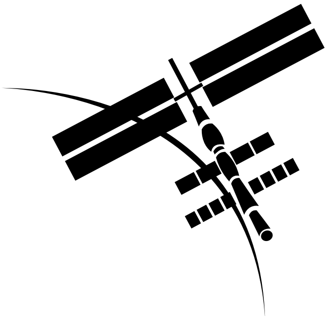
BUILDING A PERMANENT HUMAN PRESENCE IN SPACE

GRADES 9-12

LESSON 3: BUILDING YOUR SPACE STATION

The United States and its partners around the world are building the International Space Station (ISS), arguably the most sophisticated engineering project ever undertaken. The ISS is an orbiting laboratory where astronauts conduct research in a variety of disciplines including materials science, physiology in microgravity environments, and Earth remote sensing. The ISS provides a permanent human presence in low Earth orbit. This lesson is one of many grade K-12 lessons designed to bring the ISS experience to classrooms across the nation. It is part of *Building a Permanent Human Presence in Space*, one of several Education Modules developed for the *Journey through the Universe* program.

September 2007



LESSON 3:
BUILDING YOUR SPACE STATION

LESSON AT A GLANCE

LESSON OVERVIEW

The International Space Station is arguably the greatest engineering undertaking of our time. Thousands of criteria had to be considered in the design of each station segment and in planning the final assembly. One of the most powerful design tools used by engineers in developing the station design is scale modeling, allowing engineers to test ideas for station construction by actually building the station themselves, in workshops on Earth, many times over. In this lesson, students will directly experience the station design process by using scale modeling to design and test space stations of their own. Students will be provided with a broad set of performance demands and will explore how much variation these criteria permit in the design of a complete station. Students will also develop an understanding of some of the limitations of scale modeling as a design tool.

LESSON DURATION

Two to three 45-minute class periods

CORE EDUCATION STANDARDS

National Science Education Standards

Standard E1: Abilities of Technological Design

- Propose designs and choose between alternative solutions.
- Implement a proposed solution.
- Evaluate the solutions and its consequences.
- Communicate the problem, process, and solution.

Essential Questions

- What challenges did engineers face when designing the International Space Station?
- How do scale models help in designing large or complex structures?

Concepts

Students will learn the following concepts:

- Models are tools for designing and understanding large objects.
- When building a structure, engineers have to factor in constraints such as time, money, and materials.

Objectives

Students will be able to do the following:

- Calculate design parameters for their model space station.
- Create a model space station given a set of materials and parameters.

SCIENCE OVERVIEW

The International Space Station (ISS) is in Earth orbit right now. It is a facility for astronauts to live and to work in space and to learn more about how to live and to work in space in preparation for future long-duration manned missions. There are station components being readied for the completion of the station that must fit precisely together when connected to the components already in space, the first and only time. Each station segment costs hundreds of millions of dollars to create, and costs as much again for it to be launched into orbit. That is a lot to expend if there is the possibility that the pieces may not even fit together properly. What possible guarantee can there be?

The engineers who designed the ISS can be certain that the station components will fit together properly because they have assembled versions of the station themselves here on Earth probably thousands of times or more. The ISS is designed to be built and to exist in a vacuum, in microgravity conditions. Components weigh many tons on the ground and are the size of school buses. The station components are designed to plug together so that they extend in a variety of gravity-defying directions. Many station segments did not even exist yet when the first segments were launched into orbit. Under these conditions, it would have been impractical, maybe impossible, to actually assemble more than two or three segments in real life. Instead, engineers turn to precision-crafted scale models to try parts together. Modern technology makes it possible to use computer-based engineering information to fabricate full-size metal components as well as accurate plastic scale model prototypes from the same computer files.

Even before a large and complex component of any system is designed and fabricated, scale models serve a purpose in the development process. ISS engineers were faced with designing a new type of structure, with little precedent in human history. Previous space stations (Skylab, Salyut, Mir) are dwarfed by the size and capabilities of the ISS. All that engineers had available were a long set of desired performance criteria—descriptions of what the station should be able to do in final form—and constraints in the form of the shape, size, and lifting capabilities of the launch vehicles that could be used to put it into orbit. And one last constraint: money. With an infinite amount of money to spend, an engineer can overcome almost any hurdle within the bounds of nature. After all, launch vehicle limitations could be overcome simply by designing a new launch vehicle. With a limited budget, compromises and hard decisions have to be made: which basic design to follow when it is time to "cut metal," with little chance to toss out an unsuccessful design and start over. Scale models are critically important at this phase of engineering to test how all the different design requirements and constraints operate together to favor the selection of a few designs for deeper study while rejecting many others.

In this lesson, students face the same challenge as engineers for the ISS faced at the beginning of the project: a set of criteria for judging the results of their efforts in designing a space station, a set of limitations on the parts that they can use, and little prior information on what kinds of designs are most successful. Students will discover that some of the constraints will force station designs to look very similar in some features, while other constraints can be met in so many different ways that it becomes difficult to choose one right way to solve the problem. At the end, students will judge their different station designs to determine which ones are more or less successful in achieving the goals of the design effort.

