National Aeronautics and
Space Administration

Wingin' It

Educator Notes

Learning Objectives

Students will

- Describe and explain how material structure and shape, weight, and weight distribution impact a paper airplane's performance.
- Design and conduct a structured inquiry into the design of a paper airplane.
- Compare and contrast different paper airplane designs to create a justification for why one plane flies farther than the others.

Investigation Overview

Students will learn that engineers at NASA must consider various factors when designing the next generation of sustainable aircraft. Student teams will explore the impact of aircraft design on flight distance by testing designs of paper airplanes. Students will continue their investigation by testing the effect of adding weight, as well as the distribution of that weight, on the flight distance of their paper airplanes.

Note: Some 5th and 6th grade students may need assistance with parts of this activity, while some advanced 8th graders will need more of a challenge. Modify as necessary based on student needs.

Safety

Remind students to practice laboratory safety:

- Wear eye protection at all times during paper airplane flight testing for your group and other groups working nearby.
- Be aware of those passing through or near your designated paper airplane test area.
- Paper airplanes should never be thrown at others. When conducting flight tests, be sure the pathway is clear.
- Be aware of your surroundings and move carefully throughout the room when viewing other teams' work.

Investigation Preparation

- Read the Educator Notes and the Student Handout to become familiar with the activity.
- Read the NASA Context sheet at the end of the Educator Notes for helpful background information about NASA's current aviation work.
- Have videos preloaded for presentation.
- Make copies of the Student Handout (one per team).

Grades 5 to 8

Suggested Pacing

120 to 180 minutes or 2 to 3 class sessions (divided by phases)

Materials

- ☐ Writing utensils
- ☐ Paper
- ☐ Meterstick or measuring wheel
- ☐ Paper clips, pennies, or other materials used to weigh down paper airplane
- ☐ Ruler
- ☐ Lightweight tape (e.g., clear tape)
- ☐ Eye protection
- ☐ Craft sticks, straws, stir sticks, skewers, chenille stems, or other available materials to create support structures for redesigned wing
- ☐ Scale (optional)
- ☐ Protractor (optional)

National STEM Standards

- MS-PS2-5 and MS-PS2-4
- MS-ETS1-3
- NGSS Science and Engineering, Practice 3
- CCSS.MATH.CONTENT.8.SP.A.1

Illustration of NASA's all-electric X–57 aircraft. (NASA Langley/Advanced Concepts Lab, AMA, Inc.)

- Identify a safe place where students can test their paper airplane designs. Premark the testing area at 100-cm increments; a measured range from 1,000 cm (10 m) to 2,500 cm (25 m) is recommended.
- Have students research paper airplanes online to become familiar with different styles, different classifications, and what to expect from different designs.
- Consider having each student or team use a different color of paper.

Introduce the Investigation

- Explain to students that NASA's aviation research includes the design, build, and flight of experimental aircraft, which are often referred to as "X-planes." These X-planes will push the limits of what is technologically possible, and a major recent focus has been to help make aviation more Earth friendly.
- Show the video "Accelerating to New Aviation Horizons," available at https://youtu.be/Yfr6WDFN7d0.
- Demonstrate how to make and fly a paper airplane:
  - Step 1: Fold a sheet of 8.5 x 11 in. paper in half lengthwise.
  - Step 2: Fold each half in half again, toward the outside of the paper.
  - Step 3: Have students predict if the plane will fly and, if so, how well it will fly.
  - Step 4: Fly the paper airplane.

Facilitate the Investigation

? Meet the Problem

- Keep the demonstration plane displayed for students.
- Organize students into pairs or groups of three to discuss their initial observations.
  - Did the paper aircraft fly as predicted?
  - How well did the plane fly?
  - Why did the paper plane fly the way it did?
  - Do you have any assumptions about why the paper plane performed or flew the way it did?
  - How is the shape of the paper plane similar to or different than real planes?
  - What improvements could be made so that the plane flies better?
- Have students use the following websites to research the advantages of electric propulsion. Students can work individually or in small groups, or they can jigsaw.
  - NASA LEAPTech: Distributed Electrical Propulsion. https://youtu.be/hhL2-Lykl9s
  - Electric Propulsion Technologies. https://www.nasa.gov/feature/electric-propulsion-technologies
  - Benefits. https://www1.grc.nasa.gov/aeronautics/eap/eap-overview/benefits-2/
- Have students discuss what they have learned.

