National Aeronautics and Space Administration

GRADES 9-12

Space Shuttle Tiles

structures and materials

Aeronautics
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Museum in a BOX Series

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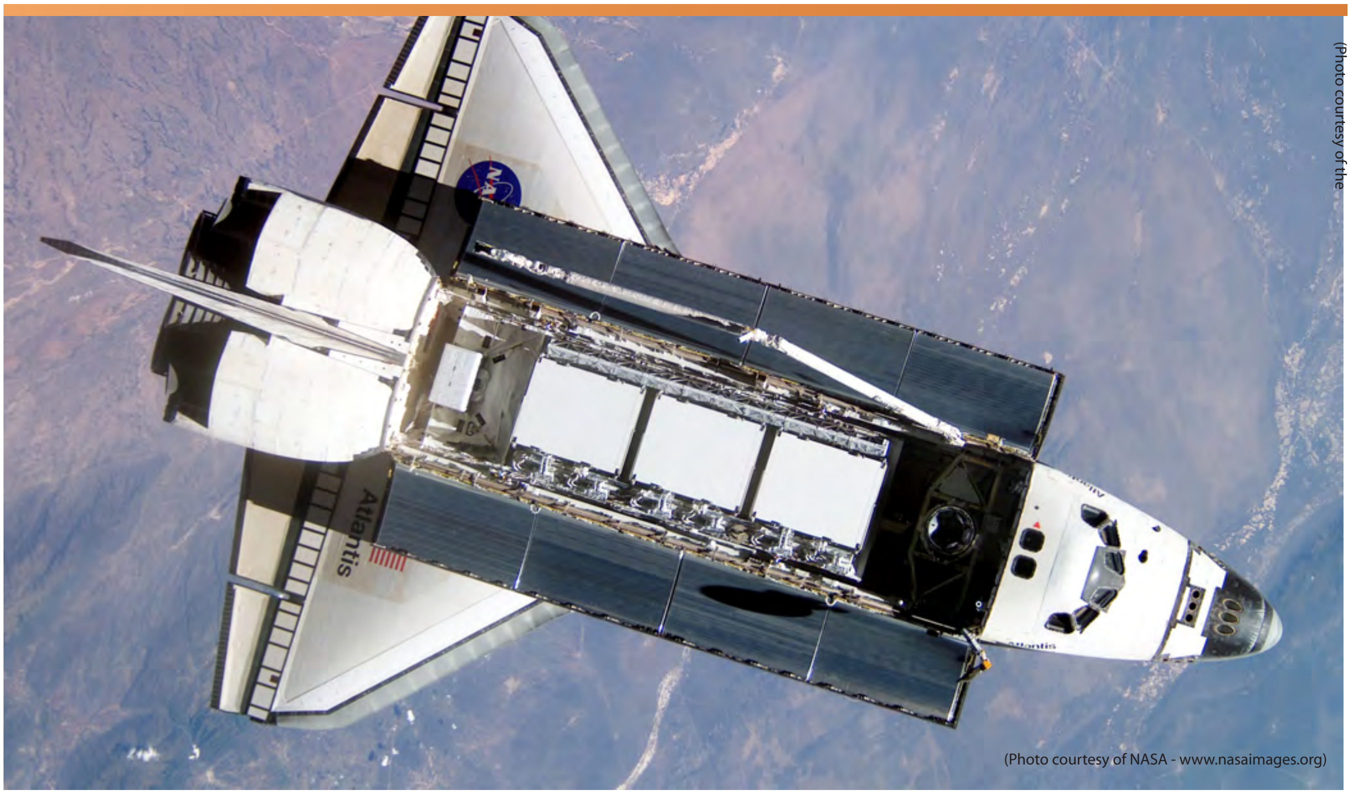


Img. 1 The Space Shuttle Atlantis in orbit.

Space Shuttle Tiles

Lesson Overview

In this lesson, students observe the properties of a space shuttle tile and consider how these properties relate to the threats imposed on the shuttle by space debris. The students will use a tissue paper covered box to represent the tile as they experiment to determine the amount of energy required to penetrate the tissue paper.

