Activity Three: Model a Spacecraft Docking System

Educator Notes

Challenge

Students will work together as a team to construct and test a model of a target docking system and crew module.

Suggested Time

60 minutes

Learning Objectives

Students will

- Make metric length measurements with 0.1-cm accuracy.
- Use given ratios to calculate dimensions of a scale model.
- Demonstrate their knowledge of traveling through and rotating about the three axes of movement.
- Demonstrate teamwork and communication skills to perform a task.

Curriculum Connection

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-PS2-2 Motion and Stability: Forces and Interactions: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. – PS2.A: Forces and Motion: The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. *Crosscutting Concepts* • System and System Models: A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.	*Crosscutting Concepts (continued)* • Structure and Function: The way an object is shaped or structured determines many of its properties and functions. *Science and Engineering Practices* • Developing and Using Models: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. • Using Mathematics and Computational Thinking: In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; statistically analyzing data; and recognizing, expressing, and applying quantitative relationships.
Technology (ISTE)	
Standards for Students • Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions. – 5c: Students break problems into component parts, extract key information, and develop descriptive models to understand complex systems or facilitate problem solving.	*Standards for Students (continued)* • Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally. – 7c: Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal.
Mathematics (CCSS)	
Content Standards by Domain • CCSS.MATH.CONTENT.6.RP.A.1: Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. • CCSS.MATH.CONTENT.6.NS.B.3: Fluently add, subtract, multiply, and divide multidigit decimals using the standard algorithm for each operation. • CCSS.MATH.CONTENT.7.NS.A.3: Use proportional relationships to solve multistep ratio and percent problems.	*Content Standards by Domain (continued)* • CCSS.MATH.CONTENT.7.G.A.1: Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale. *Mathematical Practices:* • CCSS.MATH.PRACTICE.MP5: Use appropriate tools strategically. • CCSS.MATH.PRACTICE.MP6: Attend to precision

Preparation Time

30 minutes

- Read the Introduction and Background, Educator Notes, and Student Handout to become familiar with the activity.
- Gather and prepare all supplies listed on the materials list.
- If presenting videos or web-based resources, test the links and the classroom technology ahead of time.
- Determine if students will be working independently or in small groups to construct the models. Teams of three are recommended for testing the docking system.

Materials

- ☐ Small foam cups (2 per team)
- ☐ Bendable plastic straws (6 per team)
- ☐ Construction paper
- ☐ Pens/pencils
- ☐ Tape
- ☐ Scissors
- ☐ Metric ruler
- ☐ String
- ☐ Copies of Student Handout and blank paper
- ☐ Plastic knife (optional)
- ☐ Drafting compass for drawing circles (optional)
- ☐ Calculator (optional)
- ☐ Blindfolds (optional)

Introduce the Challenge

- Provide context for this activity using the Introduction and Background information in this guide. Use the Orion: Expanded View image to identify and discuss the three functional components of a crew vehicle:
  - Crew module
  - Service module
  - Launch abort system
- Discuss how the crew module has the capability to couple, or dock, to the pressurized mating adapters of the International Space Station and future deep space spacecraft. The docking port serves as both a parking spot for the vehicle and an entrance to the spacecraft.
- Distribute the Student Handout and explain the challenge. Emphasize the importance of taking careful measurements and making accurate calculations.
- Explain the role of models and simulations in designing technology to solve problems.
- Introduce any new terminology (e.g., docking system, mockup, and scale model).

Facilitate the Challenge

Ask and Imagine

Engage students with the following discussion questions:

- Why are astronauts trained on the docking system with computer simulations before they travel into space? (See Additional Resources for a NASA Commercial Crew Program application with a simulated docking component.)
- What safety measures need to be taken into consideration when designing a space docking port?
- Why do NASA engineers build smaller scale models or mockups of NASA spacecraft before committing to an engineering design?

Create

- Each student or team will construct a model of a target docking system and crew module using the supplies provided.

Share With Students

Brain Booster

Rendezvous means to meet at a specified time and place. A spacecraft rendezvous is a tricky process. A careful series of maneuvers are required to adjust the horizontal and vertical alignment of each spacecraft. The spacecraft must also maintain a proper speed to safely approach each other for docking.

Learn more: https://www.nasa.gov/mission_pages/station/research/news/b4h-3rd/it-automating-better-space-rendezvous/

On Location

The Six-Degree-of-Freedom Dynamic Test System (SDTS) at Johnson Space Center in Houston, Texas, is a motion-based platform capable of six degrees of freedom. The SDTS is primarily used for the simulation and evaluation of the NASA Docking System (NDS) used on Orion to dock with other craft.