Explore Knowns and Unknowns

- During Phase 1, students will test three paper airplane designs to determine which will fly the farthest.
- Determine if students will work individually or in small teams of two or three. Small teams are recommended; however, some students may work better independently.
- Students can take turns flying, measuring, and recording data.

Phase 1: Overall Design

- Students should plan on designing their paper airplanes for maximum distance. Students can refer to the provided step-by-step instructions for building different types of paper airplanes, or they can choose to build their own. Make sure students do not choose a design that is too difficult to fold. Consider limiting design choices to minimize building time and any frustration students may experience in this phase.
- Have students follow these steps to construct and test their paper airplanes:
  - Step 1: Choose three different paper airplane designs. Directions for five different designs are available at the back of this guide, but you are welcome to use other designs if you would prefer.
  - Step 2: Predict which design will fly farthest and which will fly the shortest distance.
  - Step 3: Make the three different paper airplane designs you have chosen. Be sure to use the same type of paper for all three.
  - Step 4: For each paper plane design, do three test flights. Measure and record each distance to the nearest whole centimeter in a table (see the Distance Traveled Table). Distance is calculated from the point on the floor where the plane left the pilot's hand to where it first touches the ground. Students may need a team member on the flight line to mark where the plane lands. Remind students to launch in the same way for each trial, using the same force and direction.

Distance Traveled Table (Example)

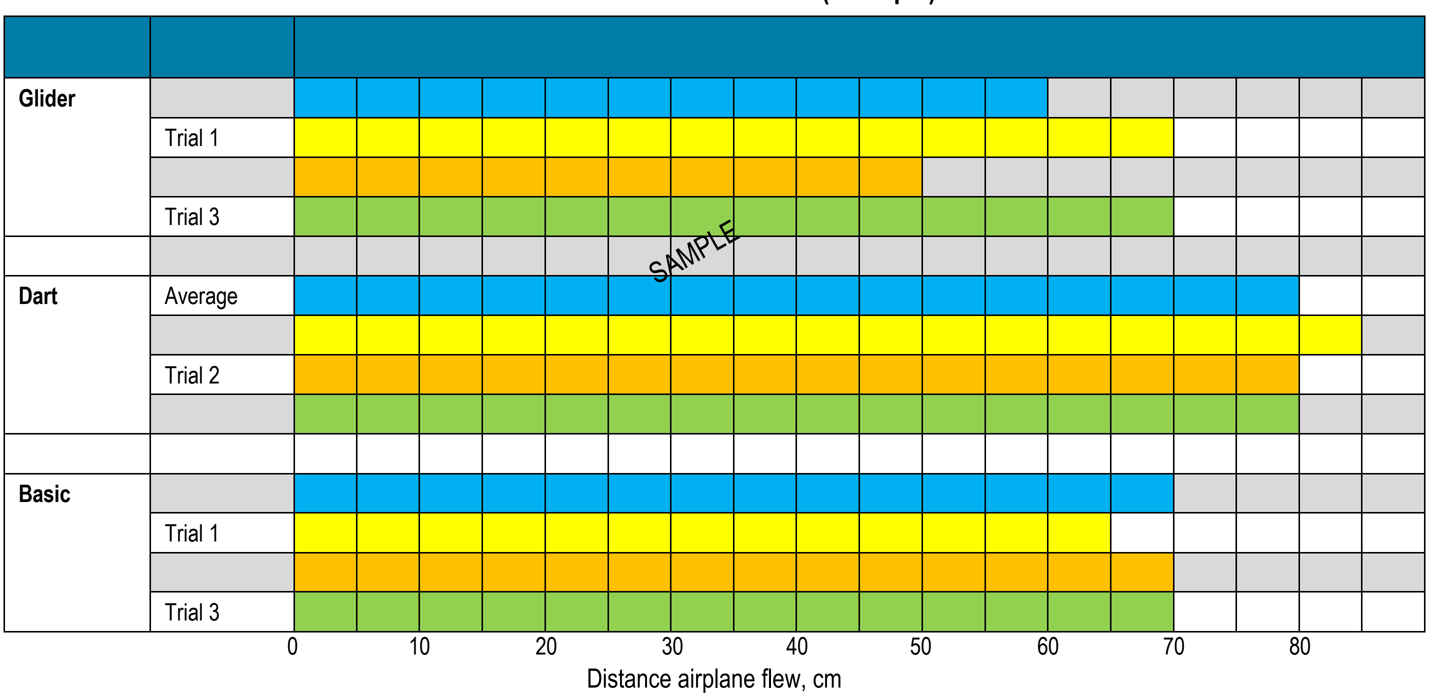
Aircraft name	Distance traveled, cm			Total of all three trials	÷	Number of trials	=	Average distance traveled (rounded to nearest cm)
	Trial 1	Trial 2	Trial 3					
Glider	77	57	62	196	÷	3	=	65
Dart	84	80	81	245	÷	3	=	82
Basic	66	69	72	207	÷	3	=	69

