Satellite Swap Game ........................................................................................................................................ 66

   *A card game like Old Maid that introduces or assesses student understanding of NASA research, science, and technology. Match pairs and answer corresponding math challenge problems.*

Satellite Swap Handout .................................................................................................................................... 69

Teacher Facts: NASA Enterprises ................................................................................................................ 72

Worksheet 1: Math Challenge Problems ...................................................................................................... 78

Worksheet 2: Continental U.S. Map Model.................................................................................................. 86

   *Students create a scale model of the layers of Earth's atmosphere and NASA aircraft, spacecraft, and satellites on a United States map.*

Map of the Continental United States ........................................................................................................ 88

Map of the Continental United States Answer Key .................................................................................... 90

Worksheet 3: Model, Scales, and Distance .................................................................................................. 91

   *Students answer questions about models and use their knowledge of scale models to perform calculations using percentages, decimals, and ratios.*
**SATELLITE SWAP GAME**

**Description**

Students play Satellite Swap to learn about NASA vehicles and the research they help to accomplish. This game can also be used as an assessment.

The game has 32 cards that go together as 16 pairs, and it can be played like several common card games, such as Go Fish, Concentration, Old Maid, or Rummy. Pairs consist of one NASA research vehicle and a corresponding research card that describes an aspect of the research conducted on the vehicle. NASA research enterprises replace the suits found in an ordinary deck of cards. Enterprises (as seen below) are indicated by a small icon on the card. Each enterprise has four NASA vehicle/research pairs.

**Materials**

- Satellite Swap Game Cards (set of 32 colored pictures)
- Satellite Swap Handout
- Math Challenge Problems

**Preparation**

1. The Satellite Swap Gamecards are the colored cards included with this educator’s guide. Before cutting the cards apart, make copies of the cards to use as an answer key.
2. Cut the cards apart.
3. Discuss the NASA Enterprises and which pairs go together using the Teacher Facts: NASA Enterprises on page 72.

**Game Suggestions**

Play games with formats that students know, introducing one enterprise at a time.

To become familiar with the enterprises and pairs, a good game to start with is Concentration. For Go Fish, students can ask for a card by enterprise: “Do you have any Earth Science cards?” For Rummy, students may make pairs (Vehicle/Research) or four of a kind (same enterprise).
NOTE: Additional sets of Satellite Swap Gamecards may be downloaded in color, printed, cut, and laminated for classroom use at NASA Spacelink and the National Center for Microgravity Research on Fluids and Combustion.


• [http://www.ncmr.org/education/k12/classroom.html](http://www.ncmr.org/education/k12/classroom.html)

**Assessment**

To use Satellite Swap as an assessment, students play any of the games suggested here to get a match for each enterprise (Figure 1).

In order to finish the assessment, students must complete the Satellite Swap Handout. This handout has four NASA enterprise sections (Figure 2).

Students write down the names of the two cards in the match in the appropriate enterprise square (Figure 3). Then, they write a sentence to summarize the purpose of the NASA vehicle and the research it helps to accomplish (Figure 3).

Figure 1: A set of paired game cards.

**Satellite Swap Handout**

![Aerospace Technology](image)

Vehicle Name: __________________
Research Title: __________________

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

Vehicle Name: __________________
Research Title: __________________

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

![Earth Science](image)

Vehicle Name: __________________
Research Title: __________________

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

Vehicle Name: __________________
Research Title: __________________

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

![Space Science](image)

Vehicle Name: __________________
Research Title: __________________

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

Vehicle Name: __________________
Research Title: __________________

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

Figure 2: The Satellite Swap Handout.

![International Space Station](image)

Vehicle Name: International Space Station
Research Title: Life Science Research

The ISS is a permanent orbiting laboratory that is currently being built. Scientists will grow better 3-D tissues there on orbit than here on Earth.

Solve the corresponding math problem on the Math Challenge Problems worksheet. Write your final answer here:

Ratio of ISS width to a football field: \( \frac{88 \text{ m}}{48.8 \text{ m}} = 1.8 \).

The ISS will be about 1.8 football fields wide when fully assembled.

Figure 3: A competed section from the Satellite Swap Handout. Note that the names of the cards and the summary sentence match.
Finally, they answer a Math Challenge question for each of their four enterprise matches. Math Challenge questions for all sixteen matches are on a separate handout called Math Challenge Problems (Figure 4).

For example: The International Space Station pair falls under the enterprises Biological and Physical Research and Human Exploration and Development of Space. So the student should flip to the page on the Math Challenge Problems Worksheet that lists those enterprises. The student finds the International Space Station problem. After completing the problem the student writes the answer on the Satellite Swap Handout. When the Satellite Swap Handout is finished, students will have solved four Math Challenge Problems, one for each enterprise.