SAFETY NOTE FOR SHUTTLE TILE:
The silica material in shuttle tiles is not classified as hazardous either by Federal SARA or CERCLA standards. However, material from the silica fiber layer can cause temporary irritation of the throat and/or itching of the eyes and skin so that touching a bare tile should be avoided. For your convenience, the tile is sealed in a protective plastic wrapping. The plastic wrap should not be removed. Never touch the shuttle tile. More information is available through MSDS (www.MSDS.gov).

Objectives

1. Compare the effect on tissue paper penetration between objects of different masses traveling the same speed.

Materials:

Included in MIB

Space Shuttle tile
Scale or balance

Provided by User

Small objects, i.e. popcorn kernels, marbles, ball bearings (up to 10 per group)
Boxes, i.e. shoebox, cardboard or plastic (1 per group)
Tissue paper (the kind for wrapping gifts; enough to cover the opening of each box)
Tape
Eye protection (1 pair per student)
Meter stick (1 per group)

GRADES 9-12

Time Requirements: 30 minutes

Background

Shuttle Tiles


(Photo courtesy of NASA - www.nasaimages.org)

Img. 2 A close-up of the underside of the orbiter.

A key to a successful thermal protection system for the Space Shuttle depends on two things—light weight and the ability to withstand the high temperatures of reentry.

When the space shuttle de-orbits and begins to return to Earth, it faces a serious problem due to frictional heating. Protecting the shuttle and the crew from such heat is very important. When the shuttle reenters Earth's atmosphere at about 400,000 feet or about 122 km, it is traveling at about 25 times the speed of sound (Mach 25). It uses the friction of reentry to slow the shuttle down, but in doing so it pays a price in the form of frictional heating. Temperatures on the shuttle reach several thousand degrees. If the shuttle had a metal exterior like an airplane, it would be burn up due to the heat produced by the friction.

The tiles on the shuttle provide a means for thermal protection.

There are some 24,300 tiles that measure about six inches long on each side (15.25cm) and vary in thickness from 1 to 5 inches (2.54 to 12.7 cm) depending on where they are attached. They are made up of what is called a porous silicon material that is very light and extremely heat resistant. There are two main types of tiles, one a black-coated tile called HRSI for High-Temperature Reusable Surface Insulation tile. These tiles can withstand up to 2,300 degrees F (1,260 degrees C). They cover the bottom of the shuttle, areas around the forward windows, and several other key areas. The densities of these tiles range from 9-22 pounds per cubic foot.


(Photo courtesy of NASA - www.nasaimages.org)

The second type are white-coated tiles and are LowTemperature Reusable Surface Insulation (LRSI). They are made to insulate the shuttle up to 1,200 degrees F (650 degrees C). These tiles are usually larger and thinner, 8 inches long on each side (20.3cm) and from less than a half inch (1 cm) thick up to 1 inch (2.54 cm) in thickness. The densities range from 9 to 12 pounds per cubic foot.

The shuttle tile is made of a material which is a silica, alumina fiber and borosilicate glass composite. The making of tiles begins with pure silica that comes from refined sand. This material is formed in fibers and mixed with

Img. 4 A damaged tile from Space Shuttle Endeavor. The tile was damaged on Mission STS-118 when a piece of foam from the external tank broke off during launch.

pure water and other chemicals, then poured into a mold where the excess water is squeezed out. This is then taken to the largest microwave oven in America located at the Lockheed Space Operations plant in Sunnyvale, California. After this, they are treated in an oven at a temperature of 2,350 F (1,288 C). This process fuses the fibers without actually melting them.

The two types of tiles are essentially the same except for the coatings and cut. No two tiles are exactly alike. They fit by being trimmed to an exact size depending on its location on the shuttle. It is the ultimate jigsaw puzzle, only in this case each piece is numbered so its location is easy to find.