  - Step 5: For each paper plane design, calculate the average distance traveled across the three trials (in whole centimeters).

$$\text{Average} = \frac{\text{Distance 1} + \text{Distance 2} + \text{Distance 3}}{\text{3 (number of trials)}}$$

  - Step 6: Graph the results of the three trials and the average for each paper airplane. A bar chart is recommended. See the sample below.

Distance Traveled Bar Chart (Example)



- After the trials have been completed and the data calculated, have students answer the following questions:
  - Was your prediction correct?
  - What characteristics contributed to the success of the plane that flew the farthest?
  - How could you improve the plane that flew the shortest distance?

Phase 2: Weight and Weight Distribution

- In this phase of the activity, students will learn about the effect of weight and weight distribution on the flight of one of their paper airplanes.
- Have students read the following website article, then lead a discussion on the pros and cons of battery usage and electric aircraft.
  - Electric Airplanes (Batteries Included). https://climate.nasa.gov/news/2482/electric-airplanes-batteries-included/
- Have students follow these steps to add weight and test their paper airplanes:
  - Step 1: Choose one of the three designs used in Phase 1. Explain which design you chose and why.
  - Step 2: Choose an object (e.g., pennies, paper clips, or other materials of similar size) that you can attach to the plane as a standard unit of weight. Paper clips are easy to attach but do not weigh much. Pennies weigh more, which means that you will not need many, but you may need to attach them with tape.
  - Step 3: Create a table to record the number of items added versus the distance traveled. A sample table is provided here.

Distance Traveled With Added Weight (Example)

Total items added	Distance traveled, cm			Total trials	÷	Number of trials	=	Average distance traveled (round to nearest cm)
	Trial 1	Trial 2	Trial 3					
0	85	86	90	261	÷	3	=	87
5	95	97	103	295	÷	3	=	98
10	90	92	92	274	÷	3	=	91
15	80	82	79	241	÷	3	=	80

SAMPLE

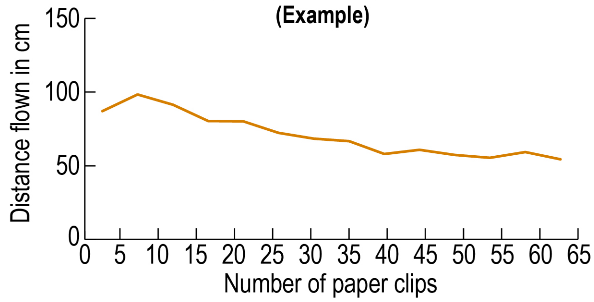
  - Step 4: Create a Qualitative Data section in your notes (observations not related to numbers). In this section, you will record where you placed the weight on the paper airplane and make observations about how the placement (distribution) of the weight affects the airplane's overall performance. You may also draw pictures or add photos to the Qualitative Data section.
  - Step 5: Fly the plane with no weight attached (i.e., zero items added). Measure and record the distance, to the nearest whole centimeter, for the flight of each of the three trials.
  - Step 6: Add weight to the plane in consistent increments. The lighter the item, the more you will need to add at a time (e.g., one penny at a time, five paper clips at a time). After each addition, fly the plane and then measure and record the distance of the flight for three trials. Continue to add weight to the plane until the plane no longer flies but drops to the ground like a ball being thrown.
  - Step 7: Average the trials using the formula shown below, and then graph your data.

$$\text{Average} = \frac{\text{Distance 1} + \text{Distance 2} + \text{Distance 3}}{\text{3 (number of trials)}}$$

The graph will be a scatter plot or line graph (see the example at right) that you will make in your notebook or on a computer.