**Worksheet 1: Math Challenge Problems**

**Earth Science**

1. **ISS**
   The ISS is about 1.3 meter in length. What percentage of the cargo bay is target altitude?

2. **Terra Satellite**
   This composite picture of the Middle East area generated using data from 15 orbital passes between August 16 and 30, 2000. The total width of the picture covers 2,700 km from east to west and 1,750 km from north to south. What is the scale of the picture?

3. **TOPEX/Posidon**
   TOPEX/Posidon has measured water levels for the Middle East. Using the axis labels and data plotted, calculate the approximate water levels for various years. What percentage of the water flow is the Hubble Space Telescope for servicing on other missions?

4. **F-15 ACTIVE**
   The F-15 ACTIVE is 24.5 km in width. To capture the Hubble Space Telescope for servicing on other missions, the Space Shuttle had to orbit at 220 km. What is the ratio of the vertical dive distance to the horizontal dive distance?

**Space Science**

1. **Candela**
   An ultraviolet (UV) lamp is 25 cm in diameter. How much bigger in diameter is an ultraviolet (UV) lamp than the tip of a pencil?

2. **Chamber Space Observatory**
   Chamber at apogee compared to perigee?

3. **Hubble Space Telescope**
   The Hubble Space Telescope is 13.2 m in length. What percentage of the Hubble's length is the height?

4. **SEDA**
   Most of the mass of Earth's atmosphere is within 30 km of Earth's surface. What percentage of this 30 km distance is SEDA's crossing altitude?
## Satellite Swap Handout

### Aerospace Technology

**Vehicle Name:**

**Research Title:**

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

### Biological and Physical Research and Human Exploration and Development of Space

**Vehicle Name:**

**Research Title:**

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

### Earth Science

**Vehicle Name:**

**Research Title:**

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

### Space Science

**Vehicle Name:**

**Research Title:**

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:
Satellite Swap Answer Key

Each student’s assessment will be different. They will make different matches and have different Math Challenge Problems.

This Answer Key corresponds to the first two fill-in-the-blanks for each enterprise listed on the Satellite Swap Handout.

Enterprise Name, Vehicle, and Research

To grade students’ answers, locate the enterprise first and then the matching pair in which Card 1 is the NASA vehicle name and Card 2 is the Research Title. See game card pair in Figure 1 on page 67.

Summary Sentence

Summary Sentences are not included in the answer key table because answers will vary. However, the text on the two cards is included, and this is the information that students will summarize.

Math Challenge Problem

To correct the Math Challenge Problem for each enterprise section of the Satellite Swap Handout consult the Math Challenge Problems Answer Key (pages 82–85). Again, problems are listed by enterprise.
Vehicle Name:

Research Title:

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

Summary Sentence

Math Challenge Problem
TEACHER FACTS: NASA ENTERPRISES

The National Aeronautics and Space Administration (NASA) conducts research in five areas called enterprises:

1. Aerospace Technology
2. Biological and Physical Research
3. Earth Science
4. Human Exploration and Development of Space
5. Space Science

Two enterprises (Biological and Physical Research and Human Exploration and Development of Space) are closely aligned, so they will be grouped together to simplify the Satellite Swap game.

**Aerospace Technology**

[http://aerospace.nasa.gov](http://aerospace.nasa.gov)

This enterprise conducts research to make possible safer, cleaner, quieter, and faster air travel and routine space transportation. A part of its mission is to develop and commercialize innovative technologies using research facilities like wind tunnels and other technologies to improve aeronautics safety and reliability. The following are four examples of NASA aerospace technology research vehicles:

- Blended Wing Body
- F-15 ACTIVE
- Helios Prototype
- X-37

**Biological and Physical Research**

[http://spaceresearch.nasa.gov](http://spaceresearch.nasa.gov)

The enterprise of Biological and Physical Research seeks to create an interdisciplinary research program focused on biology and brings together physics, chemistry, biology, and engineering. This newest enterprise leads the Nation’s efforts in life and microgravity sciences. This includes studying the three fundamental states of matter—solids, liquids, and gases—and the forces that affect them. Related aspects of research and technology using the space environment will improve the quality of life on Earth and strengthen the foundations for continuing the exploration and utilization of space. This enterprise typically uses research vehicles managed by the Human Exploration and Development of Space Enterprise for its research. Four research aircraft and spacecraft follow:

- International Space Station
- KC-135
- Sounding Rocket
- Space Shuttle

**Earth Science**


Earth Science is dedicated to understanding the total Earth system and the effects of natural and human-induced changes on the planet’s environment. Earth Science is pioneering the new interdisciplinary field of research called Earth System Science, born of the recognition that Earth’s land, oceans, atmosphere, ice, and life are both dynamic and highly interactive. The following are four examples of Earth Science satellites:

- Geostationary Operational Environmental Satellite (GOES)
- Terra
- TOPEX/Poseidon
- Tropical Rainfall Measuring Mission (TRMM)
Human Exploration and Development of Space

http://spaceflight.nasa.gov

Human Exploration and Development of Space (HEDS) seeks to increase human knowledge of nature’s processes using the space environment, to explore and settle the solar system, to achieve routine space travel, and to enable the commercial development of space. This enterprise involves the astronauts, human space flight, living and working in space, and space product development.

