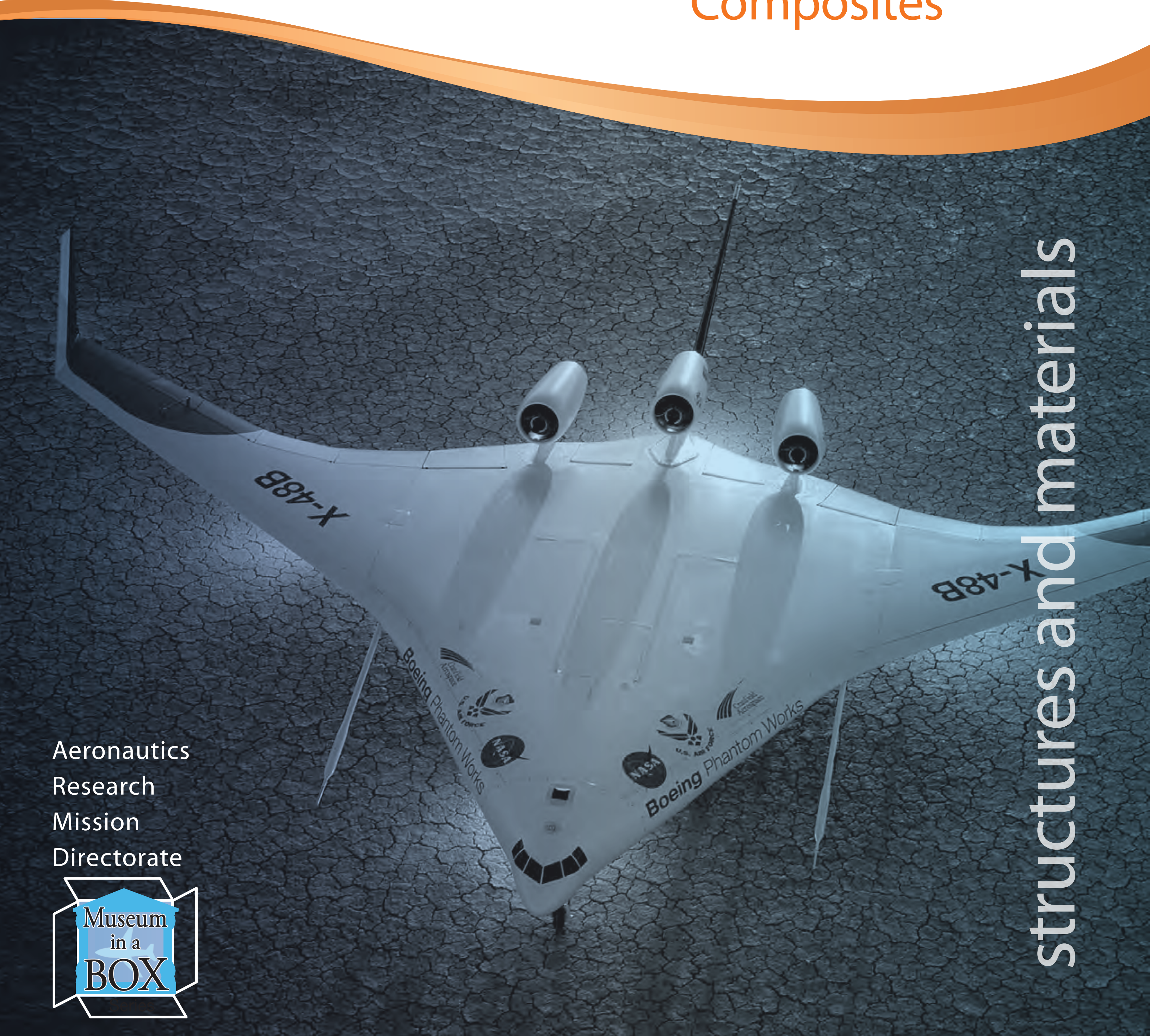
National Aeronautics and Space Administration

GRADES K-12

Composites



structures and materials

Aeronautics Research Mission Directorate

Museum in a BOX

www.nasa.gov

Composites

Lesson Overview

In this lesson, students will examine some of the materials used in the field of aerospace. Through demonstration and experimentation, students will learn how modern technologies have allowed us to fly faster and travel deeper into our solar system.

X-48B Blended wing body during its first flight on July 20, 2007

Objectives

Students will:

1. Learn that the materials used in airplane construction have changed over time.
2. Discover that a material's density does not correspond to its strength.
3. Experiment with Shape Memory Alloys and discover their properties.
4. Compare the densities of a variety of metals and learn how material selection affects the cost of flight.

SAFETY STATEMENT:

Do not attempt to cut any of the carbon fiber materials!

Caution: Handle the balance carefully. The capacity is 210 grams, which is less than half a pound. Anything heavier, including pushing on the balance, can damage this delicate apparatus.

Note: Testing has shown that there is a strong urge for students to push down on the balance!

