National Aeronautics and Space Administration

Propeller Palooza!

A classroom design challenge for students

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Propeller Palooza!

A two-part challenge in which students:

1) design propellers that generate enough thrust to move an air trolley a distance of two meters.

2) test the amount of weight (in the form of pennies) that their air trolleys can carry.

Grades: 5–8

Time: 2 hours

Objectives

Students will understand:

- how to apply the engineering design process.
- the importance of reproducibility and reliability.
- that experimentation often involves non-successful trials and that useful information is learned from these trials.
- that different materials and the shapes and sizes of propellers affect the distance (or amount of thrust) of an aircraft.
- that unbalanced forces cause an object's motion to change.

Main Concepts

- Engineers must make tradeoffs when designing aircraft to overcome weight.
- NASA researchers use the engineering and the scientific design and experimentation processes when creating new aircraft technologies.
- Unbalanced forces are required to change an object's motion.

Education Standards

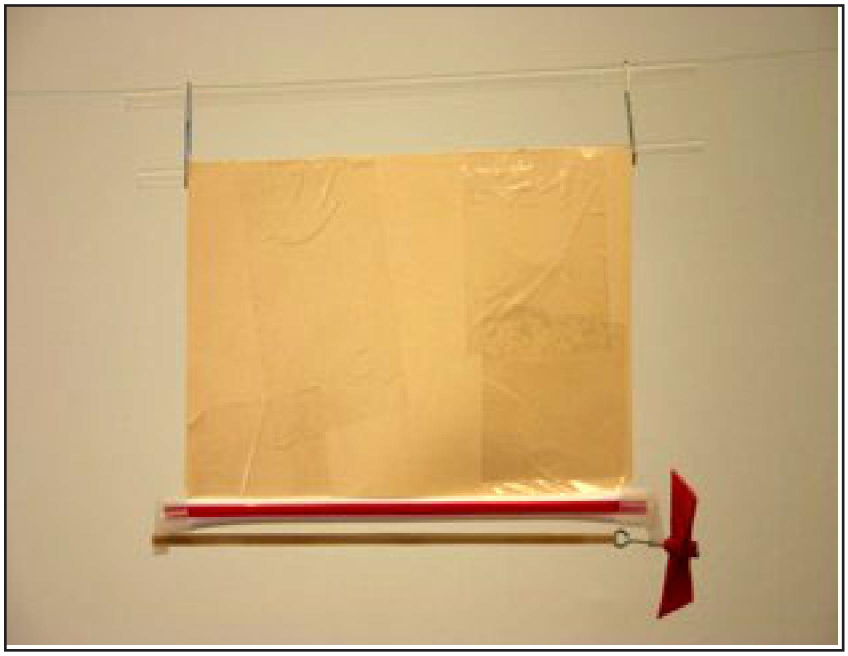
National Science Education Standards	*California Science Content Standards*
Grades 5-8 Science & Technology, Content Standard E • Abilities of Technological Design: a, b, c, d, e • Understanding About Science and Technology: d, e Physical Science, Content Standard B • Motions and Forces: b, c	Grade 5 • Investigation & Experimentation: 6e, 6f, 6g, 6h Grade 6 • Investigation & Experimentation: 6b Grade 7 • Investigation & Experimentation: 7a Grade 8 • Forces: 2a, 2c, 2d, 2e • Investigation & Experimentation: 9a, 9b, 9c, 9e, 9f

~ Materials List ~

- ***Propeller Palooza Mission*** (overhead transparency, p.14)
- ***Weight For Me Mission*** (overhead transparency, p.15)

Each team of 2–3 students will need 1 pre-assembled air trolley using the following materials:

- 2 clear straws (not cocktail style)
- 1 super jumbo straw (milk shake style)
- 1 index card (size 4” x 6”)
- 1 modified rubber-wound propeller assembly (used in Propeller Palooza)
- 1 regular rubber-wound propeller assembly (used in Weight for Me)
- 1 propeller hook
- 1 rubber band (size #64)
- 1 meter stick or meter tape
- 1 pair of scissors
- Clear mailing tape (2” wide)
- 1 brass brad (size 3/4”)
- Various lightweight materials to be used in propeller designs, such as paper, card stock, foam plates or meat trays, balsa wood, tongue depressors, popsicle sticks, tissue paper, etc.