PERFORMANCE REQUIREMENTS

One of the most influential requirements for the ISS design is the necessity that all electrical power for the station must be generated in orbit from solar photovoltaic panels. Rechargeable batteries are used to store power during the frequent periods when the ISS orbit carries the station through Earth's shadow. Batteries alone are not sufficient to support a working space station: there would be a constant need for new batteries to be flown up from the ground if they could not be recharged in orbit. The fuel cells used in the Space Shuttle are efficient and provide plenty of power, but they would need to be resupplied with fuel regularly. The Radio-isotope Thermoelectric Generators (RTGs) used for powering deep-space planetary missions may operate for a decade or two, but provide only a small amount of power. Nuclear reactors are politically and practically unacceptable for the Station's Low Earth Orbit (LEO), at least any nuclear power source that has been developed as yet. The ISS orbits at an altitude at which the tenuous outer reaches of the Earth's atmosphere constantly drag on it, slowing the station and causing it to drop gradually to a lower orbit. Without attention, the space station eventually would de-orbit and fall to the ground, so the ISS periodically is boosted back to its desired orbit. The eventual fate of the ISS, when it is old and obsolete, will be intentional de-orbiting to avoid an uncontrolled crash. The same method was used to dispose of the Mir space station. No one would like to see a nuclear power reactor re-entering the Earth's atmosphere and crashing to the ground, whether the re-entry can be handled in a controlled fashion or not. Therefore, solar electric panels are the only satisfactory choice to power the station.

The complete solar power system for the ISS provides about 110 kilowatts (kW) of electrical power. Engineers have established a "rule of thumb" to use in evaluating power requirements of the station in order to determine how much solar array area is needed: 100 cm^2 of photoelectric array for every 500 cm^3 of enclosed volume in the space station. It is difficult to determine the power use of every single device installed in the station, especially since the installed systems will change with time. The rule of thumb provides for a reasonable expectation and some margin for error. It allows for temporary increases in power demands, and the slow degradation of power output from the solar panels as they are exposed to damage from space radiation.

No electrical device is 100% efficient in accomplishing its intended work with the electrical power applied; some energy is wasted in the form of heat. Whatever waste heat is created inside the ISS by the operation of machinery and electronics, will stay there until it is removed. On Earth, heat is carried away by the flow of air or water. The ISS is equipped with radiators that cool the station by emitting infrared radiation into the empty blackness of space. These cooling panels must be kept out of sunlight so that they do not become heating panels by absorbing solar radiation and transmitting the heat back into the station. The radiators must have sufficient capacity to remove heat equivalent to all the power that the solar panels supply the station, as well as heat from sunlight on the station modules, as well as heat from the astronauts inside the station.

The ISS must provide the opportunity for astronauts to live and to work in the weightless environment of Earth orbit, working both inside and outside of the station itself. Decades-old concepts for space stations imagined spinning wheels in space to simulate gravity on the interior rim of the wheel. In reality, a design of that sort would defeat much of the purpose of building a space station. People in space must continue to live and to work in air, so astronauts need to be sealed away from the surrounding vacuum. Some work must be accomplished outside the station, but it is always hazardous to the astronauts who venture outside in pressure suits, and it may be difficult to accomplish using remote-control systems. In an air-filled environment inside the station, however, astronauts can work in an ordinary laboratory environment while taking advantage of the weightless conditions in a non-spinning space station. This is a driving factor in designing the ISS. A space station needs to provide interior laboratory space in which astronauts can work, and space in which they can live while not working. The astronauts on board the ISS are in residence for months at a time. The space station models that students will build in this lesson include separate pressurized compartments for scientific research and for habitation, and connections to the other modules of the space station.

Practical Constraints

In order to reach space, a space station needs to be launched from the ground. The ISS in orbit is a huge, extended, spindly construction with long, slender parts extending in various directions. There is no launch vehicle on Earth capable of putting that much mass or an object that size into orbit all at once, nor could the fragile structure of the ISS survive the trip intact. Instead, the station had to be put into orbit in pieces and assembled in space. The ISS was launched in segments by three different varieties of launch vehicle—two types of Russian unmanned rockets, and the U.S. Space Shuttle. The limitations of the launch vehicles require that station components be roughly cylindrical. Components launched in the Shuttle must be able to fit within the length and width of the Shuttle's cargo bay, leaving enough room for support structures to hold the component in place during launch. Generally speaking, the Shuttle cargo bay dimensions provide a reasonable measure for the maximum size of space station components.

No crews fly aboard the station components themselves on the way to orbit. Crews need to be brought to the station and taken away from the station by manned spacecraft docking with it. There are two types of space vehicle capable of bringing crews to the ISS: the Space Shuttle and the Russian Soyuz. Food and other supplies are brought to the station in the Shuttle cargo bay, or by unmanned Russian Progress freight vehicles that automatically dock with the station. The ISS features docking adapters that work with both the Russian and the U.S. vehicles. A major design constraint on the station structure is the ability to maneuver spacecraft against the docking adapter without striking any part of the vehicle against any other part of the station. The Soyuz is a sphere on the nose of a roughly conical support module, with the docking adapter on the nose of the spacecraft. It can be docked fairly readily. The Shuttle is a large vehicle with extensions in several directions. Designing the station to provide a docking adapter where the Shuttle does not need to fit into a tight space was a major safety issue.