Materials:

Included in MIB

Carbon fiber samples
Balance
Carbon fiber strip
Spruce wood strip
The Memory Metal book (pink cover)
and Nitinol sample (inside the book's front cover)
Density Cubes
Balance

Provided by the User:

Ruler
Large glass of hot water
Paperclip

GRADES **K-12**

Time Requirements: 1 hour 25 minutes minimum

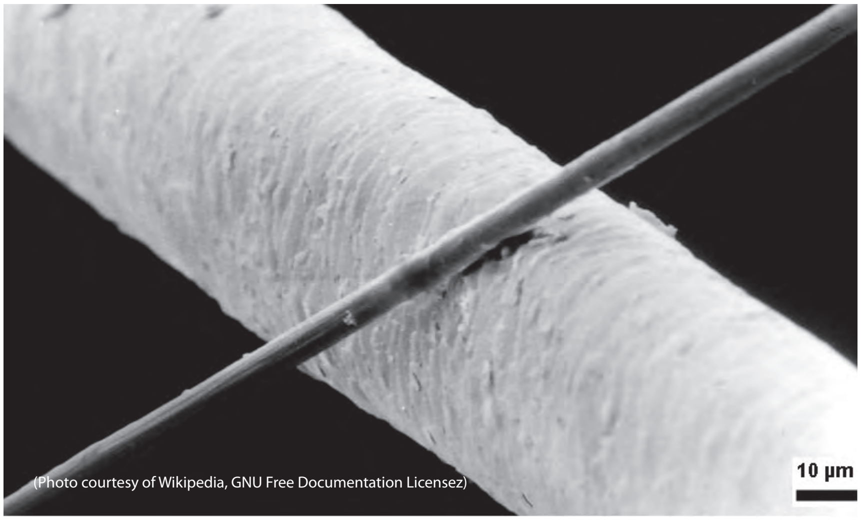
Background

Materials in Aerospace

Img. 1 The Wright Brothers' First Flight – December 17th, 1903

Ever since the Wright brothers built their Flyer back in 1903 (Img. 1), the materials used in airplane design have been constantly evolving. The original Wright Flyer was comprised primarily of spruce and ash wood with muslin covering the wings, while today's airliners are made mostly of aluminum with some structure made from steel.

In the mid 1960's, scientists and engineers began working on a new breed of aerospace materials called composites. A composite is an engineered material made from two or more ingredients with significantly differing properties, either physical or chemical. While no longer used today, an early example of a composite material was a mix of mud and straw that was used to make bricks. Composites have two significant advantages over some of the more traditional materials: greater strength and lighter weight.



Img. 2 A 6 µm diameter carbon filament (running from bottom left to top right) compared to a human hair

One of the most common forms of composite in use today is carbon fiber. It is made by heating lengths of rayon, pitch or other types of fiber to extremely high temperatures (~2000ºC) in an oxygen-deprived oven. This heat, combined with the lack of oxygen, means that instead of combusting or burning completely, the rayon strands turn into strands of pure carbon atoms approximately 6µm (six micrometers) in diameter (Img. 2). These strands are spun into a thread, then woven into sheets and mixed with hardening resins to form the various components needed.

(Photo courtesy of Boeing)

Img. 3 The Boeing 787 takes off on its maiden flight

Carbon fiber had a difficult start in the aviation industry. In 1968 Rolls Royce attempted to make the blades of a turbine engine out of carbon fiber. Unfortunately, it was determined that while they were incredibly lightweight and strong, they were unable to tolerate an impact from a bird and shattered instantly. While the US military has made a few aircraft from predominately carbon fiber, it wasn't until January 2003 that Boeing announced they intended to build a passenger aircraft predominately out of composite materials. This aircraft, the Boeing 787 (Img. 3), took flight for the first time on the 15th of December, 2009 and is scheduled to enter passenger service in late 2011.

It isn't just composites that have been advancing technologically. Metals have also seen major improvements in strength, structure and durability, which is focused on in this lesson. vNitinol is a composite of two metals, known as an alloy, of Nickel and Titanium. It was discovered in 1962 by William Buehler of the Naval Ordinance Laboratory. Nitinol (**N**i [nickel] **T**i [titanium] **N**aval **O**rdinance **L**aboratory) is one of just a few alloys that are known as Shape Memory Alloys, or SMAs. An SMA, sometimes referred to as Smart Metal, Memory Alloy or Muscle Wire, can return to its original shape after being deformed. It has many uses in the medical field as well as in aerospace, where it is used in hydraulic hose clamps, and to reduce engine noise by using the heat of the engine to control exhaust emissions.

An SMA works by having the desired shape 'set' using extremely high temperatures, usually while in a vacuum. After it has cooled, the SMA can be stretched, bent, crushed or twisted. Then by applying heat, or an electrical current which through resistance causes the wire to heat, the SMA quickly returns to its preset shape. One of the most recent breakthroughs with SMAs are the creation of shape-changing heart stents. The stent is flattened before being placed into the artery and uses the body's own heat to return it to a cylindrical form. This means that the incision needed to insert the stent can be much smaller, leading to a reduced recovery time for the patient.

Activity 1 Materials Past and Present

GRADES K-12

Time Requirement: 30 minutes

Materials:

In the Box

Carbon fiber samples

Worksheets

Material Comparison (Worksheet 1)

Reference Materials

None

Key Terms:

Carbon fiber

Objective:

Students will learn through discussion how the materials used in airplane construction have changed over time.

Activity Overview:

By using the photos supplied in the Images section, you will lead a discussion with the students on how the materials used in the manufacture of aircraft have changed over time and why. A worksheet is provided for the students to record and compare their answers.

Activity:

1. **Examine the Wright Flyer using the photos provided in the Images section (Imgs. 1, 4 and 5).** As a group, ask the students to list the materials used in the airplane's construction on their worksheet.

   Wood (spruce), steel, cloth (muslin), aluminum

2. **Ask the students why they think the Wright brothers chose those materials.** Points to consider are the material's availability, strength, elasticity, weight, cost, hardness and resistance to corrosion.

   Wood – Used in the wings. It is light, flexible and easy to shape into parts. They originally chose pine instead of spruce, but it cracked easily under pressure. Spruce was far more flexible which was especially important to consider when landing. Wood is also cheap and readily available.

