054	10.513
6°	72139 N	7450 N	0.685	0.07	9.682
7°	83202 N	9387 N	0.79	0.089	8.879
8°	94007 N	94007 N	0.893	0.11	8.102
9°	104559 N	14108 N	0.993	0.134	7.411
10°	114865 N	16915 N	1.091	0.16	6.79
11°	124374 N	19886 N	1.182	0.189	6.254
12°	132385 N	22794 N	1.258	0.216	5.807
13°	138674 N	25510 N	1.318	0.242	5.435
14°	143021 N	27898 N	1.359	0.265	5.126
15°	145196 N	29822 N	1.373	0.283	4.868
16°	144949 N	31146 N	1.377	0.296	4.653
17°	141998 N	31736 N	1.349	0.301	4.474
18°	136017 N	31474 N	1.292	0.299	4.321
19°	126611 N	30262 N	1.203	0.287	4.183

6. Using the same procedure as above collect the required data for the parameters given in B. Entry Data for FoilSim III to Determine Lift, Drag,  $C_L$ ,  $C_D$ , and L/D ratio.

B. Entry Data for FoilSim III to Determine Lift, Drag, $C_L$ , $C_D$ and L/D ratio	
Flight	
Speed - km/h	300 km/h
Altitude - m	2000m
Size	
Chord - m	4.106
Span - m	13.21 m
Area - sq m	54.2 m
Shape	
Angle - deg	To be entered for each attack angle
Camber - %c	0.0
Thick - %crd	12.5

## Worksheet 2

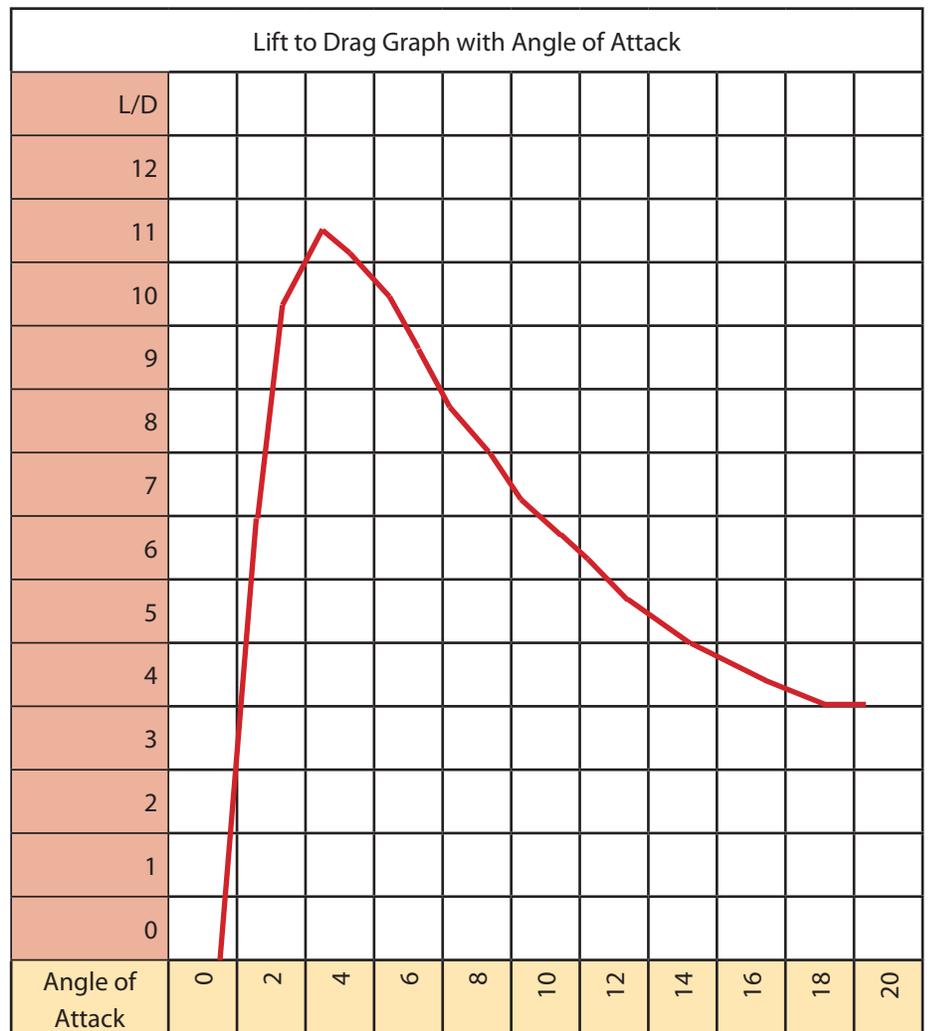
## Relationship of Lift and Drag in Flight (Teacher Version)

B. Effect of Angle of Attack on Lift and Drag Recording Form					
Angle of Attack	Lift	Drag	$C_L$	$C_D$	L/D Ratio
2°	45333 N	4239 N	0.239	0.239	10.692
5°	109341 N	10525 N	0.576	0.055	10.387
10°	206182 N	30988 N	1.087	0.163	6.653
15°	260380 N	54301 N	1.373	0.286	4.795
19°	227184 N	54531 N	1.198	0.287	4.166

During the activity you had to change the area on the wing leaving all of the other data the same? Were the coefficient of lift and drag the same in both flights?