One of the problems with the insulation material used to protect the shuttle is its inherent fragile nature. The tiles feel a bit like Styrofoam and their surfaces easily compress or rub off onto other surfaces, such as hands. Great care must be taken when installing them to the surface of the shuttle so as to not damage them before launch. However, once installed, there are still several possible hazards, the first of which is ice.

This may sound strange, as the launch facility is located in Florida, a state that seldom sees ice. The ice comes from the main fuel tank for the shuttle. This large, orange, silo shaped object to which the shuttle and solid rocket engines are attached is filled with two liquids: Hydrogen and Oxygen. These liquids are extremely cold (Liquid Oxygen is -183ºC and liquid Hydrogen is -253ºC). The tank that holds them is insulated with a thick foam-like material. This, however, is not enough, for the humid warm air of the area condenses and freezes to its surface. Upon launch, pieces of the built up ice fall off and, in some cases, impact certain areas of the shuttle. These impacts can cause considerable damage to the delicate material that makes up each tile.

The second danger is a constant threat to space travel: impacts caused by space debris. Space debris consists of everything from entire spent rocket stages and non-operational satellites, to explosion fragments, paint flakes, slag from solid rocket motors as well as many other objects. A collision with a 2.2 pound object at orbital velocities will typically destroy a spacecraft. Thank goodness the vast majority of the estimated tens of millions of pieces of space debris are small particles, like paint flakes and solid rocket fuel slag. Contact with these particles causes erosive damage, similar to sandblasting. Notice the damaged tile in image 4. The pit was caused by a piece of foam from the enternal tank striking one of the shuttle's tiles during launch.

Activity 1 Shuttle Tile Density

GRADES 9-12

Time Requirement: 10 minutes

Materials:

In the Box

Space Shuttle tile

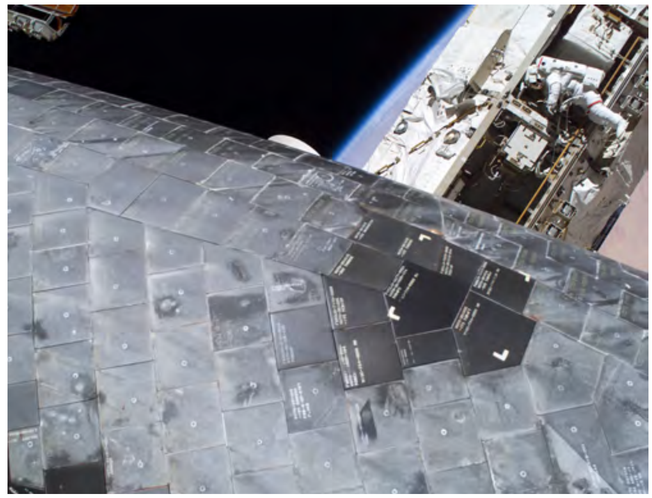
Supplied by user

None

Worksheets

Tile Material Hypothesis (Worksheet 1)

Activity:



Img. 2 A close-up of the underside of the orbiter.

1. Display the shuttle tile. Ask the students to guess what it is.

2. Pass around the shuttle tile. **CAUTION! The tile is very fragile and students must be instructed on how to handle it properly. Do not remove the shuttle tile from the plastic bag!** Do the students have any new guesses now that they have held the tile?

3. Tell the students that they are looking at a shuttle tile. Show the students **image 2** of the shuttle and point out the tiles. Ask the students to infer the purpose of the tiles. (The tiles protect the shuttle (and thus the shuttle occupants) from intense heat that is generated from the friction between the shuttle and the Earth's atmosphere during launch and entry.)

4. Explain that engineers must consider many factors when designing and choosing materials for various purposes. What would be some characteristics of materials that engineers would find desirable for a shuttle tile? As students name characteristics, write these on the board or on chart paper. (Low cost, safe, durable, high thermal insulating ability, low density.) Does the tile match all of the characteristics?

5. Distribute the student worksheets. Explain to the students that the tiles are made from silica (which comes from sand), alumina fiber, and glass composite. What are the costs/benefits to using this material? Ask your students to hypothesize about the impacts of using this material, considering the associated costs and benefits. Have your students record their thinking on their worksheets. (The students will notice that the tile has a low density, which is desirable, since it costs more than $10,000 per pound to launch items into space! However, they may notice that pieces of the tile are crumbling off. The tiles are delicate. The collisions between the tiles and ice (from the external tank) or space debris can cause considerable damage.)