Learn more: https://er.jsc.nasa.gov/ER5/

Plan, Test, and Improve

- Each team will use their completed crew modules and docking adapters to practice maneuvering and attempt docking.
- Each team will plan maneuvers in order to "dock” the crew module with the target docking system.
- After each attempted maneuver, students will replan or improve their tactics based upon previous experiences.

Share

Engage students with the following discussion questions:

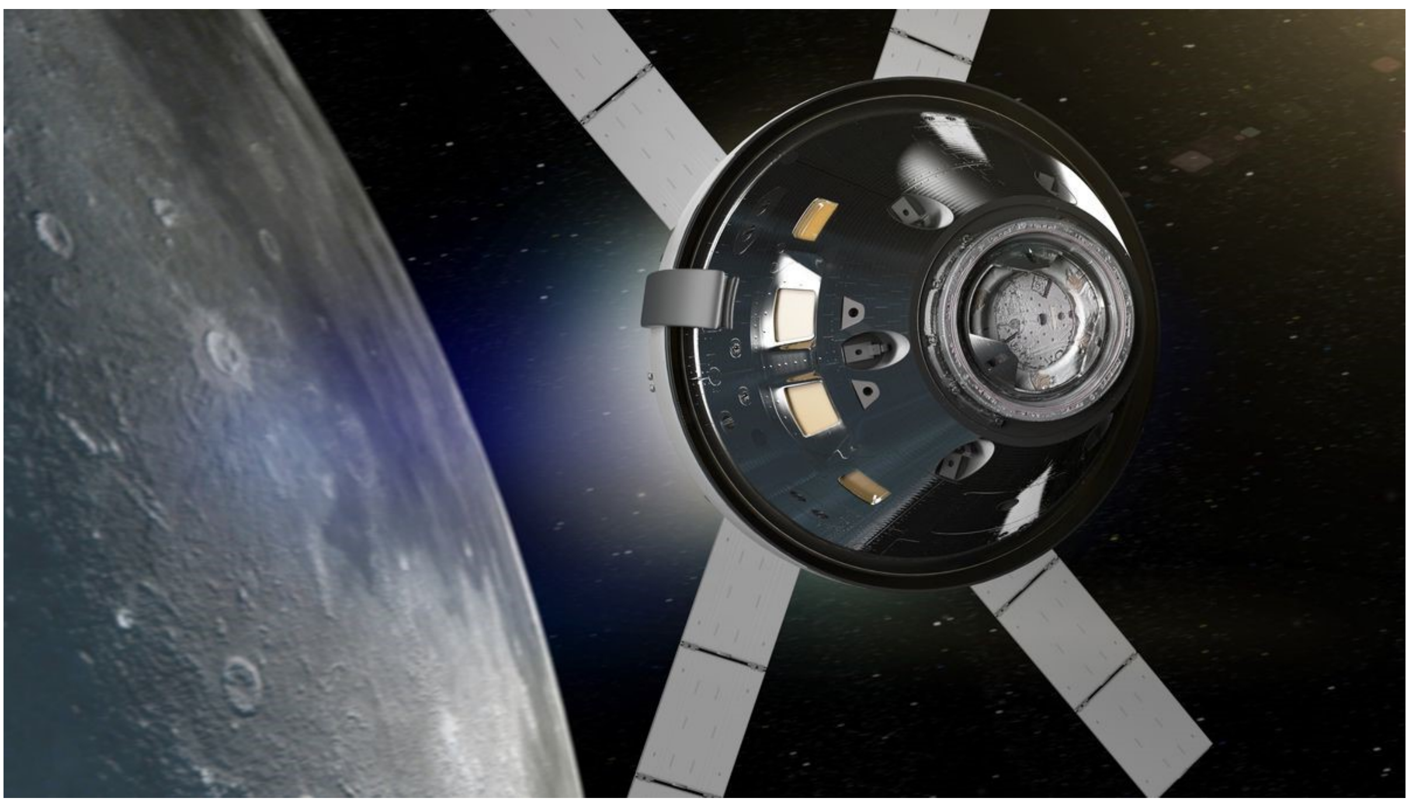
- What was the greatest challenge for your team today?
- Why was it important for your measurements and calculations to be accurate?
- The diameter of the spacecraft’s heat shield is 5.03 m. What is the scale of your model?
- Was your team successful when maneuvering the crew module model into the docking port? Why or why not?
- When spacecraft dock, they do not just share a physical airtight seal. There are also electrical and plumbing connections that can be made. What resources could be shared between two docked spacecraft?
- If you were to participate in this activity again, what would you do differently?