Answer: yes

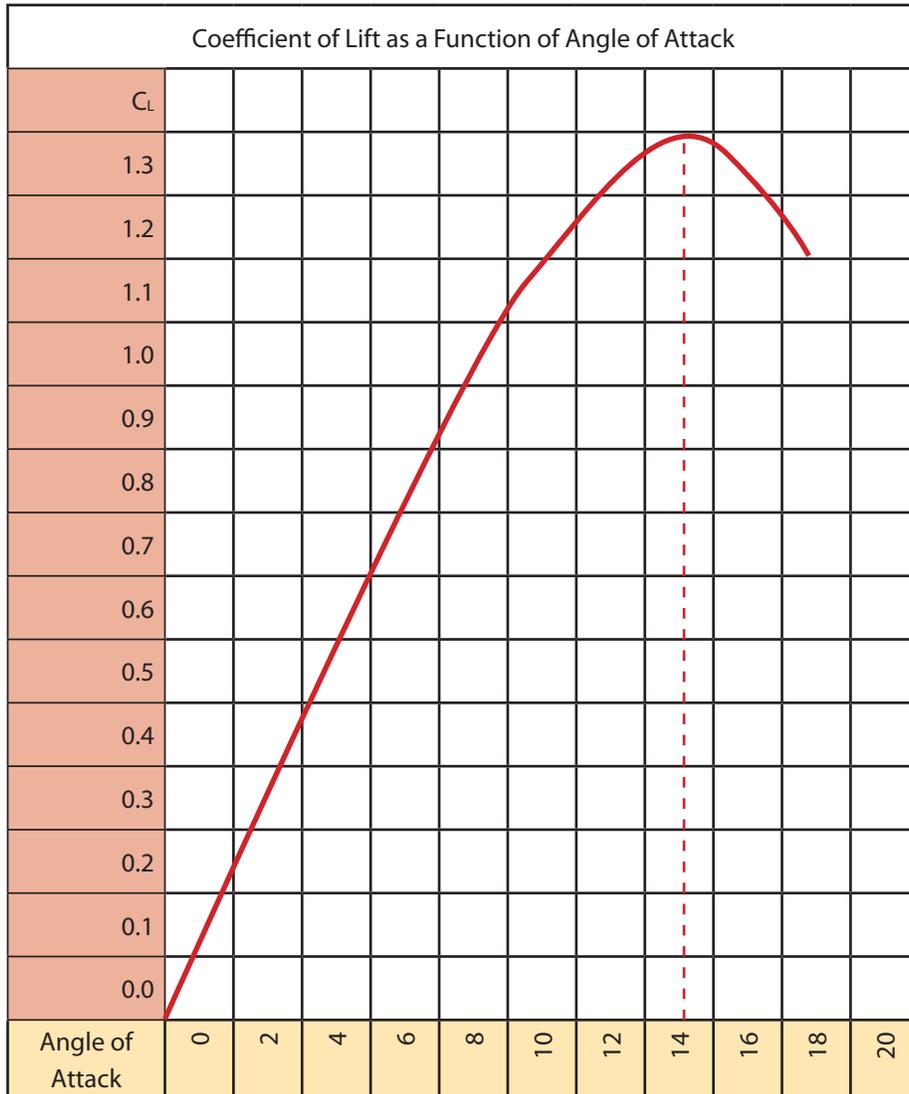
7. Use the data that you recorded in the A. Effect of Angle of Attack on Lift and Drag Recording Form to produce a line graph for the Lift to Drag Graph with Angle of Attack. The Y axis is L/D and the X axis the angle of attack.



From the graph between what angles do you get the maximum lift to drag?

Answer: 2°-6°

8. Use the data that you recorded in the A. Effect of Angle of Attack on Lift and Drag Recording Form to produce a line graph on the Coefficient of Lift as a Function of Angle of Attack Graph. The Y axis is the  $C_L$  and the X axis the angle of attack.



Look at the graph and decide what is the stall angle? Answer: 15°

## Worksheet 2

## Relationship of Lift and Drag in Flight (Teacher Version)

## Lift to Drag Problem

Assume the aircraft in this problem is the one that data has been gathered as part of Activity 2. This aircraft has a weight of 25184 Newtons. The aircraft's velocity is 300 km/hr and the angle of attack is 2°. From the data the Coefficient of Lift ( $C_L$ ) for a 2° angle of attack is approximately 0.239. For this problem Lift can be equal to the weight of the aircraft in Newtons otherwise the aircraft would not fly.

A simple formula for solving lift: **Lift = K \* velocity squared \*  $C_L$**

First solve for K (K is a constant value made up of the air density and the wing area).