   Steel – Used in numerous locations to hold parts together. Steel is easy to shape, very hard and is well suited for making bolts. It does however rust easily if untreated.

   Cloth – Used to cover the wings. It is extremely light and easy to shape but very easy to tear.

   Aluminum – Used to make the engine. Aluminum can be heated and molded easily which still today makes it popular for engine construction.

3. Examine the Boeing VC-137C (Boeing 707) using the photo provided in the Images section (Imgs. 6 and 7). Once again, have the students list the materials in the airplane's construction along with their respective properties.

Aluminum, Steel, Plastic / Glass

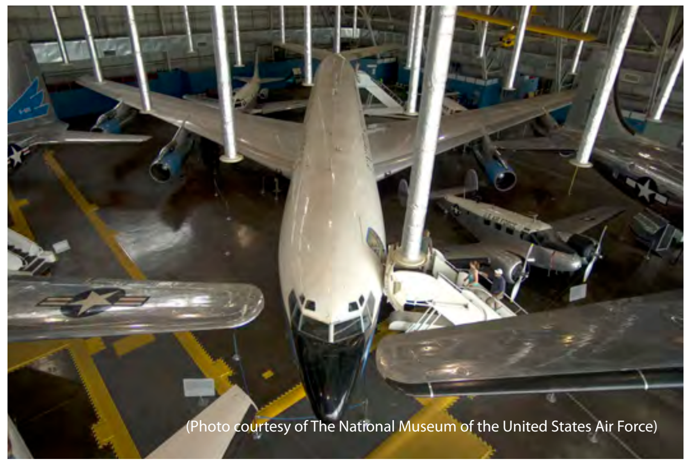
4. Ask the students why they think the VC-137C was made using different materials to the Wright Flyer. What made these materials better?

Aluminum – Used to cover the wings and fuselage. Heavier than cloth, but much stronger and can withstand many years of flying. It also enables aircraft to be pressurized which allows it to fly much higher, which in turn saves fuel.

Steel – Still used in many components today, although the newer steel alloys are much lighter and more corrosion resistant. The parts can also be made thinner as the aluminum skin provides the rigidity and strength that the cloth could not.

(Photo courtesy of The National Museum of the United States Air Force)

Img. 6 SAM 26000, a Boeing VC-137C landing at the National Museum of the United States Air Force in Dayton, OH


(Photo courtesy of The National Museum of the United States Air Force)

Img. 7 SAM 26000 on display at the National Museum of the United States Air Force in Dayton, OH

Plastic/Glass – Used in the windows, as well as in some places of the outer skin where strength isn't needed. While plastic was invented in 1862, well before the Wright Flyer was made, it wasn't readily available until the 1920s.

5. Lastly, show the students the picture of the Boeing 787 (Img. 3). Explain that while this aircraft still uses metals and plastic, it is made predominately of a material called carbon fiber. Hand out the samples of carbon fiber and ask them to describe it in comparison to the other materials.

Students should discover that carbon fiber is extremely light but very strong. They are unable to bend it or stretch it which makes it as strong as metal, without the associated weight.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

• Abilities necessary to do scientific inquiry

• Understanding about scientific inquiry

PHYSICAL SCIENCE

• Property of objects and materials

SCIENCE AND TECHNOLOGY

• Abilities of technological design

• Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

• Abilities necessary to do scientific inquiry

• Understandings about scientific inquiry

PHYSICAL SCIENCE

• Properties and changes of properties in matter

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

• Structure and properties of matter
• Interactions of energy and matter

SCIENCE AND TECHNOLOGY

• Abilities of technological design

• Understanding about science and technology

Activity 2 Material Comparisons

GRADES K-12

Time Requirements: 20 minutes

Materials:

In the Box

Balance
Carbon fiber strip
Spruce wood strip

Provided by User

Ruler

Worksheets

Material Density (Worksheet 2)

Reference Materials

None

Key Terms:

Density
Carbon fiber

Objective:

By calculating the samples' densities, students will discover that a material's density does not correspond to its strength.

Activity Overview:

In this activity, students will determine the mass, volume and density of two samples, spruce and carbon fiber. Students should discover that although the carbon fiber is less dense, it is clearly a stronger material than the spruce wood.

Prior to beginning this activity, set up the balance at the front of the classroom.If necessary, remove the cardboard protector from underneath the balance and remove the carbon fiber strip from its plastic packaging.

Activity:

1. **Pass the spruce and carbon fiber strips around the classroom.** Ask the students to GENTLY flex each strip, comparing how easily each one bends. Ask them to guess which one is heavier, or has more mass. Based on their answers, ask them to predict which one is more dense. (If needed, explain the definition of density: a measurement of the compactness of a material, measured in terms of mass per unit of volume.)

   CAUTION: The spruce strip WILL snap if over flexed. The idea is to demonstrate that spruce bends easier than carbon fiber, not to see how far both can bend!

   The students should discover that the spruce strip is more flexible and feels heavier than the carbon fiber.

2. **Ask a student to find the mass of one of the strips by placing it on the balance.** Have the students record the answer on their worksheets. Repeat the process with the other strip.

   Answers will vary by material sample.

3. Next, ask additional students to measure the length, width and thickness of the samples, again having the entire class record the data on their worksheets.

Answers will vary by material sample.