Space Science

http://spacescience.nasa.gov/ossbhome.htm

The Space Science enterprise seeks to solve the mysteries of the universe; to explore the solar system; to discover planets around other stars; to search for life beyond Earth; to chart the evolution of the universe; and to understand its galaxies, stars, and planets. Research areas of particular interest involve the origins of life, planetary bodies, galaxies, and the universe; the use of robotics to explore Earth and other planets; and the exploration of the connection between the Sun and Earth. NASA Space Science research vehicles include balloons, aircraft, and orbiting space observatories. Four examples are given below:

- Balloon Observations of Millimetric Extragalactic Radiation and Geophysics (BOOMERanG)
- Chandra Space Observatory
- Hubble Space Telescope (HST)
- Stratospheric Observatory for Infrared Astronomy (SOFIA)
**Vehicle Name** | **Research Title**
--- | ---
**Blended Wing Body**  
Someday airplanes may have blended wing bodies. This revolutionary aircraft design includes the engines, wings, and body in one structure that provides the aircraft’s lift. A double-deck passenger compartment would blend into the wings and would hold 800 persons. | **Aircraft Design**  
To make the Blended Wing Body closer to becoming a reality, extensive model development and testing must be done. Here a technician works on a 3.3-meter-wide BWB wind tunnel test model. Data will be collected to determine the performance and stability of the current design.

**F-15 ACTIVE**  
The Advanced Control Technology for Integrated Vehicles (ACTIVE) program at NASA’s Dryden Flight Research Center is a research effort to enhance the performance and maneuverability of future civil and military aircraft. For this program, advanced flight control systems and thrust vectoring of engine exhaust have been built into a highly modified F-15 research aircraft. | **Aircraft Performance Research**  
The ACTIVE research team uses a modified F-15 jet to improve the way aircraft perform and maneuver. The newly developed nozzles can redirect the engine exhaust up, down, left, and right.

**Helios Prototype**  
The Helios Prototype is a remotely piloted aircraft being developed to prove that a solar-powered aircraft can fly a maximum altitude of 30.5 km or can maintain an altitude of at least 15.2 km for a minimum of 4 days. It is being developed as part of NASA’s Environmental Research and Sensor Technology (ERAST) project. | **Solar-Powered Research Aircraft**  
The Pathfinder Plus is an earlier design in the evolution of solar-powered research aircraft. Such high-flying, remotely piloted aircraft could be used to track storms, sample the atmosphere, take spectral images for agricultural purposes, monitor natural resources, and act as a telecommunications relay platform.

**X-37**  
The X-37 will be the first of NASA’s fleet of experimental, reusable launch vehicles to operate in orbit and during reentry into Earth’s atmosphere. The Space Shuttle or rockets will be able to ferry the X-37 into orbit. There it will operate at speeds of up to 25 times the speed of sound and test technologies in the harsh environments of space and atmospheric reentry. | **Launch and Reentry Research**  
As in the artist’s concept drawing, scientists hope to do future testing of the X-37 like this, transporting it in the Space Shuttle cargo bay to do reentry testing. The X-37 is being developed to test airframe, propulsion, and operational technologies for reusable launch vehicles.
Vehicle Name

International Space Station
The ISS represents a global partnership of 16 nations. It will be a permanent orbiting laboratory enabling long-duration research in the unique microgravity environment of Earth’s orbit. When fully assembled, the ISS will look like the picture shown here.

KC-135
The KC-135 is a microgravity research aircraft nicknamed the “Vomit Comet.” It is used to fly in parabolas to induce weightless conditions for 15 to 20 seconds at a time. When some of the effects of gravity are reduced, other phenomena are more easily observed.

Sounding Rockets
Sounding rockets, such as the Black Brant shown here, are used for a broad range of scientific research. These rockets top out in the Thermosphere before falling back to Earth. Once the engine thrust is cut off, rocket payloads are in freefall and experience microgravity conditions for 6 to 10 minutes. At this point, a parachute deploys to slow the payload’s descent.

Space Shuttle
The Space Shuttle is NASA’s reusable launch vehicle that is used to conduct scientific research in the unique environment of Earth’s orbit, and to help construct the International Space Station. This picture shows the cabin of the Space Shuttle Atlantis, its remote manipulator system (RMS) arm in operational mode, and a part of the International Space Station during Shuttle mission STS-106.