Can assume the lift is equal to the weight in Newtons (25184 Newtons) since the lift must equal the weight in order for the aircraft to fly, so it must be 25184 Newtons.

$$\text{Lift} = K \times V^2 \times C_L$$

$$25184 \text{ Newtons} = K \times (300 \text{ km/hr})^2 \times .239$$

$$25284 \text{ Newtons} = 21510K$$

$$K = 1.175$$

**L/D CURVE** The ratio of Lift to Drag is a very important parameter for any airplane. Determine the speed to fly this aircraft at the most favorable lift for the amount of drag being created for this aircraft with a 6° angle of attack. The resultant speed is the most favorable lift for the amount of drag being created. This would be the speed to fly the aircraft for the maximum distance either gliding or under power.

$$\text{Lift} = K \times (v)^2 \times C_L$$

Given:

$$K = 1.17$$

Now solve for the speed that will give the maximum distance with the least amount of fuel when flying with a 6° angle of attack.

$$\text{Lift} = 25,184 \text{ Newtons}$$

$$C_L \text{ for } 6^\circ \text{ angle of attack from data} = .0685$$

Solve for speed (velocity)

$$(v^2) = \frac{L}{C_L \times K} = (v^2) = \frac{25,184 \text{ Newtons}}{.080145} = (v^2) = 314,230 \frac{\text{km}}{\text{hr}} = 560.5 \text{ km/hr}$$

Answer: 560.5 km/hr

Explain your answer:

Flying the aircraft with a 6° angle of attack with a speed of 560.5 km/hr will produce the same lift as flying the aircraft at 300 km/hr with a 2° angle of attack. From the data flying the aircraft at 560.5 km/hr would provide the maximum distance with the same amount of fuel.

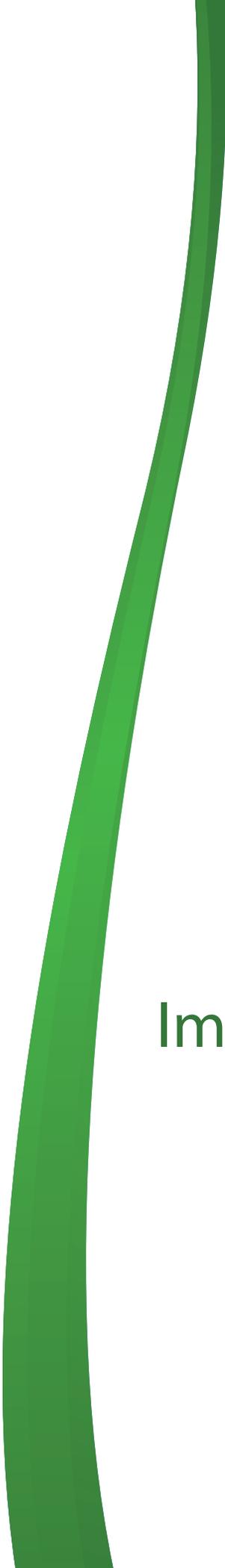
## Design a Wing

Given the following constraints, use FoilSim III to design an aircraft wing that generates 25,000 N of lift. Use the table shown below to record your answers.

1. The maximum airspeed of the plane is 250 km/hr.
2. The airplane must be able to fly at an altitude of 7000 meters.
3. Lift = 25,000 N
4. Record your values.