Extensions

- There are multiple training missions in the Student Handout to differentiate this activity and make it more or less difficult.
- Ask teams to create a model of a new docking system of their own design and demonstrate how it works.

Additional Resource

- App: Rocket Science—Ride to Station. https://www.nasa.gov/stem-ed-resources/rocket-science-ride-to-station.html
- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/



An artistic rendering of NASA’s Orion capsule flying by the Moon. (NASA)

Activity Three: Model a Spacecraft Docking System

Student Handout

Your Challenge

Construct and test a model of a target docking system and crew module.

Ask and Imagine

- Why are astronauts trained on the docking system with computer simulations before they travel into space?
- What safety measures need to be taken into consideration when designing a space docking system?
- Why do NASA engineers build smaller scale models or mockups of NASA spacecraft before committing to an engineering design?

Create

- Carefully follow the directions using the materials supplied by your teacher.
- Using measurements and mathematical ratios, you will construct a pair of docking system mechanisms, as well as a scale model of a crew module. One docking adapter will be attached to your crew module, and the other will be attached to a surface to simulate a target docking adapter.
- After completion, you will coordinate with your team to carefully maneuver the crew module in order to successfully "dock" with the target docking adapter.
- In space, the crew module would be attached to the service module until the spacecraft is ready to reenter Earth's atmosphere. For this challenge, the service module has been eliminated to give you a clearer view of the target docking adapter.

Building the Docking Adapters


1


2

1. Place one foam cup upside down on a table. Using a metric ruler and a pen, draw a line 3 cm high all the way around the cup. You can do this by holding a pen against the cup at the 3-cm mark and having a partner turn the cup while you hold the pen in place. Repeat for the second foam cup.
2. Use your markings as your guide and carefully cut off the tops of both cups. The 3-cm-tall rings will become the bases of your two docking adapters.

   For the rest of the challenge, you will be measuring the parts you have created and using ratios to calculate the sizes of other parts you will need. You will be making six "petals" for your docking adapters (three for each adapter), all from a single ring cut from a foam cup. These isosceles trapezoidal structures help align the two docking adapters during docking. Make sure to take careful measurements and record them in your tables.


3

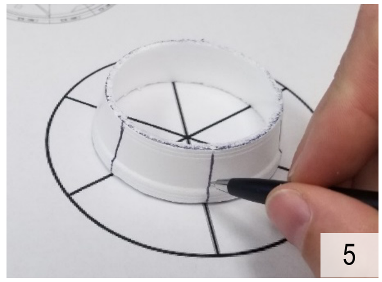
3. The height of the ring will be based on the diameter of the top of the docking adapter bases created in Step 1. The ratio of the docking adapter diameter to petal height is 1 to 0.3. First, measure the diameter of the top of the docking adapter ring to the nearest 0.1 cm (the nearest mm). Copy the following table on the paper provided by your teacher and record the diameter. Next, multiply the measurement by 0.3 to find the height of the petals. Round this number to the nearest 0.1 cm and record it in your table.

Diameter of docking adapter base, cm	Ratio	Height of petals, cm
	1:0.3	

4. Take one of the two cups that you previously cut and place it upside down on the table. As in Step 1, use a metric ruler to mark a ring around the cup, this time ***at the petal height that you just calculated***. Carefully cut off the top of the cup to create a ring, just as you did in Step 2 to make the docking adapter bases. This new ring will become your six petals.


4

5. On the last page of this activity is a template of a circle divided into sixths. To divide your ring into six equal parts, place it on the template, making sure it is centered in the circle. Have one team member hold the ring in place while another draws a vertical line where each mark meets the ring.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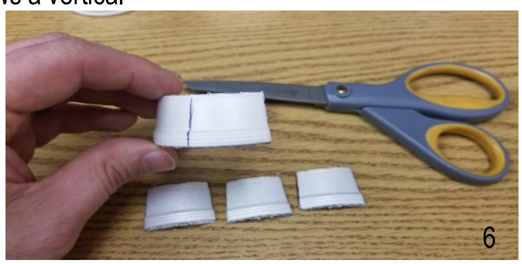
6. Using scissors, carefully cut along each vertical line, dividing the ring into six equal pieces. As you cut them out, keep them organized right side out and with the longer side on the bottom.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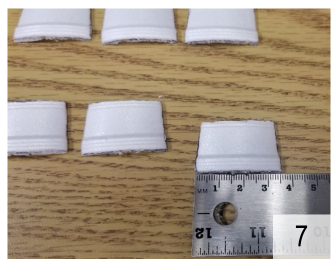
7. Because each petal is shaped like a trapezoid, the top of each petal will need to be shorter than its base. The top of each petal is about half the length of its base, or a ratio of **1 to 0.5**. To keep the petal the shape of an isosceles trapezoid, trim the remaining half from the top in equal fourths (or a ratio of **1 to 0.25**) from each side.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8. Carefully measure the length of the base of one of the petals. Copy the following table on the paper provided and record the length of the base. Then use the ratios to calculate the length of the top of each petal and how much needs to be trimmed from each side.