Lastly, the station requires significant exterior work, both to fulfill its research functions and to complete construction. ISS construction plans always called for a large number of EVAs (Extra-Vehicular Activities) in which astronauts in pressure suits work outside the Station. The ISS has airlocks for pressure-suited astronauts to exit the station. EVA puts astronauts at risk of radiation exposure and other hazards, and so EVAs are performed only when strictly necessary. To help with manipulating Shuttle cargo deliveries to the station and installing equipment on the exterior of the station, the ISS is equipped with a robotic arm similar to the robotic arm used in the cargo bay of the Space Shuttle. The Station arm is uniquely capable in that its "hand" can fasten itself to a mounting point on the surface of the ISS to become a new "shoulder," as the arm releases its old "shoulder" to become a new "hand."

Limits on Scale Models

Scale models are useful for many things, but they have their limits. The main limitations are material properties and nonlinear scaling.

The structural materials used in the model space stations in this lesson include wood, cardboard, paper, Styrofoam, glue, and thin aluminum. At the size scale of the models to be constructed, these materials are quite strong compared to the weight of the components. This helps in constructing a model for an orbital space station in a non-weightless environment. Scaled up to the dimensions of the ISS, these materials would be flimsy and the construction would collapse. This probably is not a major limitation to an effective model of a space station, since strong materials are not required in the real thing to maintain the structure. Models for Earth-bound structures, however, require careful attention to such issues in order to understand whether a modeled structure will have the anticipated strength when put into action in the full-size construction.

In a scale model, the lengths and sizes of all parts are scaled from the real object according to the same factor. Thus, in a half-scale model, every length in a model would be one half the length of equivalent parts in the real thing. If photographs of the real thing and the model were compared, but the photograph of the model were enlarged by a factor of two, the photograph of an accurate scale model would look just like the real thing. Not every property in a model scales linearly from the real thing, however. The surface area of parts in a model scales as the square of the linear scale factor, while the volume and mass (assuming the same material density in the model and in reality) scale as the cube of the linear scale factor. Thus, the surface area of the half-scale model would be one-fourth the real thing, and the mass and volume of the model would be one-eighth the real mass and volume. This most definitely has an effect upon the design of the model space station, as the application of the "rule of thumb" for identifying the area of solar panels for the station connects the required area to the enclosed volume of the space station modules. Students will be introduced to the "square-cubed law" for linear scaling as they design their station, when they compare the calculated size of solar panels determined from the model's dimensions to the calculated size of solar panels according to the full-size object that they are modeling. Other scaling problems follow from this effect—model airplanes, for example, weigh much less compared to the surface area of the wings than do the full-scale aircraft. Some early attempts to build man-carrying aircraft ended in failure, or even disaster, because of a failure to appreciate this fundamental feature of scale modeling.

Building Your Space Station
Lesson at a Glance
Science Overview
Conducting the Lesson
Resources

Conducting the Lesson

Warm-Up & Pre-Assessment

Teacher Materials

- Overhead transparency of the International Space Station (ISS)

Preparation & Procedures

1. Show students the images of the International Space Station that are included in the back of the lesson. Discuss with students their prior knowledge regarding the ISS. You may use the following facilitation to guide your discussion. Ask students what this is a picture of. (*Desired answer: the International Space Station)* Ask students where the ISS is located. *(Desired answer: in space orbiting the Earth*) Actually it orbits the Earth at an average height of 354 km (220 miles). How did the space station get there? (*Desired answer: it was brought up in pieces on the space shuttle*) Ask students what the ISS is used for. (*Desired answer: scientific research in how the human body adjusts to weightlessness, for example*)

NOTES:

Building Your Space Station

Lesson at a Glance

Science Overview

Conducting the Lesson

Warm Up & Pre-Assessment

Activity: Space Station Design

Lesson Wrap-Up

Resources

Activity: Space Station Design

Student Materials (per student)

- Student Worksheet 1
- Calculator

Student Materials (per group)

- 2 12-oz soda cans
- Individual-serving-size cereal box
- Toilet paper tube
- 5-6 pieces of black construction paper or cardboard
- A few sheets of aluminum foil
- Drinking straws (about 10)
- Craft sticks (about 10)
- Styrofoam food tray
- Hot glue gun and craft glue
- Roll of transparent tape
- Ruler
- Scissors

Preparation & Procedures

1. Collect the necessary materials or instruct students to bring them from home.

2. Discuss with students what limitations or challenges engineers faced when designing the International Space Station; you may want to use the following facilitation. Ask students what may be some design challenges when building something like the International Space Station. (*Desired answer: limited money, supplies, size, materials, complexity*) Ask students what would be limiting the size of the parts. (*Desired answer: the amount of room in the Space Shuttle to transport the parts*) Ask students what costs are involved in building a space station in addition to manufacturing the parts. (*Desired answer: getting them into space and testing for reliability*) Ask students, how would they minimize this cost? (*Desired answer: design your space station to be compact and to require the fewest number of Space Shuttle trips as possible*) Ask students if the space station needs to be compact once in space. (*Desired answer: no, only during travel*)
3. Tell students that they will be designing and building a model of

their own space station, Your Space Station (YSS). Their goal is to create a space station in which all components fit aboard the Space Shuttle and require the least number of trips. Have students follow the instructions on Student Worksheet 1.