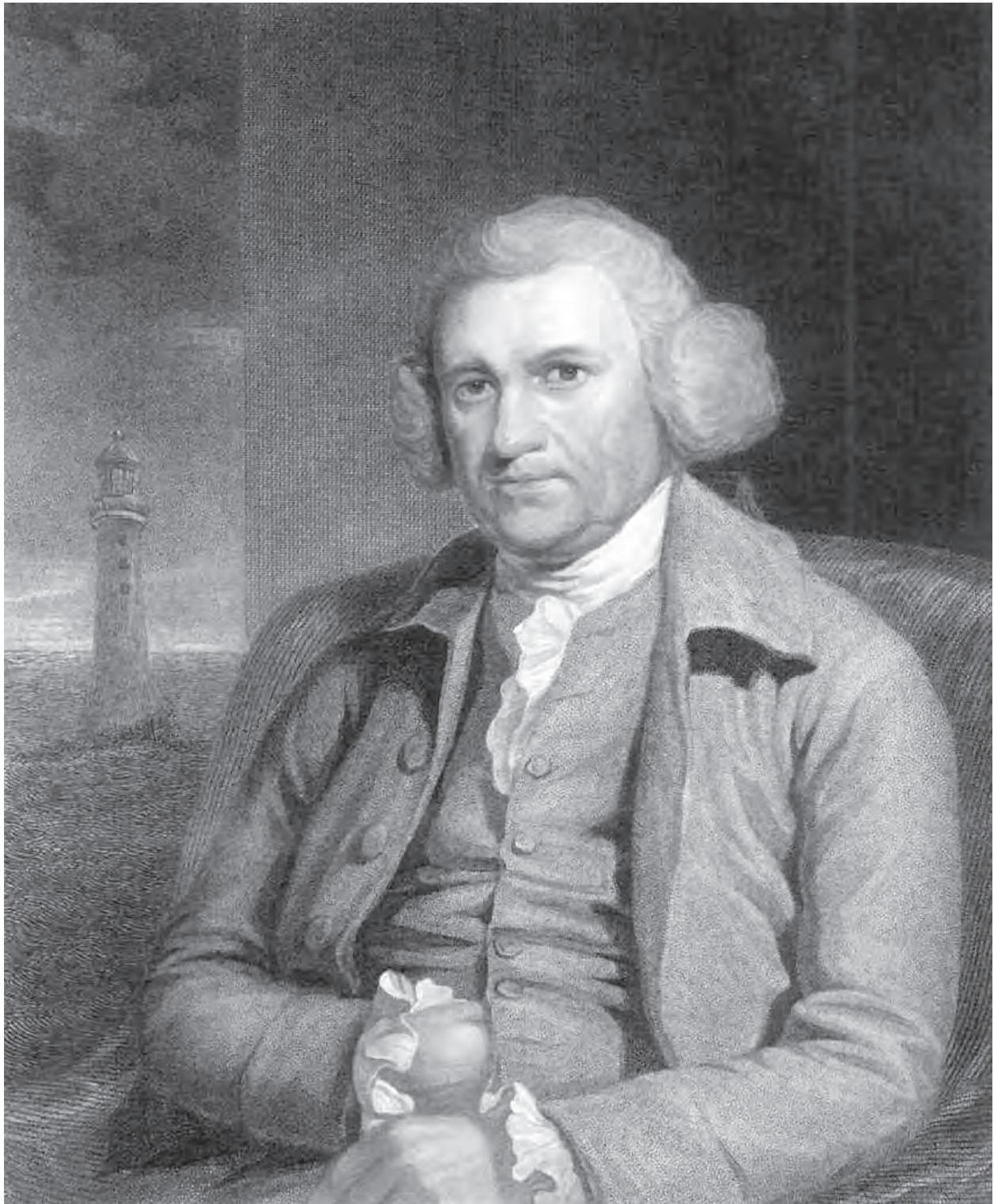
Design a Wing	
<u>Variable</u>	<u>Actual Value</u>
Airspeed:	250 km
Altitude:	7000 m
Angle:	4°
Chord:	3.4986625 m
Span	10.77468 m
Camber %chord	0
Area:	37.696968 sq m
Lift:	25,000 N
Lift/Drag ratio	10.512





Images

**Img. 1** John Smeaton



(Public Domain)

**Img. 2** George Cayley



(Public Domain)

**Img. 3** Otto Lilienthal



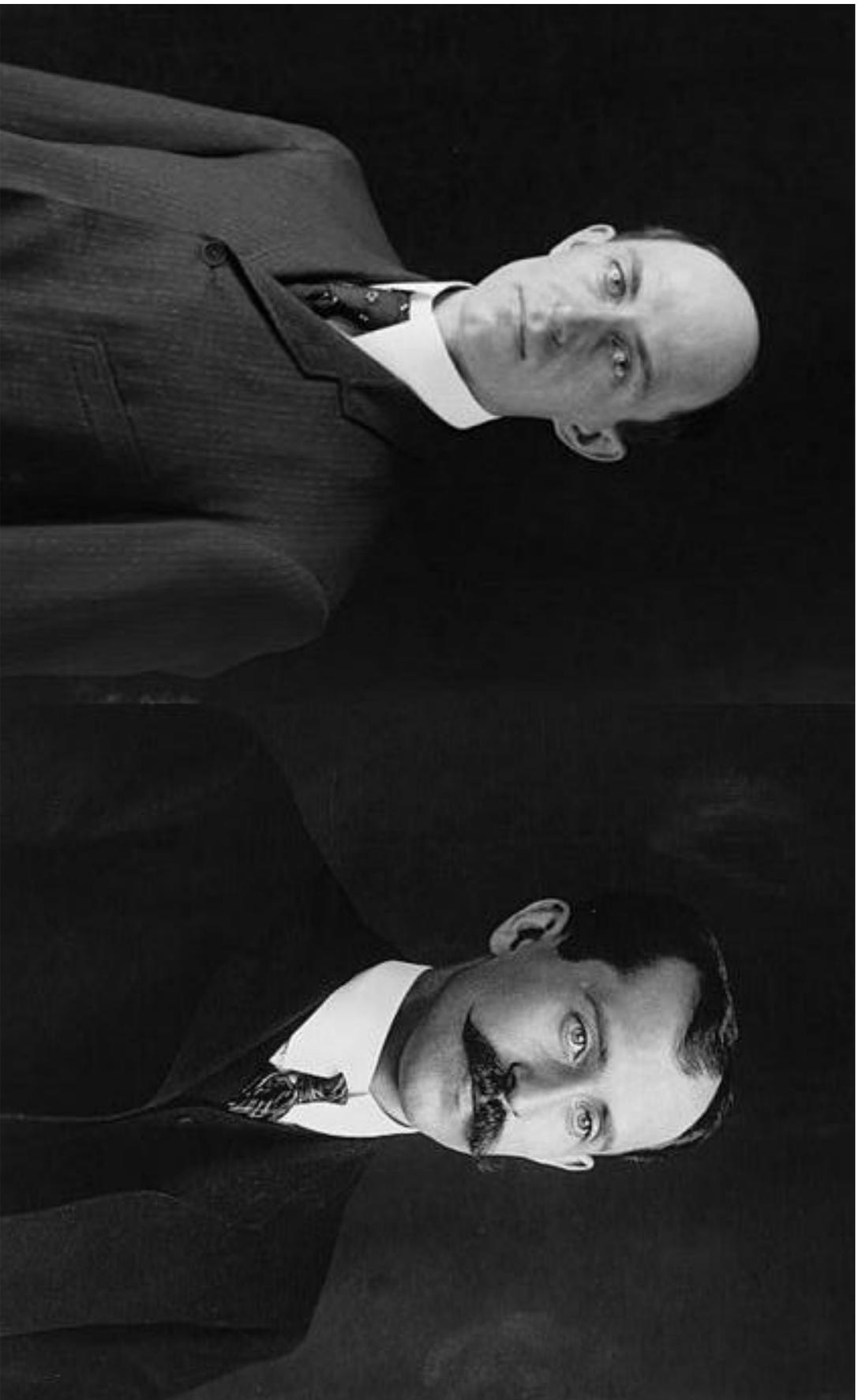
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**Img. 4** Samuel Pierpont Langley