Length of petal base, cm	Ratio of petal base to petal top	Length of petal top, cm
	1:0.5	
Length of petal base, cm	**Ratio of petal base to trim length**	**Length to trim off each side, cm**
	1:0.25	

Fun Fact

NASA collaborated with international space agencies and private aerospace companies to establish the International Docking System Standard (IDSS). The NASA Docking System (NDS) is the implementation of the IDSS. Spacecraft using the NDS can dock with other pressurized spacecraft using the same system and share air, water, power, communications, and even fuel resources.

Learn more: https://www.youtube.com/watch?v=iHomPzdPcH4

Career Corner

Do you have a passion for making scale models in your spare time? Take your hobby and skills to new heights at NASA! You can become an engineer at NASA's Subscale Research Lab and build models to test new and innovative prototypes of the next generation of spacecraft or aircraft.

Learn more: https://www.youtube.com/watch?v=H7OIxa8NQrg

9. Using the length you calculated to trim off each side of the top of each petal, measure inward from the outside edge of each side and make a mark.

10. Using your ruler as a straight edge, draw diagonal lines from the marks you made to the outer edge of the base on each side of the petal.

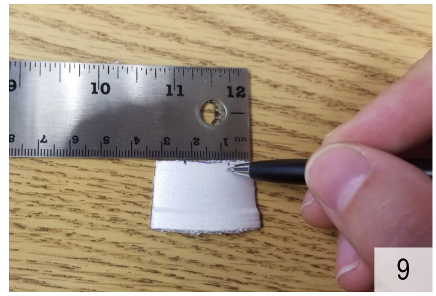
11. Finally, using scissors, carefully cut along the diagonal lines to complete each petal.

12. To attach the petals to your docking adapter, they need to be properly aligned. Take one of the docking adapter bases you completed earlier and place it upside down on the circle template you used in Step 5. While one person in your team holds it in the center, make a mark at the bottom of the docking adapter base where each line from the template meets the docking adapter base. Repeat this for the second docking adapter base.

13. Flip one of your docking adapter bases over. Hold one of the petals on top of the base as shown in the photo (13) making sure it is centered between two of the marks you made. Secure the petal to the base using tape.

14. Repeat this step two more times for this docking adapter, leaving a gap between each petal. When complete, your docking adapter should look like the photo (14). Check that your petals will bend inward when gently pressed and spring outwards when released. Repeat this process (Steps 4 through 14) to complete your other docking adapter.