  - Step 8 (optional): If you still have time, pick a medium amount of weight that successfully flew already. Experiment with the distribution of the weight by placing that specific number of items in different places on the paper airplane (e.g., all in the front, all in the back, or spread evenly everywhere). Use the Qualitative Data section in your notes to record where you added weight. Also record any of your

Weight Versus Average Distance (Example)

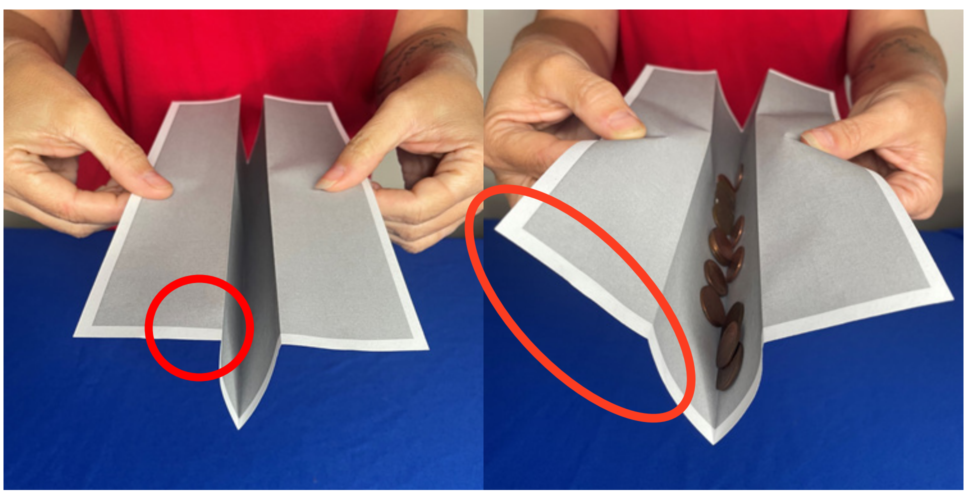


observations about how the placement (distribution) of the weight affected the airplane's overall performance. Feel free to draw a picture or take photos.

- After the trials have been completed and the data calculated, have students answer the following questions:
  - Did the plane's distance increase or decrease the first time weight was added? Why?
  - Did the plane's distance continue to change consistently throughout the activity? If so, why?
  - Did the distribution of weight have any impact on how the plane flew? If so, why?
  - Why are seats on a commercial airplane distributed the full length of the fuselage (or body) of an airplane rather than all in the front or the back?
  - Why do some airlines charge you for each piece of luggage you bring on the plane?

Phase 3: Structural Integrity

- In this phase, students will be looking at the structure of their plane. Students will not be flying this paper airplane, but they will be looking at wing design and how well the structure of the material can handle the weight. Students will add structural support materials (e.g., craft sticks, stir sticks, or cardboard) to the wings or fuselage to support the added weight. Students will be changing the structural design to simulate different material properties.
- Share the following videos with students and tell them that they should be prepared to discuss the importance and benefits of stable wings, composite materials, and thermoplastic tape.
  - X–56: The Future of Flight—Part 1: Active Controls. Watch from time stamp 0 to 3:36. https://youtu.be/igR1_grUQyI
  - NASA | Advanced Thermoplastic Tape and Composites Processing Method. https://youtu.be/U0hFnkrDjy4 (1:28 min.)
- Have students follow these steps:
  - Step 1: Choose one airplane design from the three designs in Phase 1. Remake it if needed.
  - Step 2: Hold the airplane by the edges of its wings throughout this phase, as demonstrated in the example below. Add a few weights at a time, observing the "droop" or sag in the wings. The droop is best described as "where the angle of the wing meets the fuselage" (the body of the plane).



    - Note that when weight is added to the fuselage, the angle between the wing and the fuselage is no longer a 90° angle. The properties of the material being used are unable to support the weight, and the plane is not able to keep its form.
  - Step 3: Choose an amount of weight for the paper airplane to hold in the fuselage and place the weight in the following areas, making observations of the droop after each placement: toward the front, spread out evenly, then toward the back.
  - Step 4: Document your observations in the Qualitative Data section of your student notebook, describing the number/type of weights or total weight added and the resulting droop or sag in the wings. An example table is provided below. For this step, record your observations in the Original Design column. The Improved Design column will be used in Step 7.