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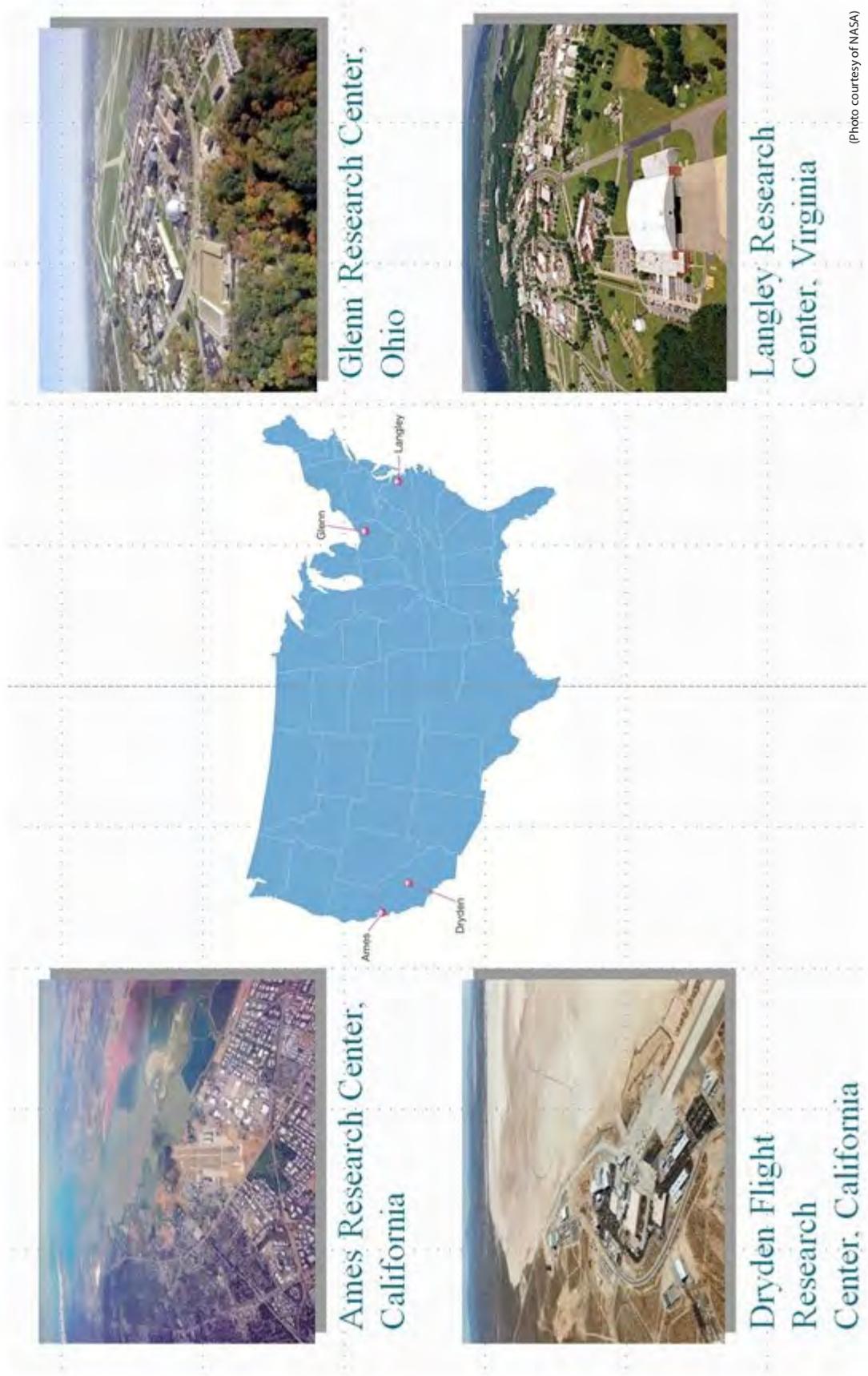
**Img. 5** Wright Brothers