15. Congratulations! You have completed a matching pair of docking adapter mechanisms. Now check to see if they will dock. Place one docking adapter face up on the table, hold the other upside down, and rotate 180 degrees. Slowly lower one docking adapter onto the other until their bases touch. The petals should bend inward slightly as the two docking adapters "dock."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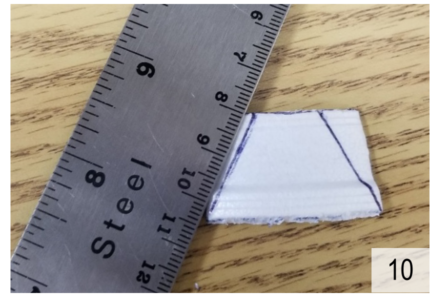
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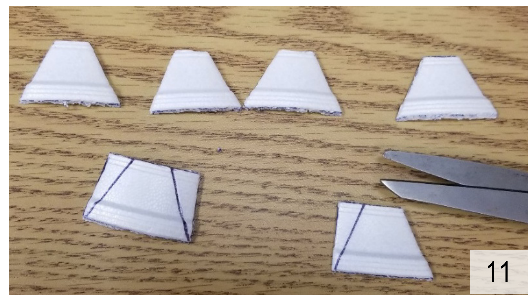
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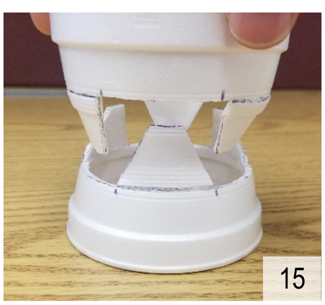
14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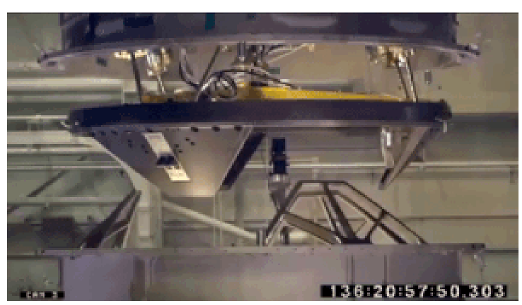
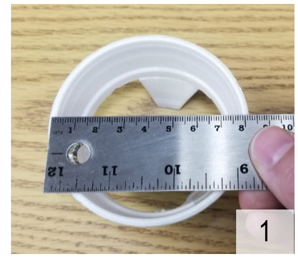


Two NASA Docking Adapter prototypes being tested.
(NASA)

Building the Crew Module Scale Model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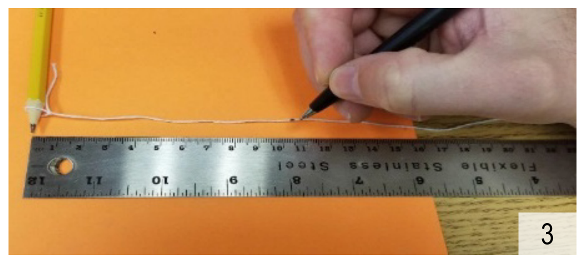
Now that you have your two docking adapters completed, it is time to construct a scale model of the crew module to test vehicle docking. Your crew module will use one of the docking adapters you have already constructed. You will also need to make a base plate and six stanchions.

1. To make these components, you will need to measure the diameter of the bottom of your docking adapter. Copy the following table on the paper provided and record the diameter.

Diameter of bottom of docking adapter, cm	Ratio of docking adapter diameter to heat shield diameter	Heat shield diameter, cm
	1:2.7	
Heat shield diameter, cm	**Ratio of heat shield diameter to heat shield radius**	**Heat shield radius, cm**
	1:0.5	
Diameter of bottom of docking adapter, cm	**Ratio of docking adapter diameter to stanchion length**	**Length of stanchion, cm**
	1:1.6	

Heat Shield

2. The diameter of the heat shield will be 2.7 times the diameter of the bottom of the docking adapter, or a ratio of 1 to 2.7. Once you have calculated the diameter of the heat shield and recorded it on your table, you will make a circle of that diameter on your sheet of construction paper. First, you will need to find the radius of the circle, which is one-half of the diameter, or a ratio of 1 to 0.5. Record this on your table.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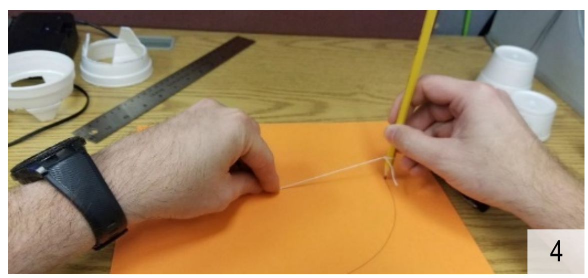
3. Next, you will use the heat shield radius you calculated to make a circle on your sheet of construction paper. You can use a compass to make the circle or you can use the string method shown in the photos (3 and 4). String method: Make a small dot in the center of your paper. Tie a string near the end of a pencil and measure out the length of the radius of the heat shield along the string, beginning at the tip of the pencil. Place a small mark on the string so you do not lose its place.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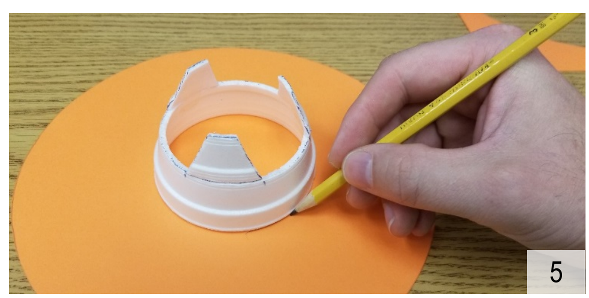
4. Place the mark you made on the string onto the dot you made in the center of the paper and stretch the pencil out to full length. While a member of your team holds the paper steady, keep the mark you made on the string in place as you rotate the pencil around in a complete circle.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5. After completing the circle for the heat shield, cut it out and place one of the docking adapters directly in the middle. Have one person on the team hold the docking adapter in place while another traces a circle onto the heat shield around the docking adapter.