6. After discussing costs and benefits, and in particular, the potential threats to the tile due to debris, show the students the picture of the damaged tile in image 4.

Img. 4 A damaged tile from Space Shuttle Endeavor. The tile was damaged on Mission STS-118 when a piece of foam from the external tank broke off during launch.

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 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 2 Tiles as Shuttle Protection

GRADES 9-12

Time Requirement: 20 minutes

Materials:

In the Box

Space Shuttle tile
Scale or balance
1

Supplied by user

Small objects, i.e. popcorn kernels, marbles, ball bearings, etc. (up to 10 per group)

Boxes i.e. shoebox, cardboard or plastic (1 per group)

Tissue paper i.e. the kind for wrapping gifts; enough to cover the opening of each box

Tape

Eye protection (1 pair per student)

Meter stick (1 per group)

Worksheets

Effect of Mass on the Penetration of Tissue Paper (Worksheet 2)

Key Terms:

Kinetic Energy

Activity Overview:

Today we will investigate the effects of debris on the shuttle tiles. We will be representing the debris with small objects (popcorn kernels, dried peas, ball bearings, marbles, etc.) and the tile with a shoebox covered in tissue paper. Ask the students to design an experiment to determine the amount of energy (in Joules) required to penetrate the tissue paper. They should record their procedure on Worksheet 2, Effect of Mass on the Penetration of Tissue Paper. A recommended procedure follows.

Activity:

1. Cover the opening of a box with tissue paper. Stretch the paper tight.

2. Determine the mass of the pea or other light projectile in grams. Then drop the pea or other projectile from a distance of 1 meter onto the tissue paper. Did the pea or object penetrate the tissue paper? Record the mass on the data sheet.

3. Select another object which is slightly heavier than the first object and determine its mass. Then drop this object from a distance of 1 meter onto the tissue paper. Did this object penetrate? Record the mass on the data sheet.

4. Keep dropping heavier objects from 1 meter until the object penetrates the tissue paper. Record the mass of each on the data sheet.

5. Investigate what happens when more than one layer of tissue paper is used to cover the box opening.

6. Solve for the velocity and kinetic energy of each object at impact and record their answers on their data charts.

a. Determine the time it takes for an object to fall 1 meter using the following equation:

$$S = \frac{1}{2} at^2$$

S = distance of fall. In this case, distance equals 1 meter.
A= acceleration of a falling body (assuming no air resistance), equals 9.8 m/s^2
T = time

$$1 \text{ meter} = \frac{1}{2}(9.8 \ \frac{\text{meters}}{\text{sec}^2})t^2$$

$$t^2 = \frac{2 \text{ meters}}{9.8 \ \frac{\text{meters}}{\text{sec}^2}}$$

$$t^2 = 0.2 \text{ sec}^2$$

$$t = .45 \text{ sec}$$

The time required for the object to fall one meter is 0.45 seconds.

b. Now solve for velocity:

$$V_f^2 = V_i^2 + 2as$$

$$V_f^2 = 0m^2 + 2 \ (9.8 \ \frac{\text{meters}}{\text{sec}^2})(1m)^2$$

$$V_f^2 = \frac{19.6m^2}{1\text{sec}^2}$$

$$V = 4.43 \text{ m/s}$$

Calculate the velocity of each object at the time of its impact with the tissue paper and record your result on your worksheet.

7. Kinetic Energy

When something is in motion, it has kinetic energy (KE). For an object that is moving the kinetic energy equals one half times the mass of the object times the square of the speed of the object. In symbols:

$$KE = \frac{1}{2} mv^2 \qquad \text{m is in kg and v in m/sec}$$

Example: Object mass is 3kg and velocity is 5 m/sec

$$KE = \frac{1}{2} \ (3kg)(5m/sec)^2 = 37.5 \text{ Joules}$$

One Joule is equal to:

- the amount of KE of an adult human moving at a speed of about a handspan every second.
- the amount of KE of a tennis ball moving at 14 miles per hour.