Picture of air trolley built according to the directions on page 4

The above list is adapted from the Full Option Science Systems (FOSS) kit Air Trolley activity in the *Force and Motion* unit. Many of these items can be obtained by ordering them online from Delta Education Refill Center. (http://www.delta-education.com Select “Delta Refill Center,” then search with keywords “Force and Motion.”) Comparable materials from other suppliers may be freely substituted.

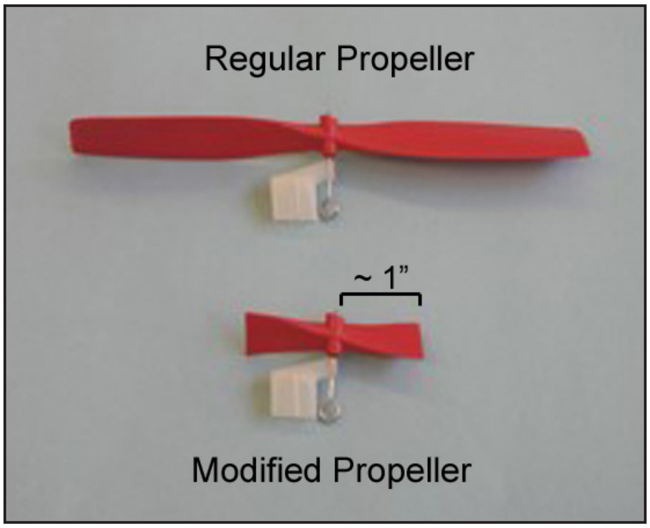
For the Extend activity, each team of 2–3 students will need:

- ***Propeller Design and Evaluation*** sheet (Teams will need multiple copies of this sheet to complete for each design they test).
- ***Final Propeller Design Solution***
- Air trolley materials listed above
- Pennies

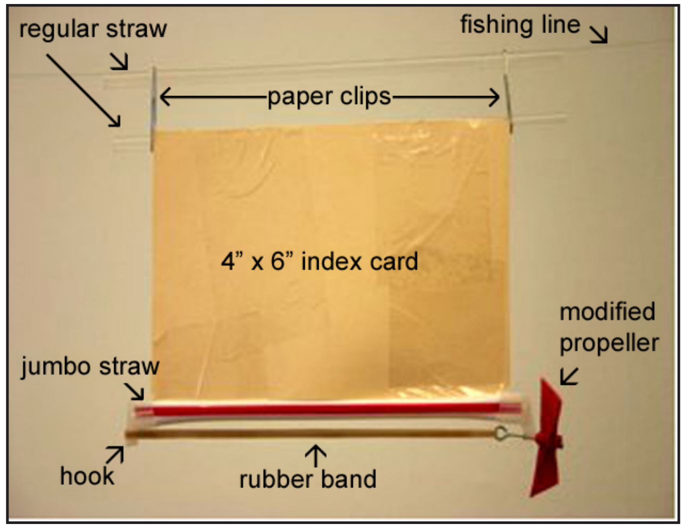
For testing air trolley designs, at least one testing station is needed:

- 1 piece of 10 lb. test fishing line (20 feet long)
- 2 paper clips (about 1” in length)