4. Using the following equations, have the students calculate the density of the samples.

$$\text{Length (mm)} \cdot \text{Width (mm)} \cdot \text{Thickness (mm)} = \text{Volume (mm}^3\text{)}$$

$$\frac{\text{Mass (g)}}{\text{Volume (mm}^3\text{)}} = \text{Density (g/mm}^3\text{)}$$

Answers will vary by material sample.

Example (Carbon fiber):

$$610\text{mm} \cdot 11\text{mm} \cdot 1.8\text{mm} = 12{,}078\text{mm}^3$$

$$\frac{19\text{g}}{12{,}078\text{mm}^3} = 0.00157\text{g/mm}^3$$

5. Summarize this activity by pointing out that while the spruce is more dense, the carbon fiber is the stronger material, as demonstrated when flexed.

The connection should be made that just because a material is dense, it does not necessarily make it strong. In this case, the carbon fiber is clearly a stronger material, despite being less dense.

Discussion Points:

1. Ask the students to name other materials they are familiar with that are very light but strong.

Some items they may suggest are Kevlar, foam, plastic, glass, fiberglass.

2. Ask the students to name everyday items that are made from the materials they identified in Discussion Point 1.

Some examples of this might be plastic drinking cups, bulletproof vests and aquariums.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

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

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

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

PHYSICAL SCIENCE

- Properties and changes of properties in matter

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

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS K-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 3 Shape Memory Alloys (SMAs)

GRADES **K-12**

Materials:

In the Box

The Memory Metal book (pink cover) and Nitinol sample (inside the book's front cover)

Provided by User

Large glass of hot water
Paperclip

Worksheets

None

Reference Materials

None

Key Terms:

Shape Memory Alloy (SMA)

Nitinol

Time Requirements:
5 minutes per student or group of students

Objective:

Through experimentation, students will learn how a Shape Memory Alloy reacts to heat in order to regain its shape.

Activity Overview:

By stretching the nitinol sample and then immersing it in hot water, students will see how the sample reacts. This can be repeated as many times as necessary with each student or group of students.

Before starting this lesson, fill a large glass with hot water and have it available. Water from the hot tap is sufficiently hot, do NOT use boiling water!

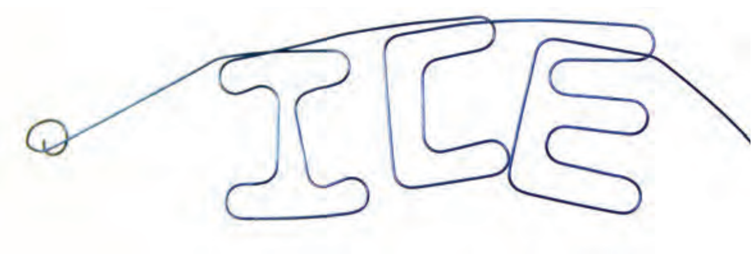
Activity:

1. **Start this demonstration by holding up a paperclip and showing it to the class.** It should be made clear to them that it is a normal paperclip.

2. **Bend the paperclip out of shape in such a fashion that it can no longer be used as a paperclip.** Ask the students what will happen to the clip if you immerse it in the hot water. Once the students have had a chance to answer, place the paperclip in the water.

   While you may receive different answers, the correct answer is that nothing will happen except the paperclip will become warmer to the touch.

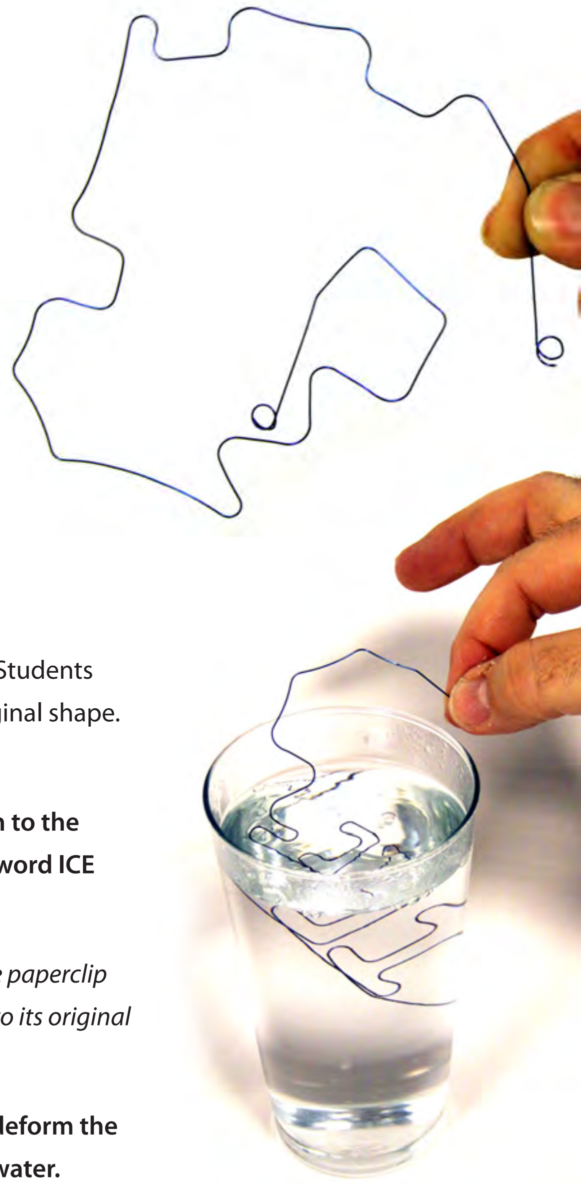
3. **Remove the nitinol sample from the envelope.** Pass the sample carefully around the class. Have the students note that it spells the word ICE.



   At this point, ensure that the students do not deform the sample so that they all clearly see it spells the word ICE.