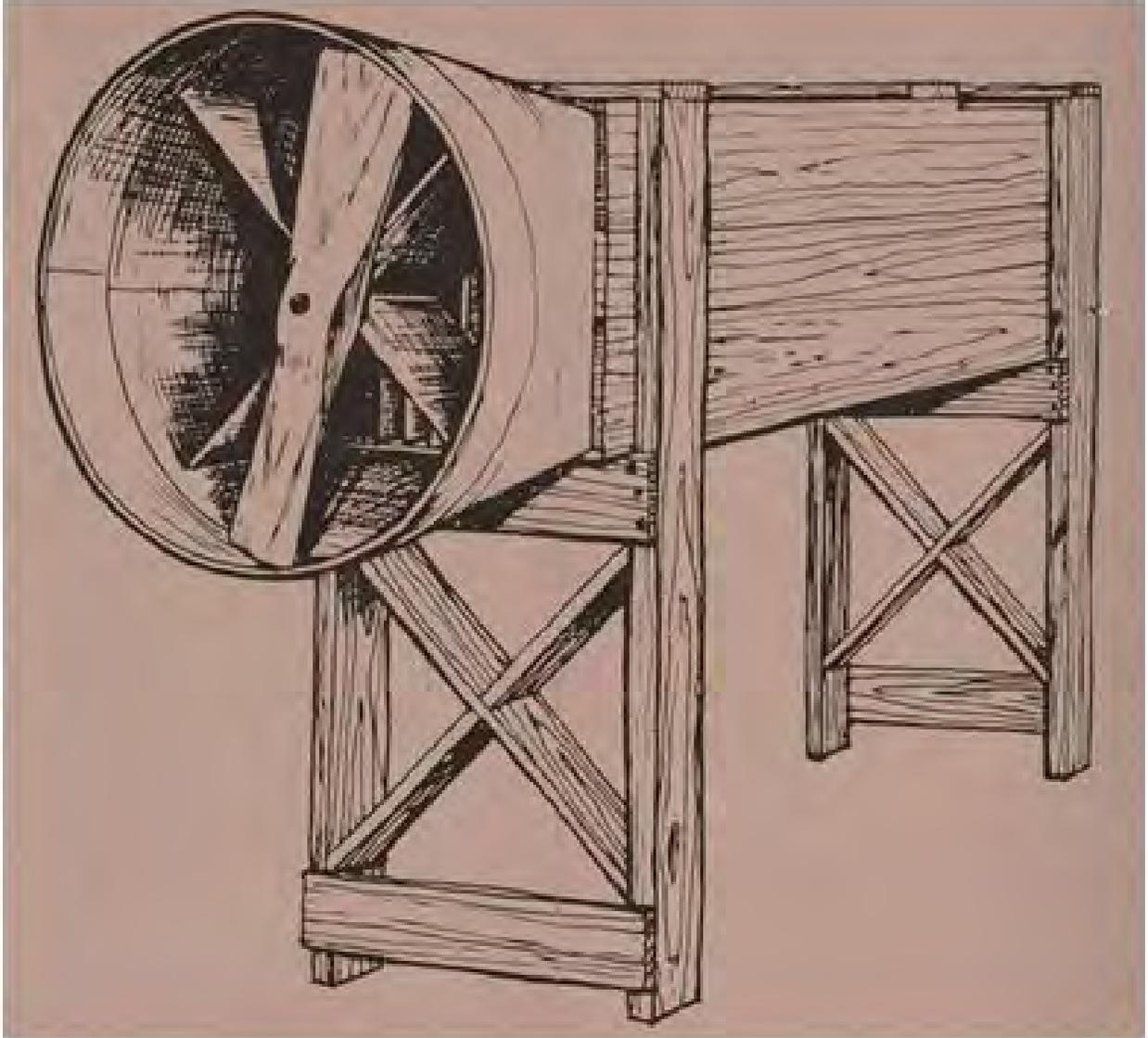
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**Img. 6** NASA's Aeronautical Research Centers