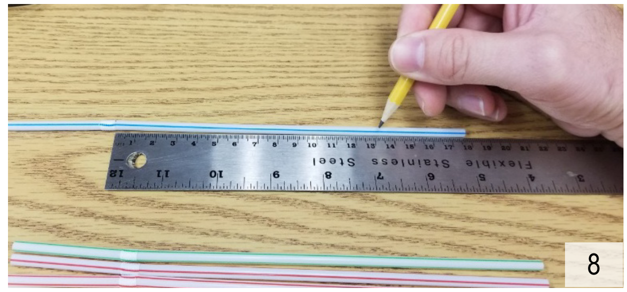
6. When completed, carefully cut out the circle. The hole in the heat shield will allow you to see through the crew module from behind, aiding in docking.


6

Stanchions

7. Next, you will measure for the six stanchions that will act as the skeletal support of your crew module. Their length is based on the diameter measurement of the bottom of the docking adapter that you recorded earlier. The ratio of the diameter of the bottom of the docking adapter to the length of the stanchions is 1 to 6. Calculate this length and record it on your table from Step 2.

8. Once you have calculated and recorded the stanchions' length, measure out the length onto each straw, beginning at the edge of the flexible joint, and toward the long end, as shown in the picture (8). Do not measure from the end of the straw! After marking each straw, cut them on your mark.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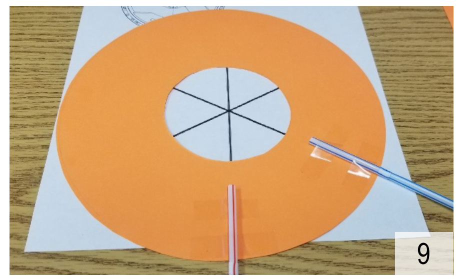
9. After cutting each straw, set them aside and retrieve the circle template used in Steps 5 and 12 of Building the Docking Adapter. You will use it to align your stanchions equally around the heat shield. Place the heat shield over the template, making sure that it is centered. Retrieve one of your stanchions and locate the end that has the shorter distance to the flexible joint. Place this end on the heat shield with the flexible joint at the edge of the circle, and the end of the straw in line with one of the lines on the template. Tape the straws into place.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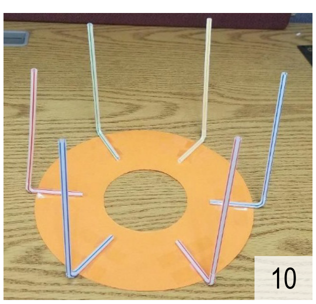
10. Repeat this process until all your stanchions have been taped down in a circular pattern. After completing this, you can remove the template. Next, extend the flexible joint in each straw, and bend the straws vertically.

11. It is now time to attach one of your docking adapters to the crew module. Retrieve one of the docking adapters and place it behind one of the stanchions so that the top of the stanchion overlaps the lip of the cup and is aligned with one of the marks you made earlier to align the petals.

12. Loosely tape the stanchion into place, and repeat the process with the stanchion on the opposite side of the crew module. Center the docking adapter at the top of the crew module. You may need to readjust the tape to get it centered.