Calculate the kinetic energy of each object at the time of its impact with the tissue paper and record your result on your worksheet.

8. Space Debris Problems

a. A bolt has escaped from a spacecraft and is in orbit around Earth. It is traveling at 20 km/sec and has a mass of 8 grams. Solve for its K**E.**

Formula: $KE = \frac{1}{2} mv^2$

1. Convert 8 grams into kg; divide by 1,000.

1 kg =1,000

$$\frac{8 \text{ grams}}{1000 \text{ grams/kg}} = .008 \text{ kg}$$

3. Convert km to meters; multiply by 1000.

1 km = 1,000 m

$$20\text{km/sec} \cdot 1000\text{m/km} = 20{,}000 \text{ meters/sec}$$

c. Now solve for KE.

$$KE = \frac{1}{2}(.008 \text{ kg}) \cdot (20{,}000\text{meters/sec})^2 = 1{,}600{,}000 \text{ Joules}$$

b. The bolt in problem 8a has the kinetic energy equivalent to how many pounds of TNT?

1. 1 gram of TNT contains 4.184 x 10^3 Joules of energy

1 kilogram of TNT contains 4.184 x 10^6 Joules of energy

Determine the bolt's energy equivalent to 1 kg of TNT. To do this, divide the KE of the bolt by the KE of 1 kg of TNT

$$\frac{1{,}600{,}000 \text{ J}}{\dfrac{4{,}184{,}000 \text{ J}}{\text{kg of TNT}}} = 0.382 \text{ kg of TNT}$$

2. There are 2.2 pounds in 1 kilogram. Convert the mass of TNT in kilograms to pounds:

$$\frac{2.2 \text{ lbs}}{1 \text{ kg}} = 0.382 \text{ kg} = 0.84 \text{ lbs}$$

Isn't it amazing that an 8 gram object traveling at 20 km/sec in space hitting an object will release the same amount of energy as exploding 0.84 pounds of TNT?

c. Now solve for the KE in terms of TNT if the speed of impact were 35 km/sec in the problem above.

1. Calulate the KE

Formula:

$$KE = \frac{1}{2} mv^2$$

V = 35 km/sec

M = 0.008 kg

1 km = 1,000 m

$$KE = \frac{1}{2}(.008 \text{ kg}) \cdot (35{,}000\text{meters/sec})^2$$

$$KE = 4{,}900{,}000 \text{ J}$$

2. Convert to TNT equivalent

$$\frac{4{,}900{,}000\text{ J}}{\dfrac{4{,}184{,}000\text{ J}}{\text{kg of TNT}}} = 1.17\text{ kg of TNT}$$

d. What generalizations can you make from your calculations?

KE is dependent on the square of the velocity. Doubling the velocity will quadruple the KE.

Discussion Points:

1. Have the students define KE and explain why KE can be a problem in space.
2. Have the students come up with solutions to protect a spacecraft from space debris impacts. Research the Skylab II mission for ideas.
3. Have students explain why driving a car at high rates of speed is so dangerous as it relates to KE.
4. Determine the KE of a 3,000 pound car traveling at 60 miles per hour hitting a tree.
   Hint: 1 kg = 2.2 lbs.
   1 mile = 1.61 km
5. Use the following equation to calculate the deceleration forces generated when an object slows from one speed to another in some given distance. The deceleration is measured in Gs.

$$\text{Decleration in Gs} = \frac{\text{speed change}^2}{(30) \cdot (\text{deceleration distance})}$$

Assume you are riding in an automobile going 60 miles per hour. An emergency occurs and you are able to stop your auto in 6 feet. How many Gs does your body experience?

$$\text{Decleration in Gs} = \frac{60^2}{(30) \cdot (6\text{ feet})} = \frac{3{,}600}{180} = 20\text{Gs}$$

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- Nature of scientific knowledge
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Glossary

Acceleration:
is the rate of change of velocity. An object is accelerating if it is changing its velocity.