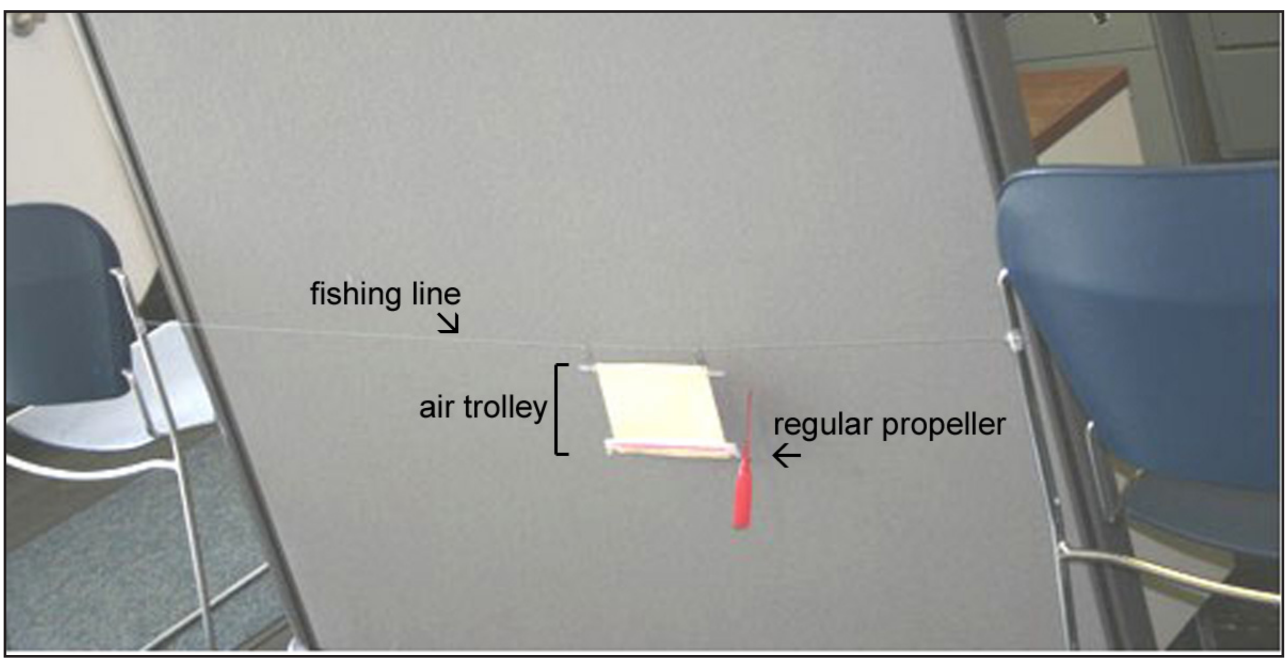
~ Directions for Air Trolley Construction ~



Modified propeller: Use scissors to cut the blades to about 1" in length. Propeller blades must be cut equally on either side of the hub.



Assembled air trolley: The top straw is threaded through a fishing line, and two paperclips are hung from the straw. Threaded through the bottom of these two paper clips is another straw that is attached with tape to a 4" x 6" card. At the bottom of the card is a jumbo straw that has been cut off. At one end of the straw is a *modified* propeller (see left picture), and at the other end of the straw is a plastic hook. A rubber band connects the modified propeller and the hook.



The fishing line is strung between two chairs. (The actual air trolley testing station should have a longer distance between the two chairs.) The air trolley shown has a *regular* propeller used in the ***Weight for Me*** challenge.

Engage

~ The Challenge ~

- Display the ***Propeller Palooza Mission*** overhead transparency. (p.14)
- Set the stage:

Today you and your team will be engineers for NASA. Engineers design solutions to real-life problems. NASA is working on aircraft designs that are more fuel-efficient, meaning they are able to travel further using less fuel.

A propeller is an important part of many aircraft. It rotates to produce a force able to move an airplane forward by deflecting air towards the back of the aircraft. NASA needs your help designing a propeller. Engineers have criteria that they have to meet, which are like rules of a game that must be followed.

Here are your criteria:

- Design a propeller that makes your air trolley move at least 2 meters down the fishing line.
- You must be in a design team of 2 or 3 people.
- Each person must contribute to the team effort.
- Your team may only use the materials provided by the teacher.
- Your team must build and use the air trolley for all experiments.
- Your propeller material should be as light as possible.
- You may only wind your propeller 40 times for each trial.