REFLECTION & DISCUSSION

1. Ask student to share their YSS models. Students should take special note of the solar photovoltaic (PV) and thermal array designs. Discuss with students how even though they all had the same constraints, everyone used their own creativity to solve the problem in a unique way.

2. Ask students to report to the class the total number of Space Shuttle flights that would be needed to transport their entire space station into space. Ask the three groups with the smallest number to explain their solar (PV) array, thermal array, and assembly design to the class. Ask students why it matters how many Shuttle flights it takes to transport Your Space Station. (*Desired answer: Shuttle flights are expensive; minimizing the number of Shuttle flights saves money*)

TRANSFER OF KNOWLEDGE

Students based their space station design on minimizing the number of Shuttle flights required to transport it, and the amount of PV and thermal radiation panels needed to operate it. However, in real life, engineers are presented with many constraints, including weight. The heavier an object, the more fuel it takes to transport it. Have students weigh their model space stations. Allow them the opportunity to revise their plans in order to reduce the weight of their station without increasing the number of Shuttle flights required to transport it.

EXTENSIONS

- Investigate the design of the ISS's robotic arm; use the Extension Worksheet to design a functional robotic arm for your space station.
- Research the careers of people who are involved with the development and maintenance of the International Space Station. What kinds of skills, education, and experience do they have?

PLACING THE ACTIVITY WITHIN THE LESSON

In this activity, students created a model space station. The only constraint they were presented with was the size of the Space Shuttle cargo bay. However, many more constraints exist. Ask students to brainstorm some of these other limiting factors. (*Desired answer: money, weight, people to assemble objects in space, etc.*)

CURRICULUM CONNECTIONS

Biology – Have students research the amount of food and water that astronauts would need for a three-month stay aboard the ISS. Research how much a three-month supply of food and water weighs, and how it gets to the ISS. Brainstorm recycling options to minimize waste.

Assessment Criteria for Activity

4 Points

- All calculations are present and correct.
- Student used creative and reasonable ways to solve the problems.
- Student identified how the problems were solved and showed a deep understanding of the problems and solutions by thoroughly explaining their answer.

3 Points

- Most calculations are present and correct.
- Student used reasonable ways to solve the problems.
- Student identified how the problems were solved and provided a clear, complete explanation of the solutions.

2 Points

- Some calculations are present and correct.
- Student attempted to solve all problems.
- Student identified how the problem was solved, but did not provide a clear explanation.

1 Point

- A few calculations are present and correct.
- Student attempted to solve some problems.
- Student identified how the problem was solved, but did not provide an explanation.

0 Points

- No work completed.

NOTES ON ACTIVITY:

Lesson Wrap-Up

Lesson Closure

Discuss with students that there always are limits on resources of time, money, materials, etc. Engineers must balance their dream space station against practical constraints. This is a universal problem that everyone faces in their daily lives. Ask students to offer examples from their lives when they had to compromise their dream due to limited resources. (For example, they may have wanted a satellite dish, but could only afford basic cable TV.)

NOTES:

RESOURCES

INTERNET RESOURCES & REFERENCES

Student-Friendly Web Sites:

Space Kids – What is the ISS?
http://www.spacekids.com/spacenews/ISS_overview_000419.html
Image of International Space Station, Assembly Complete (simulated)
http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/International.Space.Station-Assembly.Complete/.index.html
Images of International Space Station Construction
http://spaceflight.nasa.gov/gallery/images/station/assembly/ndxpage1.html
NASA – What is the International Space Station?
http://www.nasa.gov/audience/forkids/home/F_What_is_ISS.html
National Geographic for Kids – Living It Up in Space
http://magma.nationalgeographic.com/ngexplorer/0110/articles/iss_0110.html

Teacher-Oriented Web Sites:

Adaptation to grade level may be necessary.
Discovery – Life in Space
http://www.discovery.com/stories/science/iss/iss.html
International Space Station – A Unique Resource for Learning
http://spacelink.nasa.gov/Educator.Focus/Articles/011_ISS_Information/
Journey to the International Space Station – Activities and Lessons
http://www.projectview.org/spacecenterhouston.activitiesandlessons.htm
Thursday's Classroom – Far Out Chores on the International Space Station
http://www.thursdaysclassroom.com/index_04jan01.html
Journey through the Universe
http://journeythroughtheuniverse.org/