Energy:
is the capacity for doing work. You must have energy to accomplish work - it is like the "currency" for performing work. To do 1000 Joules of work, you must expend 1000 Joules of energy.

Friction:
is the surface resistance to relative motion, as of a body sliding or rolling.

Joule:
is the unit of energy equal to the energy exerted by a force of one Newton acting to move an object through a distance of one meter.

Kinetic Energy:
is the energy of motion

Mass:
is a measurement of how much matter there is in a body.

Newton:
is the unit of force equal to the force required to cause a mass of one kilogram to accelerate at a rate of one meter per second squared.

Power:
is the rate of doing work or the rate of using energy, which are numerically the same. If you do 100 Joules of work in one second (using 100 Joules of energy), the power is 100 Watts.

Work:
refers to an activity involving a force and movement in the direction of the force. A force of 20 Newtons pushing an object 5 meters in the direction of the force does 100 Joules of work.

MUSEUM IN A BOX

Student Worksheets

Worksheet 1 Tile Material Hypothesis

Shuttle tile material is made from silica (which comes from sand), alumina fiber, and glass composite.

1. What are the costs/benefits to using this material?

2. Hypothesize the impacts of using this material, considering the associated costs and benefits.

Worksheet 2 Effect of Mass on the Penetration of Tissue Paper

Today we will investigate the effects of debris on the shuttle tiles. We will be representing the debris with small objects of various masses and the tile with a shoebox covered in tissue paper. Design an experiment to determine the amount of energy (in Joules) required to penetrate the tissue paper.

Data: The Effect of Mass on Penetration of Tissue Paper

Object	Mass (g)	Penetrate tissue paper? (Y/N)	Velocity at impact (m/s)	Kinetic Energy at impact (J)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Number of Joules required for an object to penetrate the tissue paper:

Worksheet 2 Continued

Analysis:

1. Calculate the velocity and kinetic energy of each object at impact and record it in the above data table.
$V_f^2 = V_i^2 + 2as$

$KE = \frac{1}{2} mv^2$ m is in kg and v in m/sec

2. How many Joules of energy are required to penetrate the tissue paper?

3. Does the velocity at impact depend on the mass of the object?

4. Does the kinetic energy at impact depend on the mass of the object?

5. Does the mass of an object change when it travels to space?

Conclusion:

Worksheet 2 Continued

Space Debris Problems:

1. A bolt has escaped from a spacecraft and in on orbit around the Earth. It is traveling at 20 km/sec and has a mass of 8 grams. Solve for its KE.

$$KE = \frac{1}{2} mv^2$$

1 kg =1,000

1 km = 1,000 m

2. An exploding gram of TNT releases 4.184×10^3 J of energy. Using your answer from the above problem, how many kg of TNT is equivalent to the KE of an 8 g object traveling at 20 km/sec? Divide the KE of the bolt by the KE of 1 kg of TNT. Convert kg of TNT to pounds (1 kg = 2.2 pounds). Does your answer surprise you?