13. Attach the four stanchions in the same manner to complete your crew module.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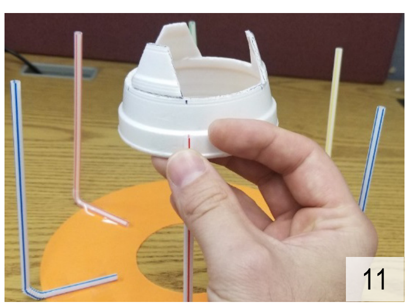
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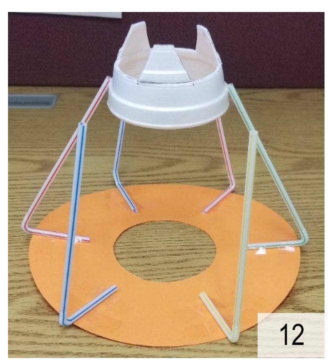
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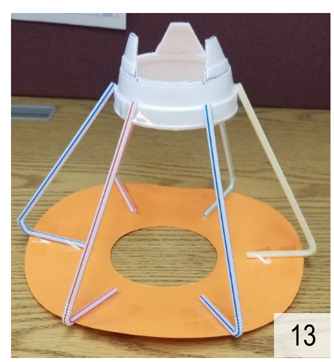
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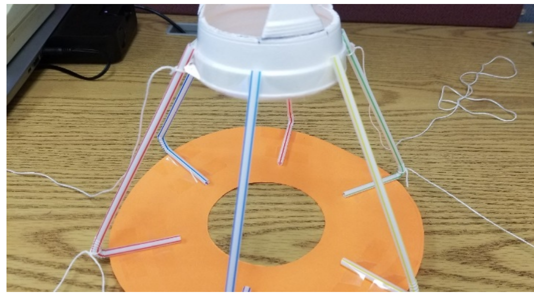
Control System



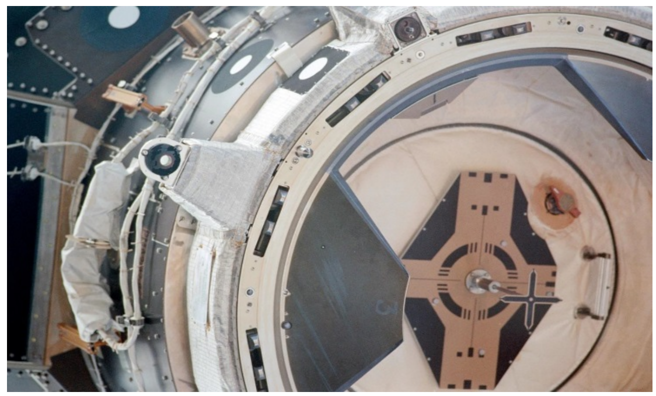
14

14. Now you will need to create a control system to make the crew module maneuverable for docking. Cut four pieces of string about 1 m in length each. Tie the end of the first string to the flexible joint of one of the stanchions. Tie the end of the second string to the flexible joint of the stanchion on the opposite side of the crew module. Tie the ends of the third and fourth strings to these same stanchions, but at the top, near the docking adapter. It may be helpful to tape the two top strings to prevent them from sliding down.

15

15. From the template page, cut out the round top-view docking adapter image. The shape in the middle is a docking target that is mounted to the exterior hatch inside the docking adapter. It aids astronauts in properly aligning the spacecraft for docking. After cutting out the image, place it on the bottom of your second docking adapter with the image facing the opening. Align the petals in the image with the petals on your docking adapter and tape the image into place.

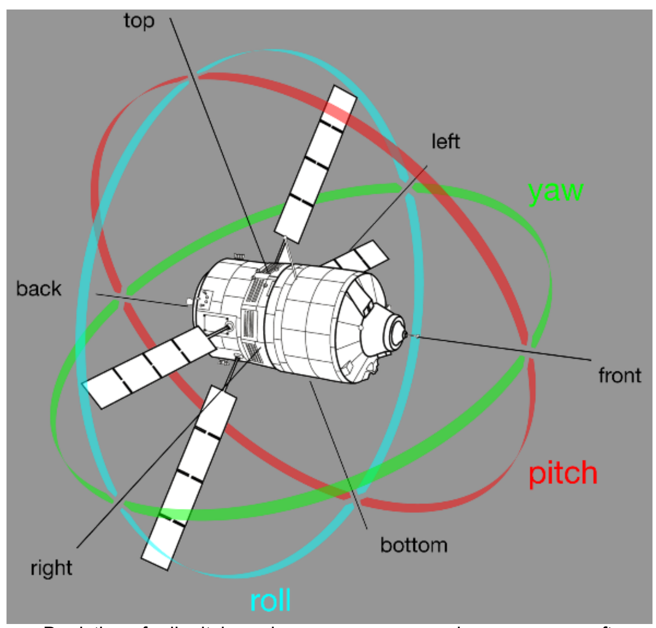
Congratulations! You have completed your crew module scale model as well as a target docking adapter. You are now ready to begin your docking training and missions.



Docking target inside one of the docking adapters aboard the International Space Station.