ACKNOWLEDGEMENTS

The model-building instructions were adapted from the NASA education guide, International Space Station, available at http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/International.Space.Station/

NOTES:

TEACHER ANSWER KEY

Step 1: Determine the Size of Your Model Components

Habitation Module (example soda can)	YSS Model Size
Height	12.7 cm
Diameter	6.6 cm
Volume $V=\pi$ x (diameter/2)^2 x height	434.5 cm^3

Laboratory Module (example soda can)	YSS Model Size
Height	12.7 cm
Diameter	6.6 cm
Volume $V=\pi$ x (diameter/2)^2 x height	434.5 cm^3

Resource Module (example cereal box)	YSS Model Size
Length	10.2 cm
Width	7.1 cm
Height	4.1 cm
Volume V = length x width x height	296.9 cm^3

a. Answers will vary. For this example,
434.5 + 434.5 + 296.9 = 1166 cm^3 = 1170 cm^3

Step 2: Determine the Scale Factor for Each Module (example components)

	Scale Factor Equation	Scale Factor
Module 1 Height	14.6 m / height of can in m	115.0
Module 1 Diameter	3.66 m/ diameter of can in m	55.4
Module 2 Height	14.6 m / height of can in m	115.0
Module 2 Diameter	3.66 m/ diameter of can in m	55.4
Module 3 Height	14.6 m / height of box in m	143.1
Module 3 Width	3.66 m/ width of box in m	51.5
Module 3 Length	3.66 m/ length of box in m	89.3

a. Choose the smallest scale factor. The size of the real object is the size of the model piece times the scale factor. With a larger scale factor, one or more pieces would have a dimension bigger than the available space in the Shuttle cargo bay.

b. Answers will vary. For the example measurements, the width of Module 3 (Resource Module) is the limiting factor. It has the smallest scale factor. That means that the real thing can be only 7.1×10^{-2} m • 51.5 = 3.66 m wide. With a bigger factor, it would be too wide to fit in the Shuttle.

c. Answers will vary. For the example measurements, the YSS scale factor is 51. This will be a 1:51 model, or 51st-scale.

Some students may notice that the Resource Module is a rectangular prism, and use this fact to calculate a better scale factor. This deserves extra credit. The diagonal width of the cereal box is square root of (width^2 + height^2) = 8.2 cm (for the example cereal box), leading to a scale factor of 44.6, rounded to 44.

d. Answers will vary. For the example scale factor, the scale length of the Shuttle cargo bay is 14.6 m / 51 = 0.286 m = 28.6 cm. This actually is big enough to fit the Habitation and Laboratory Modules simultaneously, if a single soda can were used for each. The scale diameter of the Shuttle cargo bay is 3.66 m / 51 = 0.0718 m = 7.18 cm.

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Teacher Answer Keys

e. Answers may vary. For the example components, just two flights are needed, if space within the cargo bay were the only limitation. Any two of the modules can fit together in the Shuttle's cargo bay. Not all three can fit at the same time.

Step 3: Determine the Actual Size and Volume of Your Space Station

Habitation Module (soda can) example scale factor of 51

	Full-Size YSS
Height	6.48 m
Diameter	3.37 m
Volume V=π x (diameter/2)^2 x height	57.8 m^3

Laboratory Module (soda can)

	Full-Size YSS
Height	6.48 m
Diameter	3.37 m
Volume V=π x (diameter/2)^2 x height	57.8 m^3

Resource Module (individual sized cereal box)

	Full-Size YSS
Length	5.20 m
Height	3.62 m
Width	2.09 m
Volume V = length x height x width	39.3 m^3

a. Answers will vary. For the example components and scale factor of 51, the total volume of the full-size YSS is 154.9 m^3.

b. No. Students will need to use dimensional analysis to determine the volume scaling factor, by converting the model's volume from cm^3 to m^3. Or just convert all the scale lengths from centimeters to meters first, then compute the model's volume. For the example components and scale factor, the model's volume is 0.001167 m^3, so the volume scale factor is $154.9 / 0.001167 = 132733 = 1.33\times10^5 = 51^3$.

The volume scale factor is much bigger than the length scale factor. The volume of the full-size object is computed from each of the appropriate model lengths, times its scale factor. Therefore, the volume of the final object is the model volume times the cube of the scale factor.

c. Answers may vary. The real thing will be a lot more flimsy than the model, because the weight (mass) also increases as the scale factor cubed. The sizes of components need to be calculated based on the full-size components, since PV area is based on volume. A working scale model will not function exactly the same as the real station, due to the difference in surface area and volume scaling.

Step 4: Photovoltaic (PV) Array Design

a. Answers will vary according to the full-size station volume calculated previously. The total area needed is determined from how many times a 500 cm^3 volume fits into the full-size YSS volume: $(154.9\ m^3 / 0.0005\ m^3) \bullet 0.01\ m^2 = 3100\ m^2$.