Research Title

Life Science Research
Biotechnology facilities aboard the ISS will include a bioreactor developed by NASA for 3-D tissue growth. Growing tissues in the bioreactor in microgravity produces structures, such as polyps and glands (middle and bottom), which are not present in petri dish cultures (top) grown on Earth. On-orbit cellular research has the potential to help treat diseases such as AIDS, diabetes, and cancer.

Fluids Research
Fluids research conducted on the KC-135 reveals that air and water do not flow through a pipe in microgravity in the same way that they do on Earth—with water, which is denser than air, on the bottom and air on top. In microgravity, density differences do not cause materials to layer. Bubbles and “slugs” of air flow throughout the water. Liquids do not fill the bottom of a container. Fluid studies such as this impact the design of spacecraft fuel tanks and water transfer systems.

Combustion Research
Combustion scientists hope that by studying flame spread in a microgravity environment, they will gain a deeper understanding of how fire burns and of potential fire hazards on orbit. Because combustion phenomena occur quickly, much research is done in drop towers and on sounding rockets.

Materials Science
This image shows a “forest” of dendrites, which are fern-like microstructures found in metals. Materials scientists study dendrites in space to improve the output of foundries here on Earth. Scientific data from the Isothermal Dendritic Growth Experiment are being adapted into computer models, thus reducing the casting design process from a couple of weeks to about a day.
**Vehicle Name**

**GOES**
The Geostationary Operational Environmental Satellite (GOES) is a key part of U.S. weather monitoring and severe storm forecasting. GOES orbits high above the equator at 36,000 km and remains above a specific point on Earth’s surface in what is known as a geostationary orbit. The high altitude allows the satellite to observe a large area, such as the entire continental United States, and to continually monitor weather systems in that area.

**Terra**
Terra is NASA’s flagship Earth observing satellite. In February 2000 it began collecting global data on Earth’s climate. Terra will circle around Earth, very nearly from pole to pole. The data it collects are analyzed to determine the cause-and-effect relationships among Earth’s lands, oceans, and atmosphere well enough to predict future climate conditions.

**TOPEX/Poseidon**
Every 10 days, the TOPEX/Poseidon satellite measures global sea level with unparalleled accuracy and monitors global ocean circulation. These studies reveal ties between the oceans and atmosphere and improve global climate predictions.

**TRMM**
The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and the National Space Development Agency (NASDA) of Japan. It was designed to monitor and study tropical rainfall and the associated release of energy that helps power global atmospheric circulation, which shapes both weather and climate around the globe.

**Research Title**

**Weather Monitoring**
This picture of a hurricane coming up from the southwest of the Baja peninsula is a composite image. The GOES satellite took the cloud image in visible and thermal infrared, while the colorized background is a Landsat composite map.

**Global Climate Change**
This graphic shows data collected from Terra’s multiple sensors integrated into one image. The three-dimensional cloud measurements were taken by one sensor. Another sensor collected ocean temperatures. The red area in the Pacific Ocean shows an El Niño anomaly. Red dots on land show the locations of forest fires. Together, Terra’s instruments help us understand Earth as a whole, integrated system.

**Ocean Climatology**
After three years of devastating El Niño and La Niña climate patterns, the Pacific Ocean is finally calming down to near normal sea levels (green). Above-normal sea-level heights appear in red and white, ranging from 10 to 32 cm. Blue and purple areas indicate below-normal levels, from 4 to 18 cm.

**Storm Studies**
One of the unique features of TRMM’s instrumentation is that it allows scientists to peer inside clouds. Using radar, scientists study the reflection of cloud drops, raindrops, and ice crystals within various parts of the energy spectrum, and they construct a picture of what the cloud looks like inside. TRMM's ability to distinguish between various ice and water particles in storms is beginning to shed light on how and why lightning is produced.
**Vehicle Name**

**BOOMERanG (Balloon Observations of Millimetric Extragalactic Radiation and Geophysics)**

For 10 days in 1998, BOOMERanG, a balloon-borne telescope, circumnavigated Antarctica at an altitude of 32 km, which is above much of Earth’s atmospheric mass. The telescope collected data about the early universe.