## NASA's Aeronautical Research Centers



**Img. 7** Wright Brothers Wind Tunnel



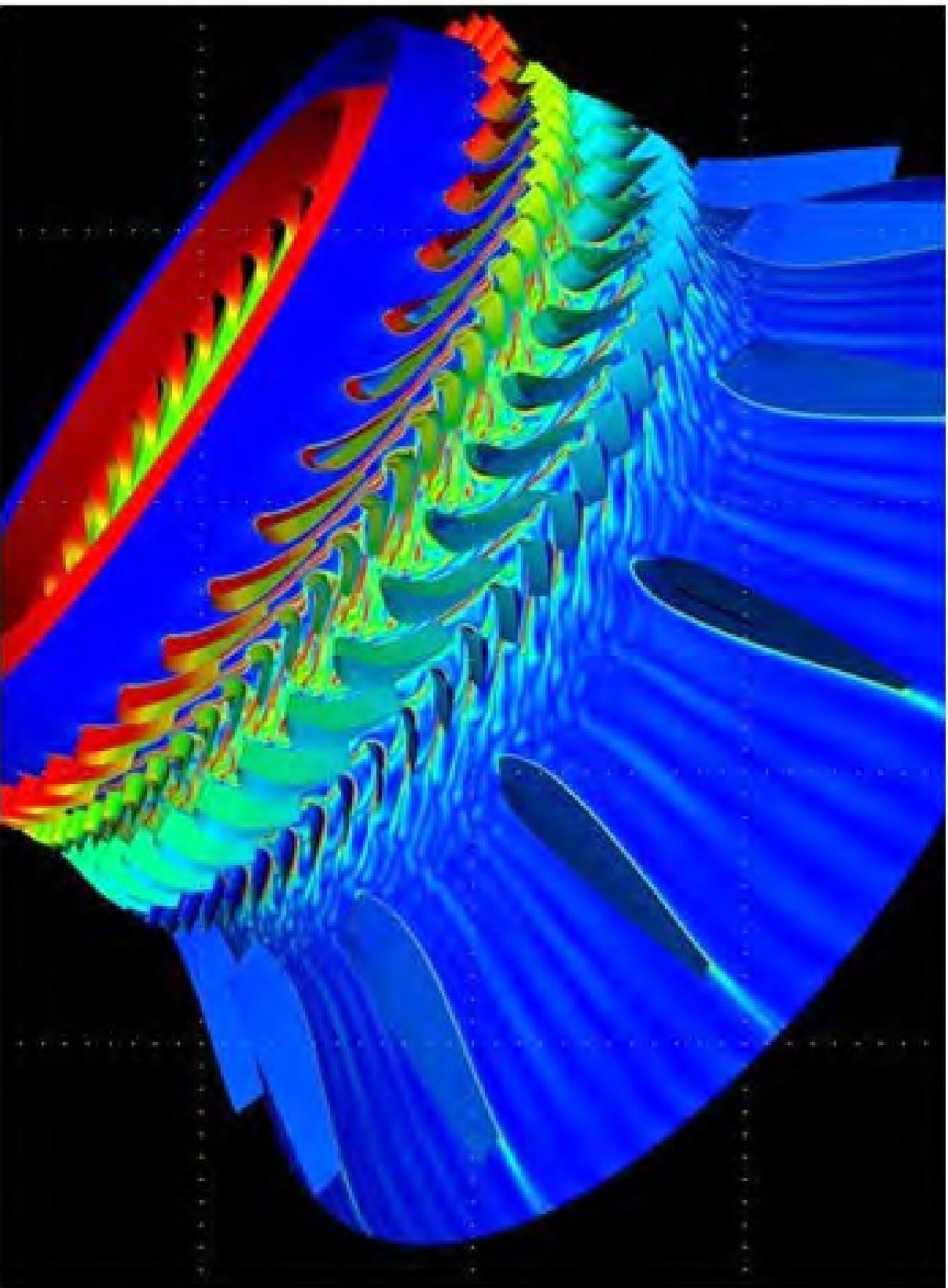
(Image courtesy of NASA)