Qualitative Observations Table (Example)

Number/type of weight *or* Weight added, g	Qualitative observations (e.g., description of droop)	
	Original design	Improved design
2 pennies (5 g)	No noticeable droop	Definitely no droop at all
5 pennies (12.5 g)	Slight droop, definitely noticeable	About half as much droop as originally

- Step 5: Brainstorm ideas on how to secure and stabilize the wing where it meets the fuselage using common materials (e.g., craft sticks, straws, stir sticks, skewers, chenille stems).
- Step 6: Make the improvements to your plane. Keep in mind the results from the earlier weight tests so that the plane does not become too heavy.
- Step 7: Repeat the testing from Steps 3 and 4 using your improved design. Make sure to document the results just as before, using the Improved Design column of your Qualitative Observations Table.

- Have students answer the following questions:
  - Why did the paper airplane start to lose its shape when weight was added to the fuselage?
  - What happened to the structure of the plane when you added support materials (since you could not change the properties of the paper)?
- Refer back to the example photo. Note that when weight is added to the fuselage, the angle between the wing and the fuselage is no longer 90°. The properties of the material being used are unable to support the weight, and the plane is not able to keep its form. If the same design was made from sheet metal instead of paper, it could support the pennies without droop, but it would be far too heavy to fly.

Generate Possible Solutions

- Teams will select one paper airplane from Phase 1 to redesign or modify so that it flies farther than it did in Phase 1. Have student teams follow these steps to generate possible solutions:
  - Step 1: Select one paper airplane from Phase 1 to redesign or modify to fly farther than it did in Phase 1.
  - Step 2: Reflect on your data from Phases 1 to 3 and brainstorm what it would take to make a paper airplane fly better than it did originally. You may use the NASA resources in this activity or the NASA.gov website to help you come up with ideas.
  - Step 3: Sketch or write out the changes you want to make and the reason for the changes.
  - Step 4: Write a justification for each of the proposed changes based on your data and/or NASA resources.
  - Step 5: Make a prediction for how much farther the improved plane will fly than before.

Consider Consequences

- Have student teams follow through on their proposed solutions and then determine if their predictions were accurate.
  - Step 1: Make the paper airplane design you chose from Phase 1.
  - Step 2: Apply the proposed modifications.
  - Step 3: Fly the paper airplane to see if it flies as predicted. Make minor adjustments as needed and then retest. As before, test by flying 3 times, taking measurements to the nearest centimeter and recording them after each trial.

Distance Traveled by Student-Designed Airplane

Aircraft name	Distance traveled, cm			Total of all three trials	÷	Number of trials	=	Average distance traveled, cm
	Trial 1	Trial 2	Trial 3					
					÷	3	=	

  - Step 4: Calculate the average distance flown across the three trials.
  - Step 5: Compare with the Phase 1 results for the original plane to see if the distance has improved. Determine whether the prediction was accurate. Be prepared to present all materials.

Present Findings

Have students

- Present charts, discuss the qualitative data, and talk about their newly designed plane.
- Defend why they made the changes they did and discuss whether or not the changes worked.
- Explain the strengths and weaknesses of the design.
- Post their work for other teams to see.

Assessment

Problem-Based Learning Step	Novice (0)	Apprentice (1)	Journeyperson (2)	Expert (3)	Level of student knowledge (Score)
Meet the problem	Student does not identify the problem	Student incorrectly identifies the problem	Student identifies part of the problem	Student fully and correctly identifies the problem	
Explore knowns and unknowns	Student does not identify knowns and unknowns	Student incompletely identifies knowns and unknowns	Student identifies knowns and unknowns using experience but uses no resources	Student completely identifies knowns and unknowns using experience and resources	
Generate possible solutions	Student does not brainstorm	Student generates one possible solution	Student provides two solutions	Student provides three or more possible solutions	
Consider consequences	Student does not identify any consequences	Student determines inaccurate or irrelevant consequences	Student identifies consequences accurately	Student identifies consequences accurately and provides a rationale	
Present findings	Student does not communicate results	Student shares random results	Student shares organized results, but results are incomplete	Student shares detailed, organized results with group	
				Total	

Reference

Aeronautics Activity F–16 Falcon Paper Airplane.
https://www.nasa.gov/sites/default/files/atoms/files/aero_teacher_activity_guide_printable.docx

Extensions

- Students can challenge family members to an airplane-making contest. Encourage students to share results, data, and pictures with the other students.
- Protractors can be used in Phase 3 to measure the “droop” or angle where the wing and fuselage meet.
- Students can design their own X-planes. https://www.nasa.gov/sites/default/files/atoms/files/design-your-own-x-plane-v4.pdf
- Students can look up other composite materials that NASA is researching.