4. **After each student has examined the sample, stretch the sample so that the word ICE is no longer discernible.**

   Caution: Do not try to remove all the small curves and kinks. Overstretching the wire will damage it and prevent it from remembering its shape.



5. **Ask the students what they think will happen when it is immersed into the hot water.**

   At this point, it will likely be assumed that the sample will react the same as the paperclip in that nothing will happen. For now, there is no need to correct their assumptions.

6. **Slowly lower the sample into the glass of hot water.** Students will see that as the sample heats up, it returns to its original shape. Ask them why they think that happened.

7. **Using the Background Information as a guide, explain to the students what a Shape Memory Alloy is and why the word ICE returned when it was immersed into hot water.**

   It is important to point out during your discussion that the paperclip was made of regular steel, which is why it failed to return to its original shape, unlike the SMA, which is made of nitinol.

8. **Either individually or in small groups, have students deform the nitinol sample themselves and immerse it in the hot water.**

   This can be repeated as many times as required without damage to the sample, provided that it is not overstretched.

Discussion Points:

1. **Ask the students to suggest places where Shape Memory Alloy's might be used. Point out that only a temperature change is needed to return the metal to its original shape; it does not need to be immersed in water.**

   Answers might include: flexible eye-glass frames, orthodontic braces, heart stents.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

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

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

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

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
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NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
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PHYSICAL SCIENCE

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SCIENCE AND TECHNOLOGY

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Activity 4 Density Cubes

GRADES K-12

Time Requirements: 30 minutes

In the Box

Density Cubes (4 sets)

Balance

Provided by User

Ruler

Worksheets

Density Cubes (Worksheet 3)

Reference Materials

None

Key Terms:

Density

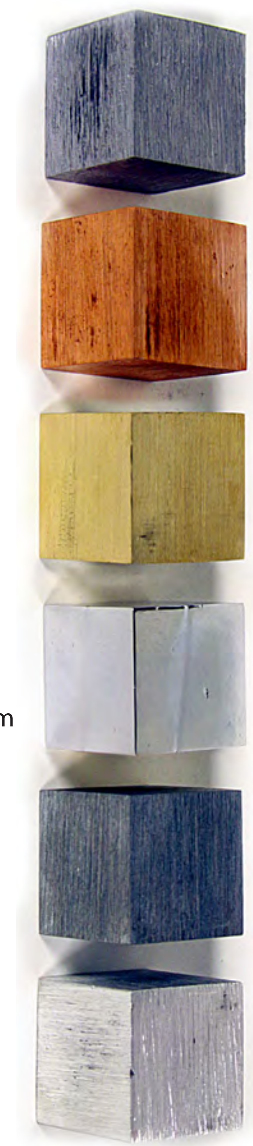
Objective:

To determine the density of different metals.

Activity Overview:

Using mathematics, students will determine the density of differing metals by first calculating each one's mass and size, then solving as required.

The sample cubes are not marked. As such, here is how to determine which cube is which:



Lead – The heaviest of the 4 silver cubes

Copper – The bright orange cube

Brass – The yellow cube

Iron – Has a bright, silver-colored mirrored finish (the finish is a chrome plating to prevent the cube from rusting)

Zinc – The darkest of the silver colored cubes

Aluminum – The lightest (in weight) of the silver-colored cubes

Activity:

1. **Divide the class into 4 groups and provide each group with a set of density cubes.** Ask the students to order them on their worksheets according to their mass (from most to least) just by judging how heavy they feel.

2. **Using the balance, have the students determine the mass of each cube and record the answer on their worksheets.**

   This can be done individually or in groups depending on class size and time available.

   Answers will vary by sample.

3. **Have the students list the cubes in order by mass (from most to least) based upon their measurements.**

4. **Using a ruler, have each student, or group of students, measure the size of each cube in millimeters and record the height, length and width on their worksheets.**

5. **Using the following formulas, calculate the density of each cube on the data sheet.**

$$\text{Length (mm)} \cdot \text{Width (mm)} \cdot \text{Thickness (mm)} = \text{Volume (mm}^3\text{)}$$

$$\frac{\text{Mass (g)}}{\text{Volume (mm}^3\text{)}} = \text{Density (g/mm}^3\text{)}$$

6. **Compare the students' answers with those in the table below.** Their answers should be very close to those shown here:

Sample Density g/ mm³	
Lead	0.0113
Copper	0.0089
Brass	0.0086
Iron	0.0079
Zinc	0.0071
Aluminum	0.0027

If there are slight differences in the results, this is due to the impurities in the samples provided. The numbers above are for the pure metals. For example, the zinc sample does contain small traces of aluminum which may cause your sample to be less dense.

If the students have completed **Activity 2 – Material Comparisons**, use their calculations of the density of carbon fiber for the remainder of this activity. If not, use a density of 0.00158 g/mm^3. Note: In our calculations, we used the pure metal densities shown in the preceding table; your students' results may differ.

7. **Compare the density of aluminum to that of carbon fiber by determining the ratio of the density of carbon fiber to the density of aluminum.** Express this ratio as a percentage.

$$\frac{\text{Density of Carbon Fiber}}{\text{Density of Aluminum}} = \text{Density Ratio}$$

$$\frac{0.00158 \text{ g/mm}^3}{0.0027 \text{ g/mm}^3} = 0.5852$$

$$0.5852 \cdot 100 = 58.52\%$$

Carbon fiber is only 58.52% as dense as aluminum

8. A Boeing 747-400ER is made predominantly of aluminum and has a mass of 184,000kg. (For the purpose of this activity, assume that the non-aluminum components are of a negligible mass.)

a. If Boeing replaced 10% of the aluminum with carbon fiber, what would its new mass be?