Each individual PV array should be about 4 times longer than your longest module with a width twice the width of that module. Calculate the dimensions of the individual PV arrays below.

(example components)

	Model-Size YSS	Full-Size YSS
Length	$4\bullet12.7$ cm = 50.8 cm	25.9 m
Width	$2\bullet6.61$ cm = 13.2 cm	6.74 m
Surface Area	671 cm^2 = 0.671 m^2	175 m^2

b. Answers may vary, according to previously-determined values. Divide the total area needed by the area of one PV array to get the total number needed = 3100 m^2 / 175 m^2 = 17.7 PV arrays of these dimensions.

c. The number should be rounded up, since it is acceptable to have more than enough power available, but it is not acceptable to have less than enough power available.

d. Answers will vary. There is no single good answer. Creativity is encouraged here.

e. No single good answer. It will depend on how well the arrays can be folded.

Step 5: Thermal Panel Design

a. Answers will vary, according to previously-determined values. The total area needed is determined from how many times a 500 cm^3 volume fits into the full-size YSS volume: (154.9 m^3 / 0.0005 m^3) • 0.0075 m^2 = 2323 m^2.

b. (example components)

	Model-Size YSS	Full-Size YSS
Length	3•12.7 cm = 38.1 cm	19.4 m
Width	2•6.61 cm = 13.2 cm	6.74 m
Surface Area	503 cm^2 = 0.503 m^2	131 m^2

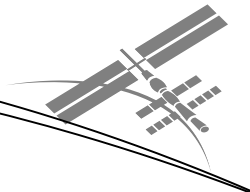
c. Answers will vary, according to previously-determined values. Divide the total area needed by the area of one PV array to get the total number needed = 2323 m^2 / 131 m^2 = 17.7 thermal panels of these dimensions needed.

d. There is no single good answer. Creativity is encouraged here.

e. No single good answer. It will depend on how well the panels can be folded.

Step 6: Assembling your Model Space Station

Answers will vary. Some items, like the three main modules, may not take a full cargo bay to get one or more components into orbit. Other station components can fill some of the extra space and reduce the number of Shuttle flights.



STUDENT WORKSHEET 1

NAME ____ DATE ___________

You will be designing and building a model of a space station, called the YSS (Your Space Station). Your goal is to build a station that can be transported to space with the fewest Space Shuttle flights possible. Below is a list of materials and their corresponding parts.

OBJECT USED TO MODEL SPACE STATION COMPONENT	QUANTITY	ACTUAL SPACE STATION COMPONENT
Cylindrical cans (e.g., soda cans, juice cans) or similar straight-sided cylinders with flat ends	2	Module 1 (Habitation) and Module 2 (Laboratory)
Individual serving size cereal box or similar size box	1	Module 3 (Resource Module)
Toilet paper tubes, cut into thirds	1 tube	Module docking adapters
Black construction paper or cardboard	5-6 pieces	Photovoltaic (PV) array surfaces
Aluminum foil	1 roll	Thermal panel surfaces
Drinking straws	As needed	Supports for PV arrays and thermal panels, truss
Craft sticks	As needed	Supports for PV arrays and thermal panels, truss
Styrofoam food trays, cut into strips	As needed	Supports for PV arrays and thermal panels, truss
Hot glue gun and craft glue	As needed	Welding

STEP 1: DETERMINE THE SIZE OF YOUR MODEL COMPONENTS

Measure your model's parts and record the information in the data tables below. When completing calculations, use 3.14 as π, and round to the nearest tenth of a centimeter.

Habitation Module (example soda can)	YSS Model Size
Height	
Diameter	
Volume $V=\pi \times (\text{diameter}/2)^2 \times \text{height}$	

Laboratory Module (example soda can)	YSS Model Size
Height	
Diameter	
Volume $V=\pi \times (\text{diameter}/2)^2 \times \text{height}$	

Resource Module (example cereal box)	YSS Model Size
Length	
Width	
Height	
Volume V = length x width x height	

a. What is the total volume for your model space station?

STEP 2: DETERMINE THE SCALE FACTOR FOR EACH MODULE

In order for you to build YSS, you must get each piece into space using the Space Shuttle. Therefore, each module must fit inside the Shuttle's cargo bay, which is cylindrical in shape with a diameter of 3.66 meters and a length of 14.6 meters. Each component of Your Space Station will need to be scaled up or down by the same factors in order to be considered a scale model. But what factor should be used? To find out, calculate the factor to which each individual component could be scaled and still fit inside the Shuttle's cargo bay.

	Scale Factor Equation	Scale Factor
Module 1 Height		
Module 1 Diameter		
Module 2 Height		
Module 2 Diameter		
Module 3 Height		
Module 3 Width		
Module 3 Length		

a. All of the space station components need to be represented on the same scale and still need to fit within the cargo bay of the Shuttle; which scale factor should you choose from the data table above? Should you choose the largest or smallest scale factor from the data table above? Why?

b. Which component will be the limiting factor? Why?

c. Based on your answer above, what is the YSS scale factor? Round down to the nearest whole number.

d. Using the YSS scale factor, calculate the length and diameter of the Shuttle's cargo bay on this scale.

e. How many Space Shuttle trips will it take to get all three of your modules into space?