<table>
<thead>
<tr>
<th>Research Title</th>
<th>Early Universe Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>In this picture, we see the universe as it makes its transition from a glowing plasma to a transparent gas approximately 14 billion years ago. The color scale of the image has been enhanced to bring out the temperature variations in the primordial plasma, which has since evolved into giant clusters and superclusters of galaxies today.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chandra Space Observatory</th>
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<tbody>
<tr>
<td>The Chandra X-ray Observatory was launched in 1999 and is NASA’s newest Great Observatory. Chandra detects and images x-ray sources that are billions of light-years away. The images from Chandra are twenty-five times sharper than the best previous available. Chandra provides more detailed studies of black holes, supernovae, and dark matter.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X-ray View of the Crab Nebula</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Crab Nebula is the remnant of a supernova explosion that was seen on Earth in A.D. 1054. It is 6,000 light-years from Earth. At the center of the bright nebula is a rapidly spinning neutron star, or pulsar, that emits pulses of radiation 30 times a second.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hubble Space Telescope</th>
</tr>
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<tbody>
<tr>
<td>Launched in 1990, the Hubble Space Telescope was the first major telescope to be placed into orbit around Earth, high above Earth’s obscuring atmosphere. Its mission is to provide the clearest views of the universe possible using optical astronomy. Hubble’s telescope can resolve astronomical objects with an angular size of 0.05 arc seconds, which is like seeing a pair of fireflies in Tokyo from Maryland.</td>
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<tr>
<th>Colliding Galaxies</th>
</tr>
</thead>
<tbody>
<tr>
<td>What appears as a bird’s head leaning over to eat a meal is a striking example of a galaxy collision in NGC 6745. The “bird” is a large spiral galaxy. Its “prey” is a smaller passing galaxy (lower right). The bright blue beak and bright, whitish-blue top feathers show the distinct path taken during the smaller galaxy's journey. These galaxies did not merely interact gravitationally as they passed one another; they actually collided.</td>
</tr>
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<table>
<thead>
<tr>
<th>SOFIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>The U.S. and German space agencies are developing the Stratospheric Observatory for Infrared Astronomy (SOFIA), a 747SP aircraft that carries a 2.5-m reflecting telescope. SOFIA will be the largest airborne telescope in the world. It will make observations that are impossible for even the largest and highest ground-based telescopes. Its planned cruising altitude of 12.5 km puts it above the water vapor in the Troposphere, which absorbs infrared radiation.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infrared Astronomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astronomical objects emit many forms of energy which neither the human eye nor ordinary telescopes can detect. Infrared is one form of this invisible energy. Infrared radiation can pass through dusty regions of space without being scattered. This means we can study objects hidden by gas and dust which we cannot see in visible light, such as the center of our galaxy and regions of newly forming stars.</td>
</tr>
</tbody>
</table>
1. **Blended Wing Body**

Wingspan models of the Blended Wing Body tested in NASA wind tunnels measure 1.5 m and 3.4 m. Plans are underway to test a remotely piloted 5.2-m-wingspan model.

What are the scale factors of these three models if the actual wingspan is 88 m?

2. **F-15 ACTIVE**

Using the information provided in the F-15 ACTIVE images shown here, determine what the scale of the drawings are in cm/m.

3. **Helios Prototype**

The Pathfinder Plus’ highest cruising altitude was 24.5 km. The Helios Prototype’s target altitude is 30.5 km.

Compared to Pathfinder Plus’ record, how much higher is the Helios Prototype’s target maximum altitude? Use percentages.

4. **X-37**

The X-37 is 8.3 m in length, with a wingspan of 4.5 m. The Space Shuttle’s cargo bay is 5.18 m wide, 18.28 m long, and 3.9 m deep.

What percentage of the cargo bay’s length does the X-37 take up?
Worksheet 1: Math Challenge Problems

**Biological and Physical Research and Human Exploration and Development of Space**

1. **International Space Station**

   The International Space Station (ISS) will be 108 m in length and 88 m in width when fully assembled. A football field is 48.8 m wide by 91.4 m long.

   About how many football fields wide is the ISS?

2. **KC-135**

   During a “campaign,” the KC-135 flies 20 to 40 parabolas in a row, like a roller coaster ride in the air. At the highest point the aircraft tops off at 11 km and pulls out of the dive at 8 km.

   What is the ratio of the vertical dive distance to the KC-135’s parabola top?

3. **Space Shuttle**

   During the STS-78 mission, the Space Shuttle orbited at 220 km. To capture the Hubble Space Telescope for servicing on other missions, the Shuttle had to orbit at 595 km.

   Using the STS-78 orbital altitude as a basis, at what percentage of this altitude is the Shuttle when it services the Hubble?

4. **Sounding Rocket**

   This sounding rocket’s flight path has a roughly parabolic shape with a peak of 208.5 km. The payloads experience “weightless” conditions from 1.2 minutes into the flight until 9 minutes into the flight, when a parachute is released.

   During what percentage of the total flight time is the experiment in weightless conditions?
Earth Science

1. **GOES**

   The Baja Peninsula is about 1,130 km in length. What is the scale on the Weather Monitoring card?

2. **Terra Satellite**

   This composite picture of the Middle East was generated using data from 16 orbital passes between August 16 and 30, 2000. The total width of the picture covers 2,700 km from east to west and 1,750 km from north to south. What is the scale of this picture?