- Have students provide suggestions for NASA subject matter experts on how to accomplish sustainable aviation with a strong but light aircraft. Students can
  - Sketch a design of the aircraft.
  - Provide details or suggestions on how to make the aircraft light.
  - Redesign parts for better performance.
  - Redesign for maximum weight distribution.
- Include any other thoughts or suggestions to improve the performance.

Resources

NASA Aeronautics | Earth Day 2021. https://youtu.be/Tb2j_Ndhq-8

The Future of Fixed Wing Aircraft (Watch excerpts: 2:24 to 6:13 and 10:09 to 15:12). https://youtu.be/24EFpyv13aw

X–57 Maxwell. https://www.nasa.gov/specials/X57/

Efficient Air Transportation Systems. https://www.nasa.gov/feature/efficient-air-transportation-systems

NASA Aims for Climate-Friendly Aviation. https://www.nasa.gov/aeroresearch/nasa-aims-for-climate-friendly-aviation

NASA Context

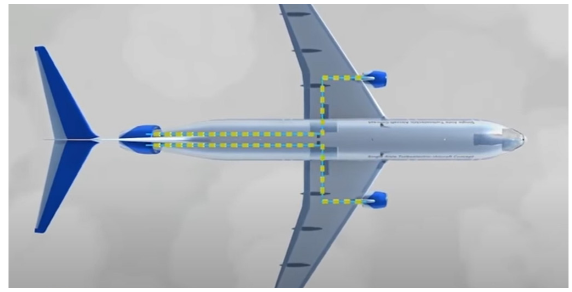
Over the next 10 years, NASA will demonstrate

- The first-ever high-power hybrid-electric propulsion systems for large transport aircraft
- Ultra-high-efficiency long and slender aircraft wings
- New large-scale manufacturing techniques of composite materials
- Advanced engine technologies based on breakthrough NASA innovations

Hybrid–Electric Propulsion

We have electric cars, so why don't we have electric aircraft yet?

Weight. Although a lighter car can have a longer range than a heavier car, weight is less of a concern for cars because ground vehicles do not have to fight against gravity. The heavier an aircraft is, the more power it requires for flight. One of the many goals of any aircraft design is to keep weight to a minimum. The lighter an aircraft is, the less fuel it requires for flight and the more payload it can carry.



NASA Glenn Research Center's research in electrified aircraft propulsion offers new possibilities for reducing fuel and energy usage.

Heat. In current power systems, 20 percent of energy is dissipated as excess heat that must be cooled.

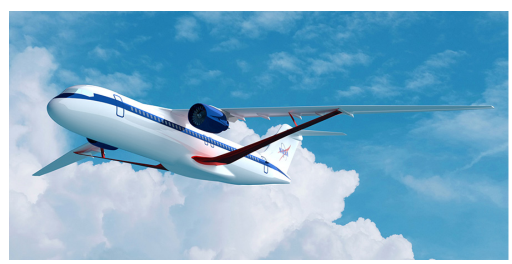
A single-aisle size electric aircraft made with the technologies currently available would ultimately be too heavy to fly and would require extra weight and energy to cool its components. Simply put, the plane would be inefficient. NASA is developing new technologies, including motors, converters, circuit breakers, batteries, and cooling systems to keep components cooled while minimizing weight and heat loss.

NASA is leading the evolution to maturity of hybrid–electric propulsion for aircraft—a game-changing development that will reset how aviation is powered. Hybrid–electric propulsion is an exciting development area that uses either fuel-fed engines, electrically driven fans, or a combination of both systems to propel the aircraft during various phases of flight. Think of a flying hybrid car.

A focus on electrified aircraft propulsion contributes to NASA's ambitious flight research goals. Several laboratories have already been converted to help explore the machines, drives, and subsystems needed for large-scale electric, hybrid–electric, and turboelectric propulsion.

Transonic Truss-Braced Wing

NASA is ground testing a promising revolutionary transonic truss-braced wing (TTBW) configuration that will achieve much higher levels of aerodynamic efficiency than possible with today's aircraft.