Explore

~ Mini Lesson ~

During the course of the challenge, allow students freedom to explore, to learn from failure, and to do many tests and iterations. Observe the students' experimental process. If they are testing their designs only once, stop the groups and ask:

- How do you know if your design will always get the same result?
- Do you think it might be helpful to test your designs once or several times? Why?
- Have you thought about what you want to change? *(Encourage students to change one thing at a time so they can see which changes make a difference.)*

Be ready for misconceptions about right and wrong. Students believe that if they solve the challenge once, they have found the "right" solution. After all, this is the case with their homework. If they get the "right" answer, then they do the problem once. Explain to them that in science and engineering there are not "right" and "wrong" solutions. Instead, the focus is on whether an idea is supported by experimental data or on how well a design solves the problem within the criteria and constraints. In engineering, there is no single right solution; rather, there are many possible solutions and solutions can be refined and improved.

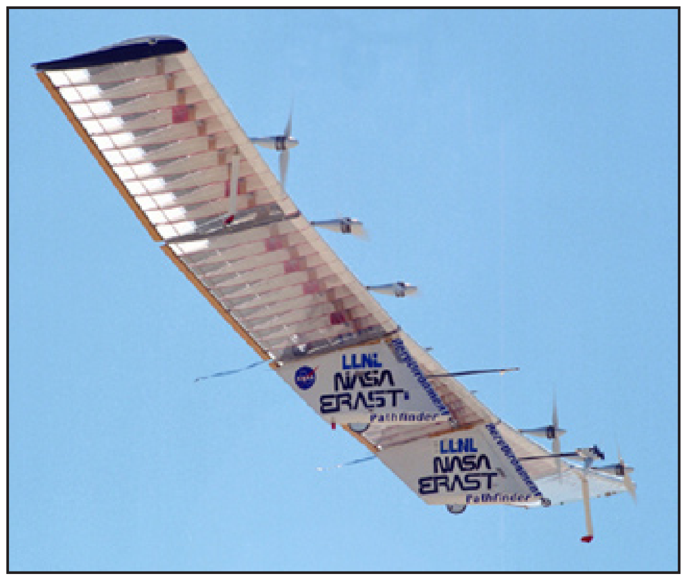
Trials are done multiple times to minimize the chance for experimental error affecting results. Trials are also conducted by many different scientists and engineers, in many locations around the world, to see if the results can be reproduced. These two important concepts, the ability for one group of researchers to get similar results doing the same trial many times and the ability of many groups of scientists and engineers to come up with similar results, are called ***reliability*** and ***reproducibility***.

~ INSPIRATION STATION ~
(optional bonus activity)

An inspiration station is a good way to provide ideas that can spark solutions while still allowing for student creativity. This is especially helpful for students who may lack prior knowledge about aircraft. At an Inspiration Station, you can provide pictures of different aircraft and their propellers. Some of the aircraft could be modern and others older in design. There could be various models of aircraft as well. Avoid using jet aircraft, as the students will not see propellers. (*See sample images on page 7.*)

The following questions can be posted at the station:

- What does a propeller do?
- What shape are these propellers?
- How long are these propellers?
- How wide are these propellers?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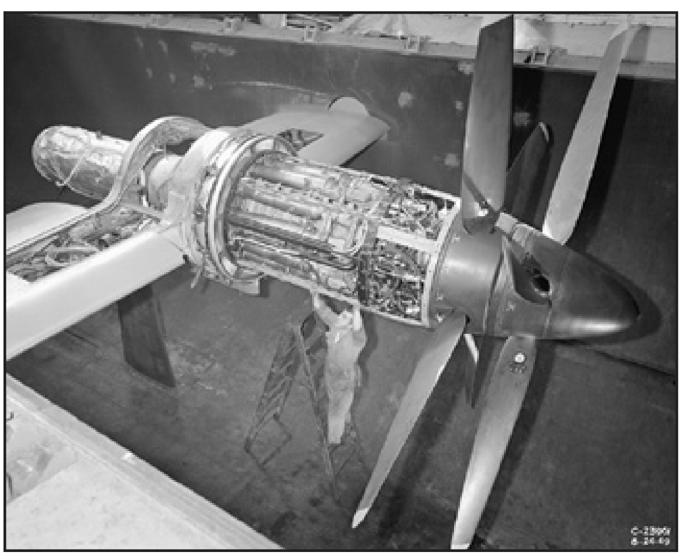