3. **TOPEX/Poseidon**

   TOPEX/Poseidon has measured variations in Lake Ontario’s surface water levels for a number of years.

   Using the axis labels and data plotted, calculate the approximate vertical scale of this plot.

4. **TRMM**

   The TRMM Precipitation Radar provides data across a swath 220 km wide.

   What scale would be needed to fit a precipitation data plot across 10 cm?
**Space Science**

1. **BOOMERanG**

A standard-sized party balloon is 23 cm in diameter. An Ultra-Long Duration Balloon is 130 m in diameter.

How many times bigger in diameter is an Ultra-Long Duration Balloon? Express your answer with no more than 3 significant digits.

2. **Chandra Space Observatory**

Chandra’s orbit is highly elliptical compared to other satellites. The orbit’s perigee (closest point to Earth) is 16,313 km. Its apogee (farthest point from Earth) is 146,341 km.

How many times farther from Earth’s center is Chandra at apogee compared to perigee?

3. **Hubble Space Telescope**

The Hubble Space Telescope is 13.2 m in length. A school bus is 10.5 m in length.

What percentage of the Hubble’s length is the school bus’s length?

4. **SOFIA**

Most of the mass of Earth’s atmosphere is within 50 km of Earth’s surface. SOFIA flies at 12.5 km.

What percentage of this 50-km distance is SOFIA’s cruising altitude?
1. Blended Wing Body

Using aircraft wingspan:
2.5 cm represents 13 m; 1 cm represents 13 m / 2.5.
1 cm represents 5.2 m for a scale of 0.2 cm/m.

Using aircraft length:
3.6 cm represents 19.4 m; 1 cm represents 19.4 m / 3.6.
1 cm represents 5.4 m for a scale of 0.2 cm/m.

2. F-15 ACTIVE

Using aircraft wingspan:
2.5 cm represents 13 m; 1 cm represents 13 m / 2.5.
1 cm represents 5.2 m for a scale of 0.2 cm/m.

Using aircraft length:
3.6 cm represents 19.4 m; 1 cm represents 19.4 m / 3.6.
1 cm represents 5.4 m for a scale of 0.2 cm/m.

3. Helios Prototype

Use Pathfinder Plus’ record altitude as the basis for answering the question.
Altitude difference = HP_{ALT} - PP_{ALT} = 30.5 km - 24.5 km = 6.0 km

As a percentage of PP record:
% altitude difference = (altitude difference/PP_{ALT}) * 100 =
(6.0 km / 24.5 km) * 100 = 24.5%

4. X-37

Percentage of cargo bay length = (length X37 / length cargo bay) * 100

This can be represented as:

X\% \text{ CB}_L = (X37_L / CBL) * 100
= (8.3 m / 18.28 m) * 100
= 45\%
1. **International Space Station**

   Ratio of the ISS width to field width = \(88 \text{ m} / 48.8 \text{ m} = 1.8\)

   The ISS will be about 1.8 football fields wide when completely assembled.

2. **KC-135**

   KC-135 Parabola Top \(d_{PT} = 11 \text{ km}\)
   Vertical Dive Distance \(d_{dive} = d_{PT} - d_B = 11 \text{ km} - 8 \text{ km} = 3 \text{ km}\)
   Ratio Dive to Parabola Top \(= \frac{d_{dive}}{d_{PT}} = \frac{3 \text{ km}}{11 \text{ km}} = \frac{3}{11}\)

3. **Space Shuttle**

   STS-78 altitude \(a_{78} = 220 \text{ km}\)
   Hubble servicing altitude \(a_{HST} = 595 \text{ km}\)
   \(a_{HST} = \% \text{ of } a_{78}\)
   \((a_{HST} / a_{78}) \times 100 = x\)
   \((595 \text{ km} / 220 \text{ km}) \times 100 = 270\%\)

4. **Sounding Rocket**

   Total microgravity time: \(t_{mg} = 9 \text{ min} - 1.2 \text{ min} = 7.8 \text{ min}\)
   % of total flight time: \((t_{mg} / t_{tot}) \times 100 = (7.8 \text{ min} / 13.5 \text{ min}) \times 100 = 58\%\)
1. **GOES**

   2 cm represents 1,130 km.
   1 cm represents $\frac{1,130}{2}$ km.
   1 cm represents 565 km, for a scale of 0.002 cm/km.

2. **Terra**

   8.2 cm represents 2,700 km.
   1 cm represents $\frac{2,700}{8.2}$ km.
   1 cm represents 329.3 km, for a scale of 0.003 cm/km.

3. **TOPEX/Poseidon**

   Measurement on plot (-1 to +1 m) represents 2 m.
   2.5 cm represents 2 m.
   1 cm represents $\frac{2}{2.5}$ m.
   1 cm represents 0.8 m, for a scale of 1.25 cm / m.