**Img. 8** Big Fan in a Langley Research Center Tunnel



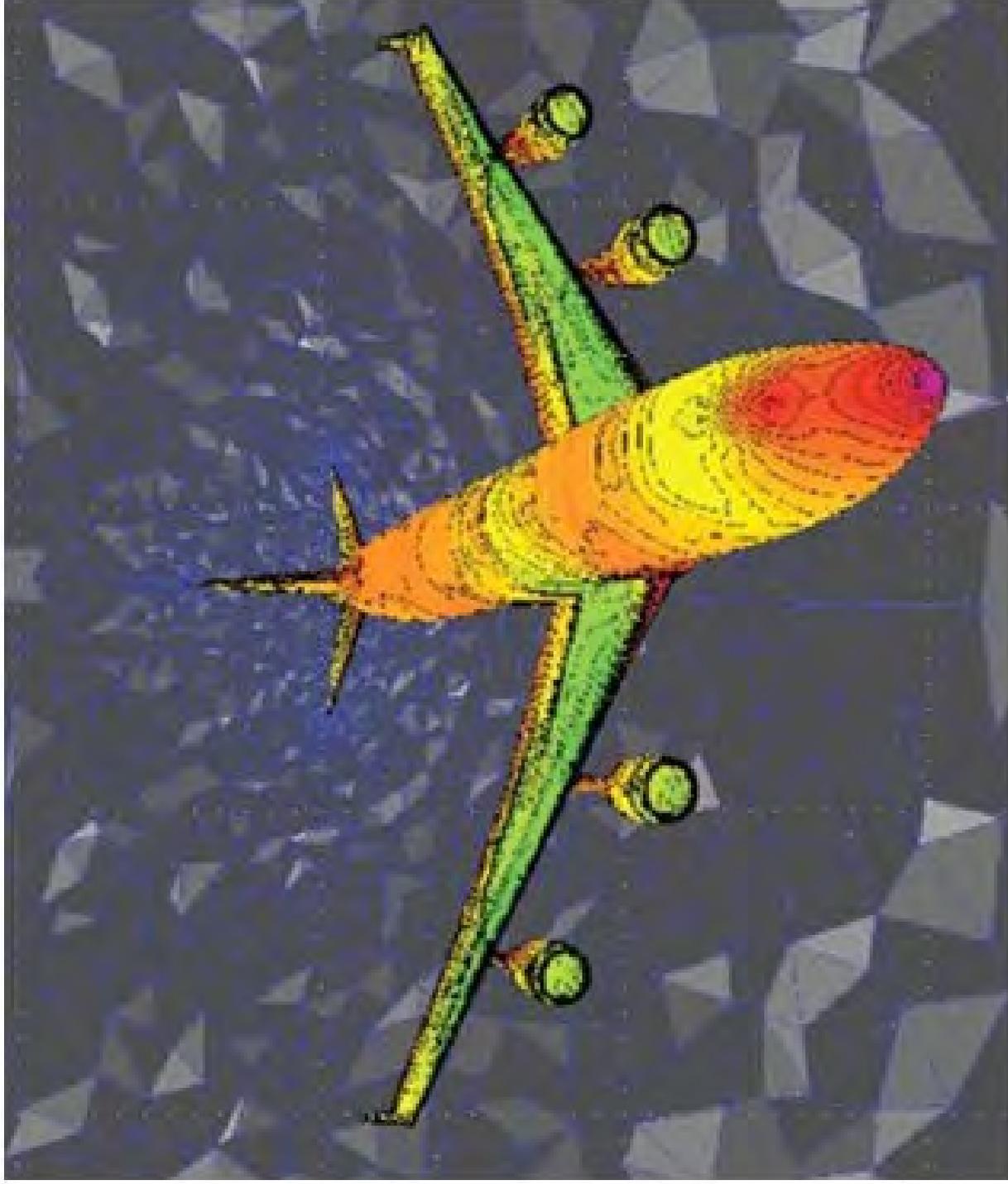
(Image courtesy of NASA)

**Img. 9** Super Computer Image of a Fan



(Image courtesy of NASA)

**Img. 10** Super Computer Image of an Airplane



(Image courtesy of NASA)

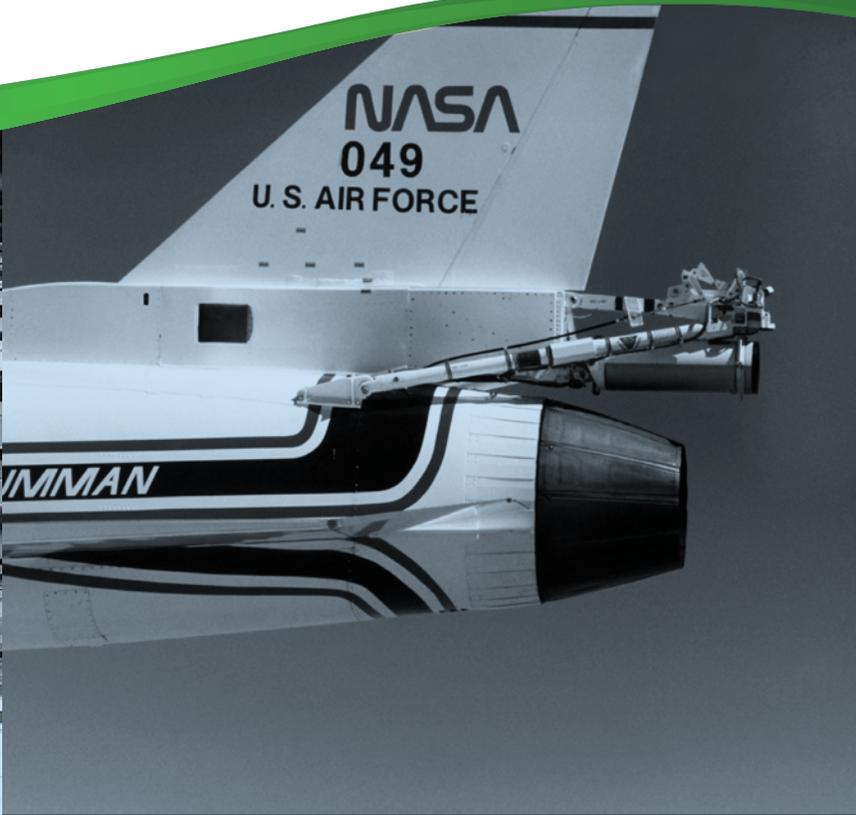
**Img. 1 1** Earth from space showing our thin atmosphere



(Image courtesy of NASA)



Aeronautics  
Research  
Mission  
Directorate



principles of flight