Explain

~ Students share their designs with the class ~

Ask students what materials, shapes, and sizes worked best. During the course of the discussion there are several major topics that should be addressed:

1. Discuss the forces of flight with a main focus on ***thrust*** and ***drag***.

Major concepts

- There are four forces of flight.
- Weight is a measure of the force of Earth's gravity on the mass of an object.
- Thrust is the force that moves an airplane forward generated by the airplane's engines and propellers.
- Drag is a force that resists the forward motion of an airplane such as the resistance of air molecules that are pushed aside as an airplane travels through the air.
- Lift is the upward force that causes an object to fly and is generated primarily by airflow over the wings of an airplane.
- In order for an aircraft to remain in flight, lift must be equal to or greater than weight and thrust must be equal to or greater than drag.

Guidelines for a discussion to help bring out these concepts

An object has many forces acting on it at any given time. Some of these forces act in opposite directions; we call these opposing forces. We often see opposing forces with aircraft. When an aircraft flies, it has forces pushing down on it, pushing up on it, pushing it backwards, and pushing it forwards all at the same time!

- With your air trolleys, you have been playing with the forward motion of the air trolley. What was pushing your trolley forward? *(The propeller.)* We call this forward force ***thrust***.
- What does an air trolley have to move through when it moves forward? *(Air)* In what direction does your hand get pushed when you hold it out the window of a car and feel the air pushing against it? *(Backwards)* We call this backward force ***drag***.
- In order for your air trolley to move forward, how did thrust compare to drag? *(Thrust had to be greater than drag).*
- In order for an object to change its motion, there has to be an imbalance between forces.
- In designing your propellers, you have been working on solutions that ***maximize thrust*** while ***minimizing drag***.
- There are two other forces on an aircraft. What is pulling the aircraft down to the ground? *(Weight)* ***Weight*** is the measure of the force of gravity on the mass of an airplane.

- Did you change the weight of your aircraft? Do you think this makes a difference in how far your air trolley can travel? *(Yes. Some propeller designs are lighter than others, and lighter designs can help if the propeller size and rigidity are not decreased.)*
- What direction is the opposite of weight? *(up)* What must an airplane do to fly? *(It must overcome weight.)* This upward force is called ***lift***.
- Our air trolleys do not generate lift, but when we go to the museum we will learn more about this force and we will work with it in our final design challenge.

2. Discuss the importance of ***materials*** in aircraft design.

Major concepts

- There are a wide variety of materials that can be used.
- While the lightest materials would probably be the most fuel-efficient, they do not always give enough thrust because strong, rigid materials are necessary for a propeller to effectively generate thrust.
- NASA and other Materials Science engineers use chemistry to develop many new materials that are very lightweight and yet strong for aircraft and spacecraft.

Guidelines for a discussion to help bring out these concepts:

- What materials did you find worked best? Why do you think that is? *(Card stock or foam materials are likely to work best because they are rigid yet lightweight.)*
- Materials are very important in aircraft and spacecraft design. This is an important area in which NASA engineers work. They design and test new materials that are lightweight yet strong. In fact, NASA engineers are even working on new materials that can heal themselves when an aircraft is hit with an object in the air! They do this by determining the temperature of an object when it hits an aircraft and then designing a material that can melt at that temperature.
- These engineers study something called Materials Science or Engineering, which involves a lot of chemistry.

3. Discuss the ***engineering process***.

Major concepts

- Engineers start with a set of parameters *or criteria* they must meet. NASA engineers are currently working on designing aircraft and spacecraft that are more fuel-efficient.
- There is no “right” order to this process. Some engineers start by drawing or conducting research, others begin by brainstorming, and others make small models. Many tests and changes are made before a final design is completed.
- Failure is very important to the engineering process. Often we learn more from failure than from success. It is important that we learn what does not work during the modeling process so that the design is improved before a full-sized design is built.