4. **TRMM**

   A length of 220 km needs to be scaled to fit on a 10-cm axis. For this, 10 cm represents 220 km.

   1 cm represents $\frac{220}{10}$ km.
   1 cm represents 22 km, for a scale of 0.04 cm/km.
Math Challenge Space Science Enterprise Answer Key

1. BOOMERanG

    Diameter comparison = ULDBd / PBd
    = 130 m / 0.23 m
    = 565.2

   An Ultra-Long Duration Balloon is about 565 times bigger than a party balloon’s diameter.

2. Chandra

    146,341 km / 16,313 km = 8.97

   Chandra is 9 times farther away from Earth’s center at apogee than at perigee.

3. HST

    x% of Hubble’s length = BL / HL * 100
    = 10.5 m / 13.2 m * 100
    = 79.5%

4. SOFIA

    x% of 50-km distance = SALT / 50 km * 100
    = (12.5 km / 50 km) * 100
    = 25%
Worksheet 2: Continental U.S. Map Model

You have learned that the atmosphere is divided into several distinct layers and is so large that it is difficult, if not impossible, to imagine. In this assessment, you will construct a scale model of the layers of the atmosphere and some of the aircraft, spacecraft, and satellites that are located there. You will compare it to another large structure, the United States, with which you are more familiar. Before beginning, make sure you have colored pencils, a drawing compass, and a metric ruler.

<table>
<thead>
<tr>
<th>Altitude from Earth:</th>
<th>Actual Distance</th>
<th>Scale Model Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Troposphere top at equator</td>
<td>12 km</td>
<td></td>
</tr>
<tr>
<td>B. Stratosphere top</td>
<td>50 km</td>
<td></td>
</tr>
<tr>
<td>C. Mesosphere top</td>
<td>80 km</td>
<td></td>
</tr>
<tr>
<td>D. Thermosphere top</td>
<td>500 km</td>
<td></td>
</tr>
<tr>
<td>E. Helios Prototype</td>
<td>31 km</td>
<td></td>
</tr>
<tr>
<td>F. KC-135 Parabolic Peak</td>
<td>11 km</td>
<td></td>
</tr>
<tr>
<td>G. International Space Station</td>
<td>400 km</td>
<td></td>
</tr>
<tr>
<td>H. Terra Satellite</td>
<td>705 km</td>
<td></td>
</tr>
<tr>
<td>I. Hubble Space Telescope</td>
<td>600 km</td>
<td></td>
</tr>
<tr>
<td>J. TOPEX/Poseidon</td>
<td>1,336 km</td>
<td></td>
</tr>
</tbody>
</table>
1. The approximate altitude of each atmospheric layer top from Earth is given in the table on the previous page. Convert each altitude using a scale of 1 mm = 5 km. Place the scale model altitude in the appropriate space in the table.

2. As accurately as possible, place a dot that identifies the location of your school on the map of the United States. This dot will represent the Earth’s surface at Sea Level in the scale model. Label it Earth.

3. Using a metric ruler, a compass, and the scaled altitudes from the table, draw the upper boundary for each layer. Label (or color in) each layer.

4. Mark and label the altitudes at which the various aircraft, spacecraft, and satellites operate. Use the altitudes from the table on the previous page.

5. Using the same scale, indicate what the scaled altitudes are for these items:
   a. Chandra Space Observatory (139,970 km) = __________
   b. Global Positioning Satellites (20,200 km) = __________
   c. Tracking and Data Relay Satellite (35,700 km) = __________
   d. Moon (384,430 km) = __________
### Worksheet 2 Answer Key

<table>
<thead>
<tr>
<th>Altitude from Earth:</th>
<th>Actual Distance</th>
<th>Scale Model Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Troposphere top at equator</td>
<td>12 km</td>
<td>2.4 mm</td>
</tr>
<tr>
<td>B. Stratosphere top</td>
<td>50 km</td>
<td>10 mm</td>
</tr>
<tr>
<td>C. Mesosphere top</td>
<td>80 km</td>
<td>16 mm</td>
</tr>
<tr>
<td>D. Thermosphere top</td>
<td>500 km</td>
<td>100 mm</td>
</tr>
<tr>
<td>E. Helios Prototype</td>
<td>30 km</td>
<td>6 mm</td>
</tr>
<tr>
<td>F. KC-135 Parabolic Peak</td>
<td>11 km</td>
<td>2.2 mm</td>
</tr>
<tr>
<td>G. International Space Station</td>
<td>400 km</td>
<td>80 mm</td>
</tr>
<tr>
<td>H. Terra Satellite</td>
<td>705 km</td>
<td>141 mm</td>
</tr>
<tr>
<td>I. Hubble Space Telescope</td>
<td>600 km</td>
<td>120 mm</td>
</tr>
<tr>
<td>J. Topex/Poseidon</td>
<td>1,336 km</td>
<td>267.2 mm</td>
</tr>
</tbody>
</table>

2-4. To personalize this question for your school’s location, you will need to use a compass and ruler to correctly measure where the above answers fit on the map starting from your school’s location. The sample included begins in Washington State. See next page.