First, determine how much mass equates to 10% of the plane's total mass.

184,000kg • 10% = 18,400kg

To find the mass of the portion of the plane that will be made of carbon fiber, multiply the difference by the density ratio found in the previous problem.

18,400kg • 0.5852 = 10,767.68kg would be made of carbon fiber

Now, determine how much of the plane is still made of aluminum.

$$\begin{matrix}\text{Airplane's} \\ \text{Original Mass}\end{matrix} - \begin{matrix}\text{Amount Changed} \\ \text{to Carbon Fiber}\end{matrix} = \text{Total Aluminum Remaining}$$

184,000kg – 18,400kg = 165,600kg

Add the aluminum and carbon fiber components to determine the plane's new mass.

165,600kg + 10,767.68kg = 176,367.68kg

b. As a percentage, how much lighter is the new aircraft?

$$\frac{\text{New Mass}}{\text{Original Mass}} \cdot 100 = \text{Percentage of Original Mass}$$

$$\frac{176{,}367.68\text{kg}}{184{,}000\text{kg}} \cdot 100 = 95.852\%$$

100% - 95.85% = 4.15%

The aircraft is 4.15% lighter

9. The airplane burns approximately 3,600 gallons of fuel every hour. Assuming that the mass (and therefore the weight) of the aircraft is directly proportional to its fuel consumption, how many gallons per hour would an airline save if it replaced 10% of the aluminum materials in the plane with carbon fiber?

Fuel Consumption (gal/hr) • Percentage Savings = Gallons Saved per Hour

3,600 gal/hr • 4.15% = 149.4 gal/hr

10. If the fuel costs $4/gallon, how much money would an airline save on one 16 hour flight from London to Sydney?

Fuel Savings • Length of Flight • Cost of Fuel = Money Saved

149.4 gal/hr • 16 hrs • $4/gal = $9,561.60

Discussion Points:

1. What are some benefits of using carbon fiber and other composite materials over traditional materials (wood, metal, glass, etc.) in the aviation industry?

The airplane will burn less fuel as the plane will be lighter.

Composite materials can cope with the stresses of continual heating and cooling better than traditional metal components.

Composites are usually easier to work with in manufacturing facilities. It takes less energy to form components made from composites.

2. What are some of the challenges in designing new materials to replace existing ones, in ANY industry?

The new materials must retain all of the desirable qualities that the old materials had, such as impact-resistance and strength.

They must also be cost-effective to produce.

There are long term effects that have not had time to surface. For example, asbestos was used for decades until its health implications were discovered.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

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

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
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NATIONAL SCIENCE STANDARDS 5-8

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NATIONAL SCIENCE STANDARDS 9-12

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NATIONAL MATH STANDARDS K-12

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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

Carbon fiber:
An extremely strong fiber, consisting of long, chain-like molecules of nearly pure carbon that are made by burning fibers such as rayon in the absence of oxygen

Density:
A measurement of the compactness of a material, measured in terms of mass per unit of volume

Shape Memory Alloy (SMA):
An alloy that via a process of extensive heating "remembers" an assigned shape

Nitinol:
An example of a Shape Memory Alloy

Student Worksheets

Worksheet 1 Material Comparison

	1903 Wright Flyer	Boeing VC-137C	Boeing 787
Materials			**Carbon fiber** **Steel** **Aluminum**
Properties			**Carbon fiber** • lighter than metals • easier to shape than metals • very strong **Steel** • easy to shape • very hard and rigid • can rust **Aluminum** • strong • lighter than steel, heavier than cloth • rigid

1. Examine the photos of the Wright Flyer and list the materials they used in the chart above.

2. Why did the Wright brothers choose these materials?

3. Examine the photos of the Boeing VC-137C (Boeing 707) and list the materials they used in the chart above.

4. Why was the Boeing VC-137C (Boeing 707) made using different materials to the Wright Flyer?

Worksheet 2 Material Density

	Mass (g)	Length (mm)	Width (mm)	Thickness (mm)	Volume (mm^3)	Density (g/mm^3)
Spruce						
Carbon fiber						

1. Using the balance, determine the mass of the strips of spruce and carbon fiber. Record your results in the table above.

2. Measure the length, width and thickness of the strips of spruce and carbon fiber. Record your results in the table above.

3.Using the formulae below, calculate the density of the strips. Record your results in the table above.

$$\text{Length (mm)} \cdot \text{Width (mm)} \cdot \text{Thickness (mm)} = \text{Volume (mm}^3\text{)}$$

$$\frac{\text{Mass (g)}}{\text{Volume (mm}^3\text{)}} = \text{Density (g/mm}^3\text{)}$$

Worksheet 3 Density Cubes

1. Predicted order of cubes by mass, from least to most, judged by feeling of heaviness:

   1.
   2.
   3.
   4.
   5.
   6.

2. Actual order of cube by mass, from least to most:

   1.
   2.
   3.
   4.
   5.
   6.

3. Measure each cube, then calculate its volume and density. Record your measurements and results in the table below.

	Mass (g)	Length (mm)	Width (mm)	Height (mm)	Volume (mm^3)	Density (g/mm^3)
Lead						
Copper						
Iron						
Brass						
Aluminum						
Zinc						

Length (mm) • Width (mm) • Thickness (mm) = Volume (mm^3)

$$\frac{\text{Mass (g)}}{\text{Volume (mm}^3\text{)}} = \text{Density (g/mm}^3\text{)}$$

Worksheet 3 Continued

4. Compare the density of aluminum to that of carbon fiber by determining the ratio of the density of carbon fiber to the density of aluminum. Express this ratio as a percentage.