1 gram of TNT contains 4.184×10^3 Joules of energy

1 kilogram of TNT contains 4.184×10^6 Joules of energy

MUSEUM IN A BOX

3. Now solve for the KE in terms of TNT if the speed of impact was 35 km/sec in the problem above.

$$KE = \frac{1}{2} mv^2$$

4. What generalizations can you make from your calculation?

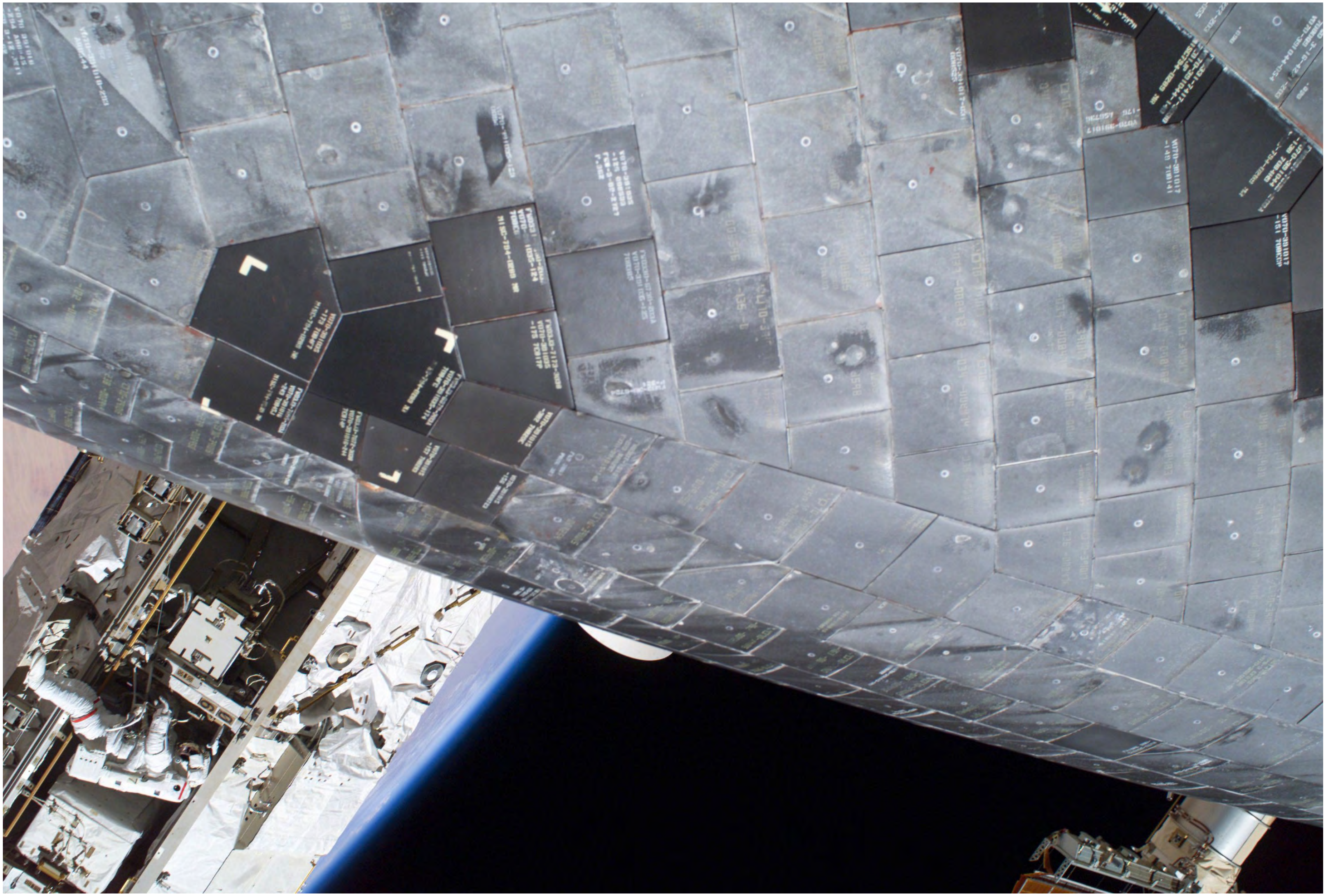
MUSEUM IN A BOX

Images

Img. 1 The Space Shuttle Atlantis in orbit.

(Photo courtesy of NASA - www.nasaimages.org)

Img. 2 A close-up of the underside of the orbiter.