Guidelines for a discussion to help bring out these concepts:

- In doing this design challenge, you have been engineers. Just like NASA scientists, you started with a problem to solve and *criteria* (or rules) that you had to follow.
- How did you get started? How did you come up with ideas for possible solutions? *(Like real engineers, different teams may have used different methods. Some may have started brainstorming. Some may have gone to the Inspiration Station or to the Internet for ideas. Some may have drawn a design, and some may have begun building right away.)*
- How many of you built more than one design? Why? *(Most should have tested multiple materials, shapes, and sizes until they found the best solution.)* Testing and refining many designs is very important to engineering.
- How many of you found a successful solution with your very first design? *(Very few should have had success on their first try.)* Congratulations! You are true engineers if you were not afraid to fail and if you learned from your failures. In engineering, we celebrate failure. Failure teaches us what does not work.
- Why do you think it might be important to learn all the things that do not work with our models rather than after we build the real aircraft that people are going to fly in? *(People's lives could be endangered.)*
- Two of the most famous aeronautical engineers were a pair of brothers, Wilbur and Orville Wright. Their design challenge was to build a powered airplane capable of controlled flight with a person on board. They started off with non-powered gliders, and their designs were not always successful! They built and tested gliders every year between 1900 and 1902 and each time learned something new when their glider did not work the way they expected. It was not until 1903 that the Wright brothers were successful in building and flying a powered machine that went down in history as the first airplane.

Extend / Apply

1. Display the ***Weight For Me Mission*** overhead transparency. (p.15)

   Now that you and your partner have completed the Propeller Palooza Mission, NASA needs your help designing another air trolley. Here are your criteria:

   - Design an air trolley that carries the maximum number of passengers (pennies) 3 meters down the fishing line.
   - You must be in a design team of 2 or 3 people.
   - Each person must contribute to the team effort.
   - Your team must build and use the air trolley for all experiments.
   - Your team may only use the materials provided by the teacher.
   - You may only use the propeller given to you by your teacher to power the trolley.
   - You may only wind the rubber band 60 times for each trial.

   Note: You might allow students to be creative in how they attach the pennies to their air trolley. Tape is the most obvious solution. However, in testing, our high school interns came up with a very clever method that allowed them to easily add, subtract, and change the location of pennies without tearing the air trolley. They wrapped clear packing tape around the air trolley so that the sticky side was facing out.

2. Have students share solutions applying the four forces.

   - How many pennies were you able to move 3 meters?
   - Did it matter where you placed the pennies? *(Students may see better results when pennies are balanced and closer to the center of the air trolley.)*
   - What force moves your trolley forward? *(thrust)*
   - How is ***thrust*** produced by your trolley? *(The turning propeller produces thrust.)*
   - Did you change the ***weight*** of your aircraft?
   - Do you think this makes a difference in how far your air trolley can travel? *(Yes. The more passengers there are, the more weight the trolley has and the more friction there will be between the trolley and the fishing line. This is a form of drag, so the trolley travels less distance.)*
   - The fourth force, ***lift***, is the opposite of weight. Our air trolleys do not generate lift, so it is the fishing line that holds the trolley up. In real aircraft design, lift is the primary force used to overcome weight. When we go to the museum we will learn more about lift, drag, and thrust, which will help us in our final design challenge.

3. You may want to have teams study all of the Propeller Palooza propeller designs done in the class and then decide on the best design. The final design may take ideas from multiple designs. Students/teams should complete a Propeller Design and Evaluation Sheet for each design they test. They should then complete the Final Propeller Design sheet, providing written justification why their design should be funded for further research and explaining the process they used to determine this. They might present their solutions to the class as well.

> **Note**: Students may use propeller design ideas from other teams. This is *okay* and should be encouraged. Many engineers take ideas from other engineers—often modifying them and improving them, which results in improved designs and new innovations.