Density of Carbon Fiber ÷ Density of Aluminum = Density Ratio

$$\frac{\_\_\_\_\ g/mm^3}{\_\_\_\_\ g/mm^3} = \_\_\_\_$$

____ • 100 = ____ %

Answer: Carbon fiber is only ____ % as dense as aluminum

5. A Boeing 747-400ER is made predominantly of aluminum and has a mass of 184,000kg. (For the purpose of this activity, assume that the non-aluminum components are of a negligible mass.)

a. If Boeing replaced 10% of the aluminum with carbon fiber, what would its new mass be?

First, determine how much mass equates to 10% of the plane's total mass.

____ kg • 10% = ____ kg

To find the mass of the portion of the plane that will be made of carbon fiber, multiply the difference by the density ratio found in the previous problem.

____ kg • ____ = ____ kg would be made of carbon fiber

Worksheet 3 Continued

Now, determine how much of the plane is still made of aluminum.

Airplane's Original Mass – Amount Changed to Carbon Fiber = Total Aluminum Remaining

______ kg – ______ kg = ______ kg would remain aluminum

Add the aluminum and carbon fiber components to determine the plane's new mass.

______ kg + ______ kg = ______ kg

b. As a percentage, how much lighter is the new aircraft?

$$\frac{\text{New Mass}}{\text{Original Mass}} \cdot 100 = \text{Percentage of Original Mass}$$

$$\frac{\_\_\_\_\_\_ \text{ kg}}{\_\_\_\_\_\_ \text{ kg}} \cdot 100 = \_\_\_\_\_\_ \%$$

100% - ______ % = ______ %

The aircraft is ______ % lighter.

6. The airplane burns approximately 3,600 gallons of fuel every hour. Assuming that the mass (and therefore the weight) of the aircraft is directly proportional to its fuel consumption, how many gallons per hour would an airline save if it replaced 10% of the aluminum materials in the plane with carbon fiber?

Fuel Consumption (gal/hr) • Percentage Savings = Gallons Saved per Hour

______ gal/hr • ______ % = ______ gal/hr

Worksheet 3 Continued

7. If the fuel costs $4/gallon, how much money would an airline save on one 16 hour flight from London to Sydney?

Fuel Savings • Length of Flight • Cost of Fuel = Money Saved

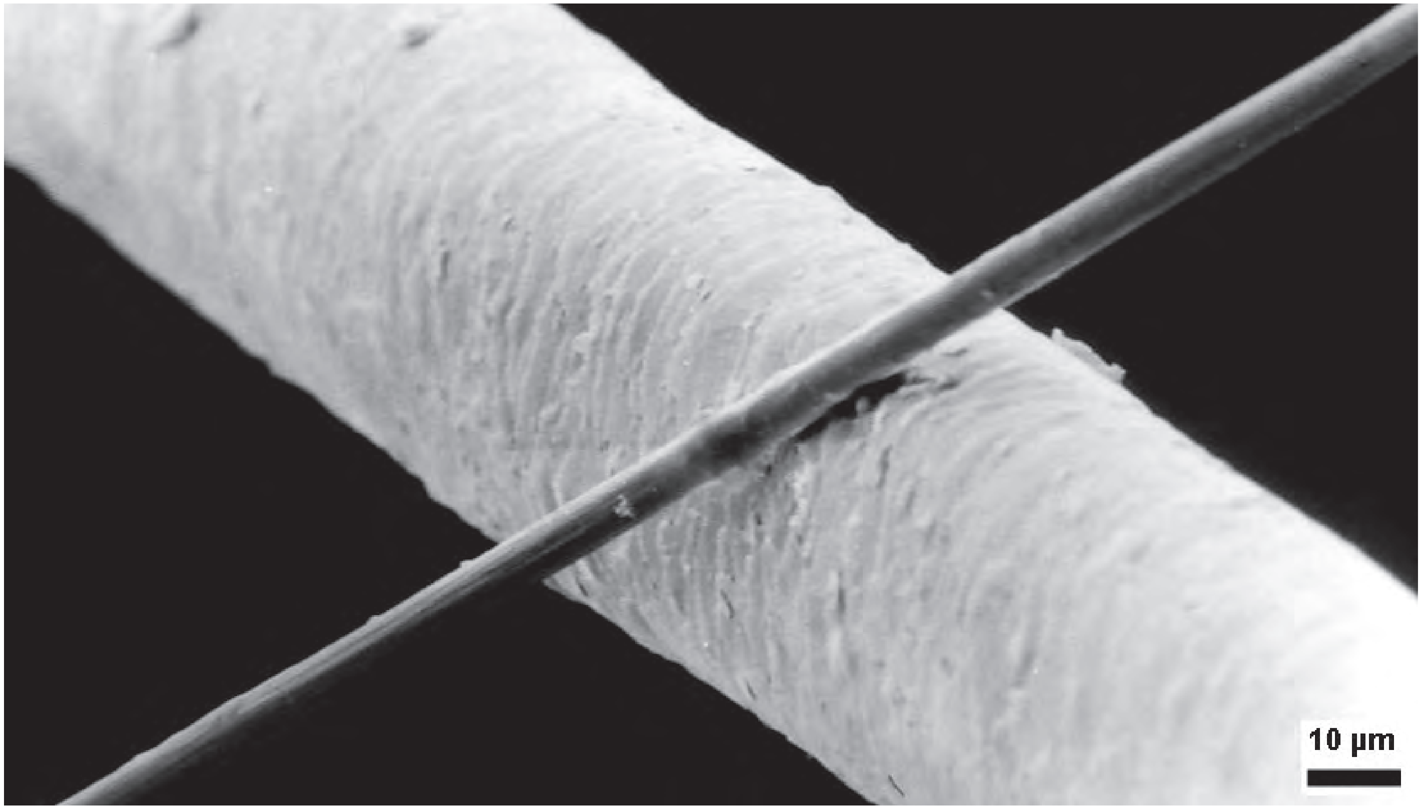
_____ gal/hr • _____ hrs • $ _____ /gal = $ _____