STEP 3: DETERMINE THE ACTUAL SIZE AND VOLUME OF YOUR SPACE STATION

Using the YSS scale factor you determined, calculate the actual dimensions of YSS and the volume of each module.

Habitation Module (soda can)

	Full-Size YSS
Height	
Diameter	
Volume V=π x (diameter/2)^2 x height	

Laboratory Module (soda can)

	Full-Size YSS
Height	
Diameter	
Volume V=π x (diameter/2)^2 x height	

Resource Module (individual sized cereal box)

	Full-Size YSS
Length	
Height	
Width	
Volume V = length x height x width	

a. What is the total volume of your full-size space station?

b. Does the volume you calculated for your model differ by the YSS scale factor from the volume you calculated for your full-size space station? Explain.

c. The square-cubed law expresses the fact that surface area scales as the square of the length scale factor, while the volume scales as the cube of the length scale factor. What limitations might this law present for your model?

STEP 4: PHOTOVOLTAIC (PV) ARRAY DESIGN

Your Space Station needs power, and that power comes from very large solar panels called photovoltaic (PV) arrays. On your full size space station, the electric needs of 500 cm^3 (0.0005 m^3) of module volume can be supported by 100 cm^2 (0.01 m^2) of PV array.

a. Calculate the total area of solar arrays needed by your full-size space station. Show work.

Each individual PV array should be about 4 times longer than your longest module with a width twice the width of that module. Calculate the dimensions of the individual PV arrays below.

	Model-Size YSS	Full-Size YSS
Length		
Width		
Surface Area		

b. Calculate the number of full-size solar arrays needed to power your full-size space station.

c. Should you round this number up or down? Why?

d. Design and build your model-size PV arrays using black construction paper (or cardboard) for the photovoltaic surface and use craft sticks, straws, or Styrofoam strips for support and to hold them together. You may design your PV arrays in any arrangement and they can have the ability to fold. Create the most efficient design possible in order to minimize the number of Shuttle flights that will be needed to transport the PV arrays into space (you have already calculated the size of the Shuttle's cargo bay on your scale in Step 2, question d). Sketch your design below.

e. How many Shuttle missions will it take to get your PV arrays into space?

STEP 5: THERMAL PANEL DESIGN

There is no breeze in space to cool things down. Everything must be cooled artificially, so the ISS and Your Space Station must have thermal panels to remove heat in the station to keep it from heating up and endangering the crew or damaging equipment. The heat has to be moved from the inside of the station to the thermal control panels by a heat pump similar to the heat pumps used in houses and refrigerators. The cooling needs of 500 cm^3 (0.0005 m^3) of module volume can be supported by 75 cm^2 (0.0075 m^2) of thermal panels.

a. Calculate the total area of thermal panels needed by your full size space station. Show work.

b. Each individual thermal panel should be about 4 times longer than your longest module with a width twice the width of that module. Calculate the dimensions of the individual thermal panels below.

	Model-Size YSS	Full-Size YSS
Length		
Width		
Surface Area		

c. Calculate the number of full-size thermal panels needed to power your full-size space station.

d. Design and build your model-size thermal panels using aluminum foil for the radiator surface and use craft sticks, straws, or Styrofoam strips for support and to hold the panels together. You may design your thermal panels in any arrangement, and they can have the ability to fold. Create the most efficient design possible in order to minimize the number of Shuttle flights that will be needed to transport the thermal panels into space (Hint: you have already calculated the size of the Shuttle's cargo bay on your scale in Step 2, question d). Sketch your design below.

e. How many Shuttle missions will it take to get your thermal panels into space?

STEP 6: ASSEMBLING YOUR MODEL SPACE STATION

Sixteen countries are participating in the ISS, contributing components, materials, and expertise. Parts built in different countries must fit together perfectly in orbit, possibly the first time that many components will have been brought together to test the fit. It is now time to assemble Your Space Station (YSS) based on your plans. Make sure your space station meets the following requirements:

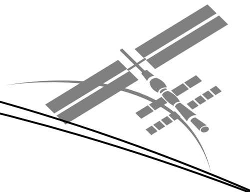
- Each module must connect to at least one other module; use a module docking adapter (toilet paper tube section) between them.
- The thermal panels should be out of the sunlight when the PV arrays are in full sunlight, so that they can radiate heat freely.
- The ISS has a truss, a long backbone that holds the PV arrays and thermal panels; whether you feel your space station needs one or more trusses is up to you.
- Visiting spacecraft will need a place to dock. Use a module docking adapter that is free from obstruction.
- Use glue to hold your pieces together.

Draw a sketch of your plan below before you begin.

Calculate the surface area of each object you added to assemble Your Space Station.

How many Space Shuttle flights are required to transport these items?

How many total Space Shuttle flights would be required to transport your entire space station into orbit?