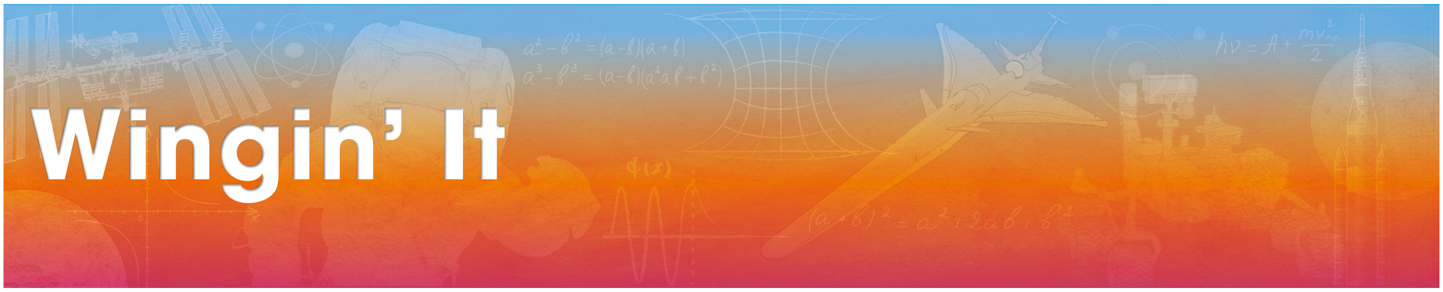
Transonic truss-braced wings can help reduce fuel consumption by up to 10 percent. (NASA)

Adding trusses to the wings helps support the wings, allowing them to be longer than conventional wings. This helps reduce drag, meaning that the plane burns less fuel while flying. Historically, swept-back wings increase the stability of the plane. They also reduce turbulence when flying at different speeds and can be made thin to reduce friction from airflow over the wings. https://youtu.be/Wqh_ihyKpQY

Advanced Composites Manufacturing Technologies

Engineers are also developing advanced composite materials and advanced engine technologies based on breakthrough NASA innovations. Many external airplane components are constructed of metal alloys, although composites made of materials such as carbon fiber and a variety of fiberglass resins are becoming more popular as technology improves. NASA's new techniques for large-scale manufacturing of composite materials will revolutionize the future of aviation!

Innovative technologies will turn NASA's vision of efficient flight from science fiction to reality. (NASA)



Wingin' It

Student Handout

Your Investigation

You will work in teams to explore how material structure and shape, weight, and weight distribution impact a paper airplane's performance. You will begin by exploring the impact of aircraft design on flight distance by testing designs of paper airplanes. You will continue your investigation by testing the effect of weight and weight distribution on the flight distance of your paper airplane. To conclude your investigation, you will observe the importance of material properties in sustainable aviation.

Meet the Problem

- Observe the paper airplane flown by your teacher.
- As a group, discuss and write down answers to these questions:
  - Did the paper aircraft fly as predicted?
  - How well did the plane fly?
  - Why did the paper plane fly the way it did?
  - Do you have any assumptions about why the paper plane performed or flew the way it did?
  - How is the shape of the paper plane similar to or different than real planes?
  - What improvements could be made so that the plane flies better?
- Use the following websites to explore the advantages of electric propulsion. Be prepared to share your findings.
  - NASA LEAPTech: Distributed Electrical Propulsion. https://youtu.be/hhL2-Lykl9s
  - Electric Propulsion Technologies. https://www.nasa.gov/feature/electric-propulsion-technologies
  - Benefits. https://www1.grc.nasa.gov/aeronautics/eap/eap-overview/benefits-2/

Explore Knowns and Unknowns

- During Phase 1, test three paper airplane designs to determine which will fly the farthest.
- If working in teams, take turns flying the plane, measuring the distance, and recording the distance.

Safety

Wear eye protection at all times during paper airplane flight testing for your group and other groups working nearby. Be aware of those passing through or near your designated paper airplane test area.

Phase 1: Overall Design

- Step 1: Choose three different paper airplane designs. Directions for five different designs are available at the back of this guide, but you are welcome to use other designs if you would prefer.
- Step 2: Predict which design will fly farthest and which will fly the shortest distance.
  - Farthest ____________________
  - Shortest ____________________
- Step 3: Make the three different paper airplane designs you have chosen. Be sure to use the same type of paper for all three.
- Step 4: Test each plane three times in the designated area. Measure each distance to the nearest whole centimeter and record the data in the Distance Traveled Table.
  - Launch the plane the same way, using the same amount of force and throwing it in the same direction for each trial.

- Calculate the plane's distance from the point on the floor where it left the pilot's hand to where it first touches the ground.
- You may need a team member down the flight line to mark where the plane lands.