Images

Img. 1 The Wright Brothers' First Flight – December 17th, 1903

(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 2 A 6 μm diameter carbon filament (running from bottom left to top right) compared to a human hair



(Photo courtesy of Wikipedia, GNU Free Documentation License.)

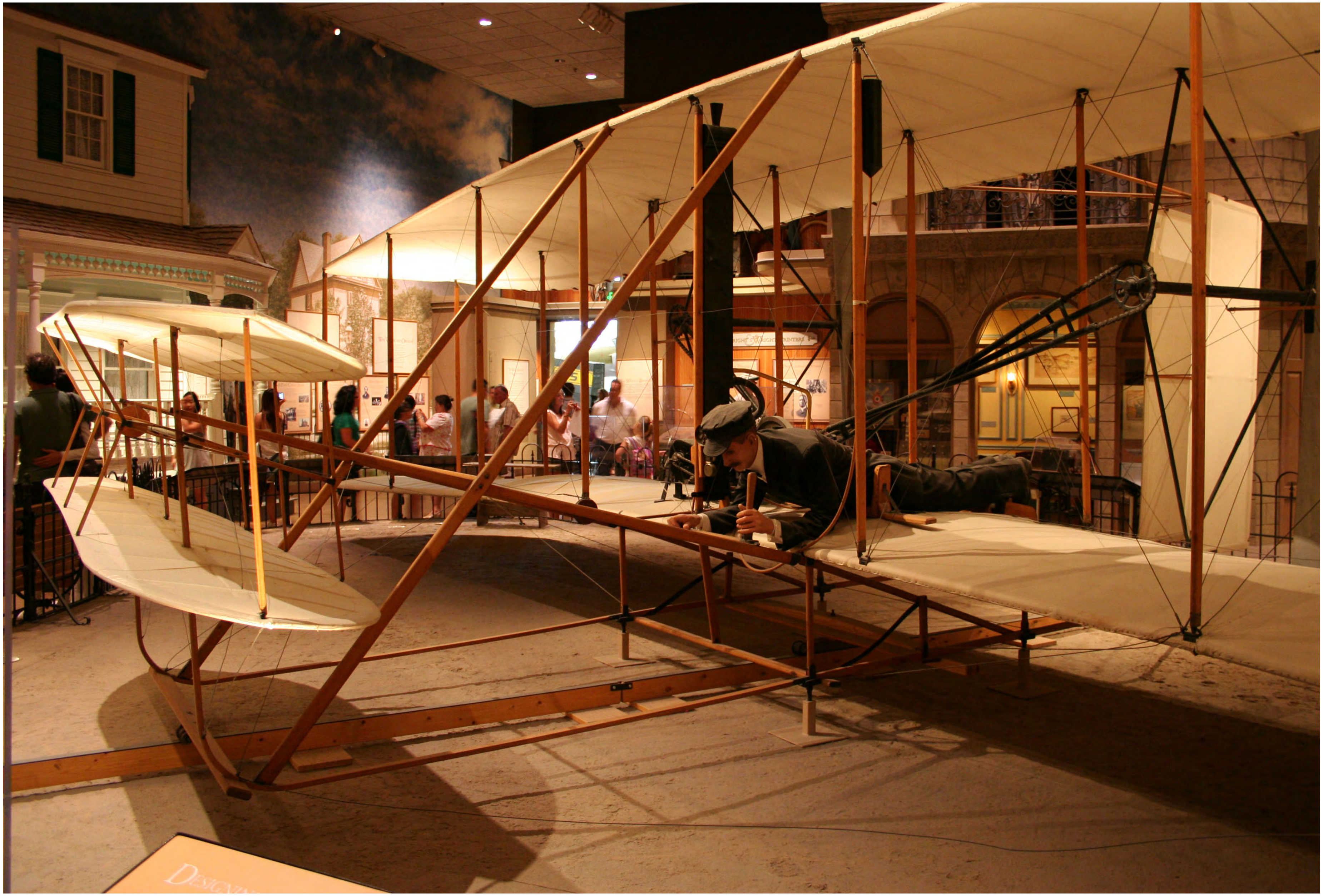
Img. 3 The Boeing 787 takes off on its maiden flight

(Photo courtesy of Boeing)

Img. 4 The Wright Brothers' 1903 aircraft, the Wright Flyer, in the Smithsonian National Air and Space Museum

(Photo courtesy of Smithsonian National Air and Space Museum)

Img. 5 The Wright Brothers' 1903 aircraft, the Wright Flyer, in the Smithsonian National Air and Space Museum



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 6 SAM 26000, a Boeing VC-137C, landing at the National Museum of the United States Air Force in Dayton, OH

(Photo courtesy of The National Museum of the United States Air Force)

Img.7 SAM 26000 on display at the National Museum of the United States Air Force in Dayton, OH

(Photo courtesy of The National Museum of the United States Air Force)

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