EXTENSION WORKSHEET: THE ROBOTIC ARM

NAME ____ DATE ___________

The real arm on the ISS has a “wrist” on the end, with a “hand” attached. The hand can grab onto prepared points on the ISS and detach the original “shoulder”, becoming the new hand and wrist; the original hand and wrist become the new shoulder. In this way, the arm can relocate around the ISS to reach new operating locations. Imagine that your space station has an arm that works the same way.

DESIGNING YOUR ROBOTIC ARM

1. The robotic arm (Remote Manipulator System) has two joints in the middle of its length. You can make the joints by interlocking two loops of pipe cleaner.

2. How long is the arm? You can’t constantly move it to new locations, especially if it’s holding a load in the hand that it has to move. Pick a central location for the arm to be usually mounted. Design the arm so that it can reach as many places as possible, with only two joints in the middle.

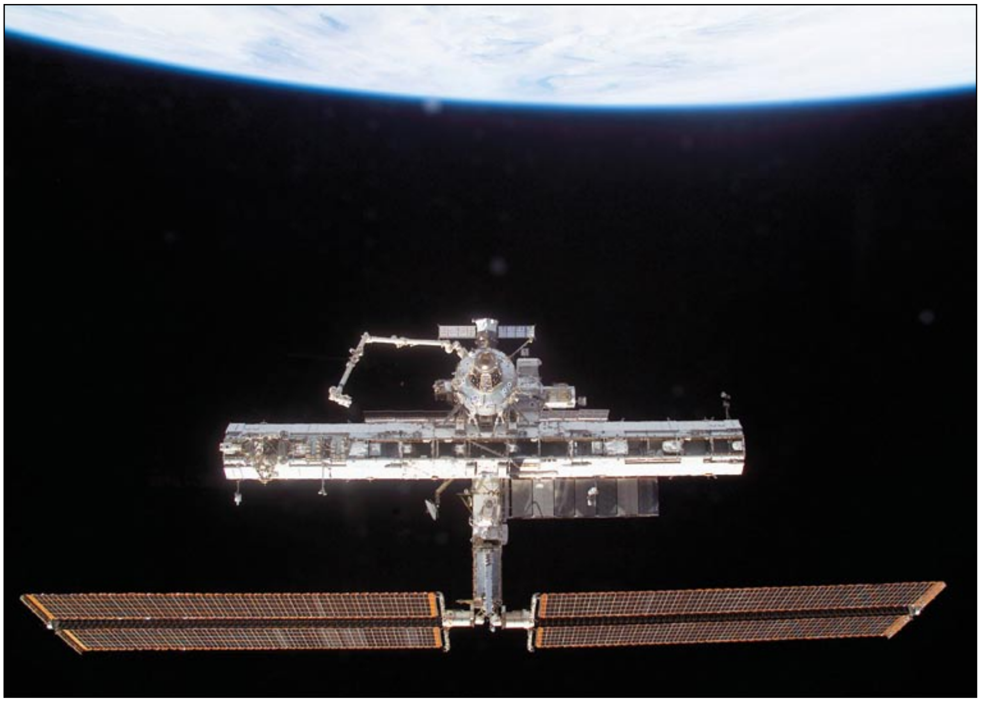
3. Since the arm can reattach itself and switch ends in the process, design your arm to be symmetrical so that it works the same regardless of which end is attached to the station.

4. Now, at last, build your arm and attach it to the station. How long did you make the sections?

ROBOTIC ARM SECTION	YSS MODEL SIZE	FULL SIZE YSS
Section 1		
Section 2		
Section 3		

The design of the arm is distinctive for each station and for its placement. Make sure that the scaling factor is applied correctly for the dimensions of the full-size YSS arm.

STS112-E-05823 (16 October 2002) - Backdropped against the blackness of space and Earth's horizon, the International Space Station (ISS) was photographed through an aft flight deck window following separation from the Space Shuttle Atlantis. The orbiter pulled away from the complex at 8:13 a.m. (CDT) on October 16, 2002. (Image downloaded from http://spaceflight.nasa.gov/gallery/images/station/assembly/ndxpage1.html)



STS113-E-05413 (2 December 2002) - Backdropped by the blackness of space and Earth's horizon, this full view of the International Space Station (ISS) was photographed by a crewmember on board the Space Shuttle Endeavour following the undocking of the two spacecraft. Endeavour pulled away from the complex at 2:05 p.m. (CST) on December 2, 2002 as the two spacecraft flew over northwestern Australia. The newly installed Port One (P1) truss now complements the Starboard One (S1) truss in center frame. (Image downloaded from http://spaceflight.nasa.gov/gallery/images/station/assembly/ndxpage1.html)

STS105-707-019 (20 August 2001) - Backdropped by Earth dotted with clouds, this close up view of the International Space Station (ISS) was taken by one of the crew members on the Space Shuttle Discovery after undocking at 9:52 a.m. (CDT), August 20, 2001 after more than a week of joint operations. (Image downloaded from http://spaceflight.nasa.gov/gallery/images/station/assembly/ndxpage1.html)