Plan, Test, and Improve

Now that you have completed your crew module with the docking adapter attached, as well as a second docking adapter with the docking target installed, it is time to learn how to maneuver your crew module and dock with another object. You probably already know that spacecraft can move in three dimensions in the direction of each axis. They can move forward and backward, up and down, and left and right. In order to orient themselves in line with the docking hatch on another craft, they also need to be able to turn on three different axes of rotation. These three turns are called pitch, turning the nose of the craft up or down; yaw, turning the nose of the craft left and right; and roll, spinning the nose of the craft clockwise or counterclockwise. Study these maneuvers in the diagram shown here and picture your crew module moving in the same way.

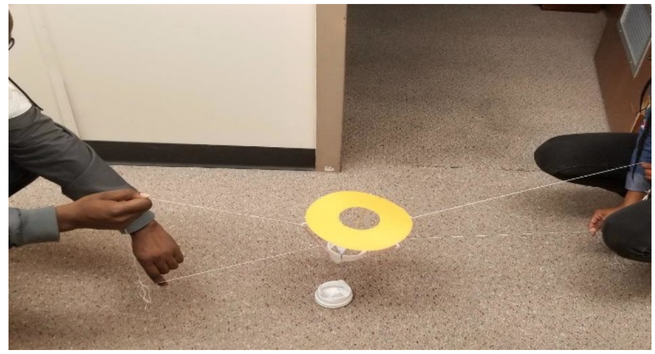


Depiction of roll, pitch, and yaw on an uncrewed cargo spacecraft. (ESA-I/Baroncini)

Docking Simulation

Your crew module is maneuvered by two copilots. Facing each other, each pilot holds two strings on opposite sides of the crew module. The pilots will pull the strings, but not hard enough for them to be pulled loose. A third member of your team will act as the commander and give verbal commands on how to maneuver the crew module into docking position. Your crew module will be successfully "docked" when its docking system petals are interlocked with those on the target docking system. These missions will require teamwork and communication. Good luck!

Training Missions

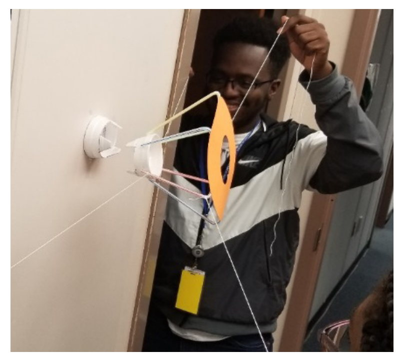


- Copilots practice holding the crew module steady in midair with the nose facing forward, down, and upside down.
- Copilots hold the crew module steady while the commander presses the other docking system onto the crew module so the pilots can feel how much pressure needs to be applied for a successful dock.
- Copilots practice the following 12 maneuvers as given to them by their commander: move up, move down, move left, move right, move forward, move backward, pitch up, pitch down, yaw left, yaw right, roll clockwise, roll counterclockwise.

Rookie Missions

- Place your target docking system facing upward on a flat surface (it may help to tape it down). Copilots maneuver the crew module, following commands from the commander, and successfully dock.
- Using tape, place the target docking system on a wall or other vertical surface. Copilots maneuver the crew module, following commands from the commander, and successfully dock.
- Place your target docking system, facing upward on a flat surface (it may help to tape it down). Copilots with blindfolds maneuver the crew module, following commands from the commander, and successfully dock.

Veteran Missions



- Using tape, place the target docking system on a wall or other vertical surface. Copilots with blindfolds maneuver the crew module, following commands from the commander, and successfully dock.
- Using tape, place the target docking system at an angle on a table corner or other surface. Copilots maneuver the crew module, following commands from the commander, and successfully dock.
- Partner with another team and successfully dock your two crew modules together midair.

Expert Missions

- Using tape, place the target docking system at an angle on a table corner or other surface. Copilots with blindfolds maneuver the crew module, following commands from the commander, and successfully dock.
- Partner with another team and successfully dock your two crew modules together midair with blindfolded copilots.
- Partner with another team. Place the target docking system in various locations in the room and challenge each other to dock with the target, with blindfolded copilots, in the shortest amount of time or with the fewest number of commands given by the commander.

Share

- What was the greatest challenge for your team today?
- Why was it important for your measurements and calculations to be accurate?
- The diameter of the spacecraft's heat shield is 5.03 m. What is the scale of your model?
- Was your team successful when maneuvering your crew module model into the docking port? Why or why not?
- When spacecraft dock, they do not just share a physical airtight seal. There are also electrical and plumbing connections that can be made. What resources could be shared between two docked spacecraft?
- If you were to participate in this activity again, what would you do differently?

Activity Three Templates