5. Using the same scale, indicate what the scaled altitudes are for these items:
   a. Chandra Space Observatory (139,970 km) = 27,994 mm or 28 m
   b. Global Positioning Satellites (20,200 km) = 4,040 mm or 4 m
   c. Tracking and Data Relay Satellite (35,700 km) = 7,140 mm or 7.1 m
   d. Moon (384,430 km) = 76,886 mm or 76.9 m

NOTE: With the very large numbers, it is suggested that students find the scale altitudes and then convert millimeters to meters. This will aid in their understanding of the vastness of the altitudes of these objects in comparison to the layers of the atmosphere.
1. Calculate the diameter of a model of Earth when using a scale of 1 cm = 200 km. Note: Earth’s actual diameter is 12,742 km.

2. A model airplane was built on a 1:24 scale. If the length from front to back is 30.5 cm, what is the length of the life-size counterpart of the real plane?

3. The range of the Mesosphere is 2.5 times that of the Troposphere’s range, which is 12 km. What is the range of the Mesosphere?

4. The International Space Station orbits at a maximum altitude of 463 km. Over the course of 80 days, the ISS’s orbital altitude decreases 33.3%. The ISS is then reboosted back to its maximum altitude over 10 days. What is the ISS’s altitude when reboost begins?

5. The F-15 ACTIVE aircraft can fly a maximum altitude of 18 km. The BOOMERanG research balloon circumnavigated the Antarctic Circle at an altitude 205.6% higher. What was BOOMERanG’s flight altitude?

6. The International Space Station is 108 meters long end-to-end. That’s the equivalent to the length of a football field, including the end zones. If you wanted to make a scale model of the International Space Station that you could bring to school for a science project and that fits on a desk (about 60 cm), what would be a reasonable scale to use? Explain your answer.
7. What other types of objects are commonly built to scale? What models do you use everyday? What scale is used? How could you find the scale?

8. A model may represent a system. A model may be an object, a drawing, or a mathematical equation. Give an example of each kind of model.

9. What are some reasons to make models?

10. How is a model different from the object which it represents?

11. What is a scale?

12. Using this map, answer the following question. If the actual distance from Williamsburg to Yorktown is 161 km, give the map scale: 1 cm = _______.

![Map of Virginia with cities labeled: Richmond, Williamsburg, Yorktown, Newport News, Hampton, Norfolk, Virginia Beach, Jefferson Lab.](image)
Worksheet 3 Answer Key

1. Scale: 1 cm = 200 km. (Scaled distance = 12,742 km / 200 km/cm = 63.7 cm)

2. Scale is 1/24 (24 * 30.5 cm = 732 cm)

3. 2.5 * 12 km = 30 km

4. The ISS’s altitude (463 km) decreases 33.3%. So, 463 km * 0.333 = 154.179 km. 463 - 154.179 = 308.8, which rounds to 309 km. At the time of reboost, the ISS’s orbital altitude is about 309 km.

5. F-15 ACTIVE’s flight altitude is 18 km. 18 km * 2.056 = 37.008, which can be rounded to 37 km. So, 205.6% higher = 18 km + 37 km = 55 km

6. Answers may vary but should allow a model small enough to be transported to school and fit on a desk of about 60 cm long. Any scale where the model will be less than 60 cm is valid. Here is one example that works, where:

60 cm represents 108 m.
1 cm represents 108 m / 60.
1 cm represents 1.8 m, or 1 m = 0.55 cm.

7. Answers may vary, but examples are model planes, trains, automobiles, and doll houses. Scale is sometimes given, or you can select a full-size dimension and compare it with same dimension on the model and calculate the ratio between them.

8. Answers may vary, but examples include:
   - Object = model of Earth, an atom, a cell
   - Drawing = house plans, maps
   - Diagram = circulatory system, electrical circuits
   - Mathematical equation = formula for area, volume.

9. Models are made to help in our understanding of objects that are microscopic, are extremely large, or are too far away or too dangerous to study directly.

10. Models are either smaller or larger than the original object. They are a simpler version of the real object. They may have some features in common, but they are less complex and are often not made of the same materials.

11. A scale is the ratio between the dimensions of a model and the dimensions of the object that the model represents.

12. Max distance from Williamsburg to Yorktown is 1.5 cm, which represents 161 km. Set up a ratio:

   1.3 cm / 161 km = 1.0 cm/x

   Solve for x = 123.8 km.