(Photo courtesy of NASA - www.nasaimages.org)

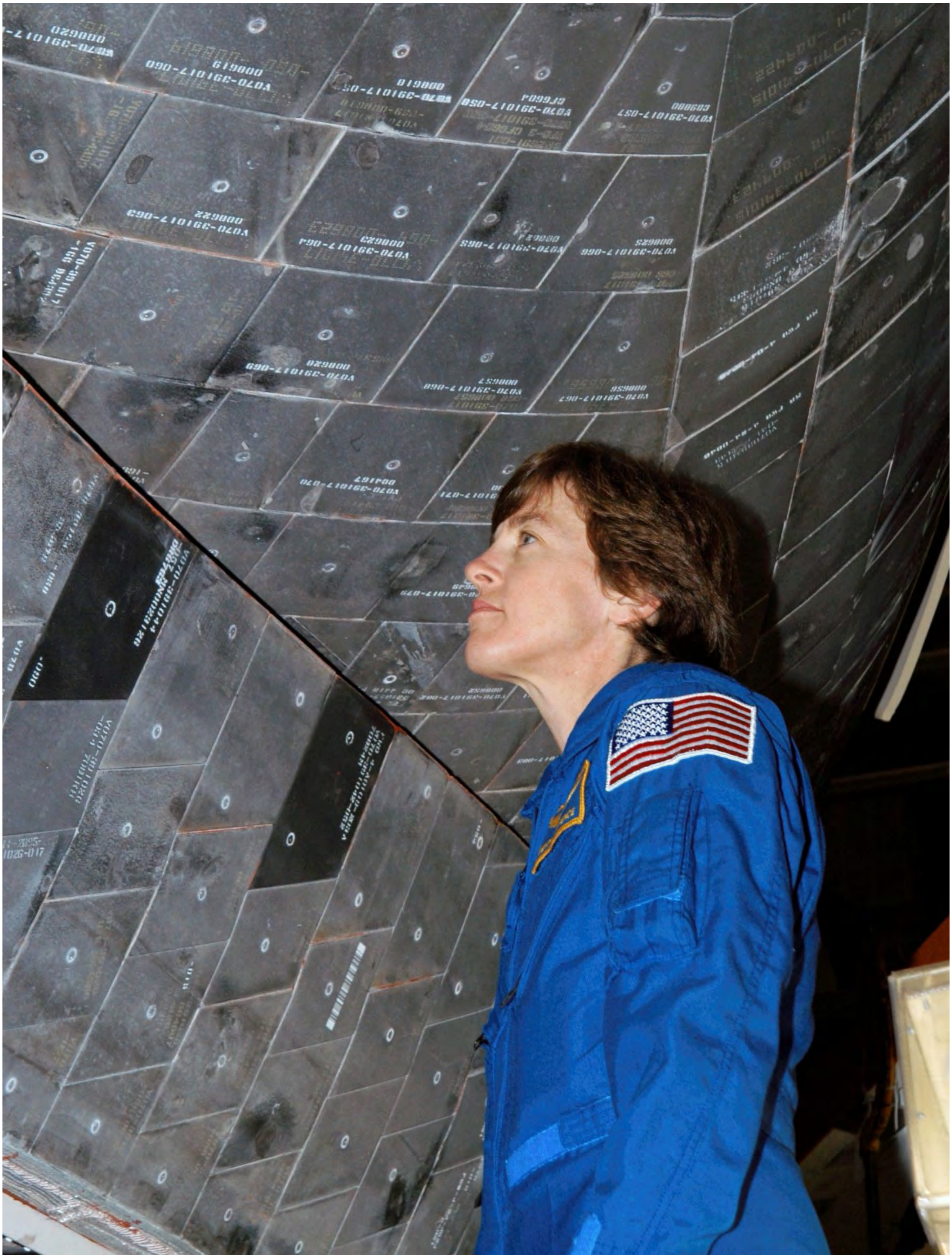
Img. 3 Replacing a shuttle tile.

(Photo courtesy of NASA - www.nasaimages.org)

Img. 4 A damaged tile from Space Shuttle Endeavor. The tile was damaged on Mission STS-118 when a piece of foam from the external tank broke off during launch.

(Photo courtesy of NASA - www.nasaimages.org)

Img. 5 A close-up of the tiles numbering system.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 6 The underside of the Space Shuttle in orbit.

(Photo courtesy of NASA - www.nasaimages.org)

Img. 7 The underside of the Space Shuttle during re-entry.

(Photo courtesy of NASA - www.nasaimages.org)

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Museum in a BOX Series

structures and materials