4. Students may test whether there is a relationship between surface area of a propeller and the distance traveled.

> **Note**: If students do this experiment, they should use the same material and the same number of propeller turns for all propeller designs so that *shape* is the only variable being altered. Younger students can use graph paper and count squares to determine surface area.

5. Students can research careers in Materials Science, Aeronautical Engineering, Aeronautics, and Aviation.

Evaluate

~ Assessment ~

- Students' oral presentations of their designs and how the forces apply to their designs.
- Completion of the ***Propeller Design and Evaluation*** sheet, the ***Final Propeller Design Solution*** sheet, and presentation of these recommendations.
- Students' use of the engineering process as they work on the problem.

Dryden Flight Research Center EC80-13848 Photographed 1980
XV-15 Tilt Rotor

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: EC86-33555-2 Date: 1986 Photo by: NASA

X-Wing Research Vehicle

Resources

- NASA Engineering Design Challenges, Centennial of Flight, Propeller Design Challenge, http://edc.nasa.gov/docs/PROPELLER.pdf, pages 44-46.
- Full Option Science System (FOSS), Force and Motion Science kit, Air Trolley, Reagents of the University of California. Lawrence Hall of Science, www.lhsfoss.org/fossweb/worksheets/protected/6-8/ForceNMotionLabNtbk.pdf
- Future Flight Design, NASA, Career Fact Sheets, http://futureflight.arc.nasa.gov/cfs.html
- Astro Venture, NASA, Career Fact Sheets and Trading Cards http://astroventure.arc.nasa.gov
- Virtual Skies, NASA, each section has career information, http://virtualskies.arc.nasa.gov/vsmenu/vsmenu.html
- NASA Quest, a great resource for careers and further technical information related to the lessons, http://quest.nasa.gov

Propeller Palooza Mission

NASA PROBLEM

NASA is working to improve aircraft design so that future aircraft can fly further with less fuel. NASA needs your help to design a better propeller.

YOUR CHALLENGE

Your mission is to build a propeller with the best shape, size, and material to make an air trolley move the farthest. Design a propeller that can move an air trolley at least 2 meters using only 40 turns.

YOUR CRITERIA

- Design a propeller that makes your air trolley move at least 2 meters down the fishing line.
- You must be in a design team of 2 or 3 people.
- Each person must contribute to the team effort.
- You may only use the materials provided by the teacher.
- Your team must build and use the air trolley for all experiments.
- Your propeller material should be as light as possible.
- You may only wind your propeller 40 times for each trial.

Weight For Me Mission

NASA PROBLEM

NASA is working to improve aircraft design so that future aircraft can fly further carrying more passengers or cargo while using less fuel. NASA needs your help to design a better aircraft.

YOUR CHALLENGE

Your mission is to build an air trolley that can carry as many pennies (passengers) as possible. Design an air trolley that can carry the greatest number of pennies at least 3 meters down the fishing line using only 60 turns of the propeller.

YOUR CRITERIA

- Design an air trolley that can carry the most pennies for at least 3 meters down the fishing line.
- You must be in a design team of 2 or 3 people.
- Each person must contribute to the team effort.
- You may only use the materials provided by the teacher.
- Your team must build and use the air trolley for all experiments.
- You may only use the propeller given to you by your teacher to power the trolley.
- You may only wind the propeller 60 times for each trial.

Propeller Design and Evaluation

Team Name: ______________________________ Date: ________________

Team Members: ____

____

1. Sketch a front view of the propeller.

2. Test your design and record the results in the table. *(Only 40 turns of the propeller!)*

Trials	**Distance (cm)**
Test 1	
Test 2	
Test 3	
Total combined distance of all 3 trials:	
Average distance of the 3 trials (÷ by 3):	

3. What have you learned from this test that will help you design the next version?

Final Propeller Design Solution

Team Name: ______________________________ Date: ________________

Team Members: ____

____

1. Sketch a front view of the propeller you recommend for future research.

2. Why should this propeller be researched further? What makes it the best design?

3. How did you determine that this was the best design? What process did you use?

4. How did you make sure that your results are reliable and reproducible?