Distance Traveled Table

Aircraft name	Distance traveled, cm			Total of all three trials	÷	Number of trials	=	Average distance traveled (rounded to nearest cm)
	Trial 1	Trial 2	Trial 3					
					÷	3	=	
					÷	3	=	
					÷	3	=	

- Step 5: For each of the three designs, calculate the average distance traveled across the three trials (round to the nearest whole centimeter).

$$\text{Average} = \frac{\text{Distance 1} + \text{Distance 2} + \text{Distance 3}}{\text{3 (number of trials)}}$$

- Step 6: Graph the results of the three trials and the average for each paper airplane. A bar chart is recommended.

Distance Traveled Bar Chart

Aircraft name	Trial	
	Average	
	Trial 1	
	Trial 2	
	Trial 3	
	Average	
	Trial 1	
	Trial 2	
	Trial 3	
	Average	
	Trial 1	
	Trial 2	
	Trial 3	

0 10 20 30 40 50 60 70 80

Distance airplane flew, cm

Phase 1 Questions

- Were your predictions correct?
- What characteristics contributed to the success of the plane that flew the farthest?
- How could you improve the plane that flew the shortest distance?

Phase 2: Weight and Weight Distribution

- Read through “Electric Airplanes (Batteries Included).” https://climate.nasa.gov/news/2482/electric-airplanes-batteries-included/
- Take notes on the pros and cons of battery usage and be prepared to discuss them with the whole group.

In this phase of the activity, you will be observing the effect of weight and weight distribution on the flight of one of your paper airplanes. Record all observations made in the Qualitative Data section you will make in your notebook. Qualitative data are things you observe that are important but do not always fit into a graph. Not everything you observe is measurable, but your observations are important data and need to be recorded.

- Step 1: Choose one of the three designs you used in Phase 1. Scientists and engineers would make their choice based on the data collected. You can make your choice by comparing the average distance traveled by your three aircraft from Phase 1.
  - Explain which design you chose and why.

    Design chosen is the ______________________________. I chose this one because ____.

- Step 2: Choose an object (e.g., pennies, paper clips, or other materials of similar size) that you can attach to the plane as a standard unit of weight. (In Step 6, you will be adding weight to the plane in increments as you test the distance the plane can fly.) Paper clips are easy to attach but do not weigh much. Pennies weigh more, which means that you will not need many, but you may need to attach them with tape.
- Step 3: In your notebook, create a table to record your data. A sample table is provided here, but you will need more rows for the table you create in your notebook.

Distance Traveled With Added Weight (Example)

Total items added	Distance traveled, cm			Total trials	÷	Number of trials	=	Average distance traveled (round to nearest cm)
	Trial 1	Trial 2	Trial 3					
0	85	86	90	261	÷	3	=	87
5	95	97	103	295	÷	3	=	98
10	90	92	92	274	÷	3	=	91
15	80	82	79	241	÷	3	=	80

- Step 4: Create a Qualitative Data section in your notebook (observations not related to numbers). In this section, you will record where you placed the weight on the paper airplane and make observations about how the placement (distribution) of the weight affects the airplane’s overall performance. You may also draw pictures or add photos to the Qualitative Data section.
- Step 5: Fly the plane with no weight attached (i.e., zero items added). Measure and record the distance, to the nearest whole centimeter, for the flight of each of the three trials.
- Step 6: Add weight to the plane in consistent increments. The lighter the item, the more you will need to add at a time (e.g., one penny at a time, five paper clips at a time). After each addition, fly the plane and then measure and record the distance of the flight for three trials. Continue to add weight to the plane until the plane no longer flies but drops to the ground like a ball being thrown.

Fun Fact

NASA is leading the nation to quickly open a new era in air travel called Advanced Air Mobility, or AAM. In the future, electric vertical takeoff and landing (eVTOL) aircraft could serve as air taxis for those in cities and surrounding areas around the country, adding another mode of transportation for moving people and goods!

Learn more: https://www.nasa.gov/centers/armstrong/features/aam-plans-for-vertiports.html

Career Corner

Danielle Koch is an aerospace engineer at NASA and calls her work “an engineering journey.” She leads a team of engineers who study ways to reduce engine noise by designing, building, and testing new parts that can be installed in an airplane’s engine to do the job. Learn how she uses nature to inspire her acoustic designs on aircraft.

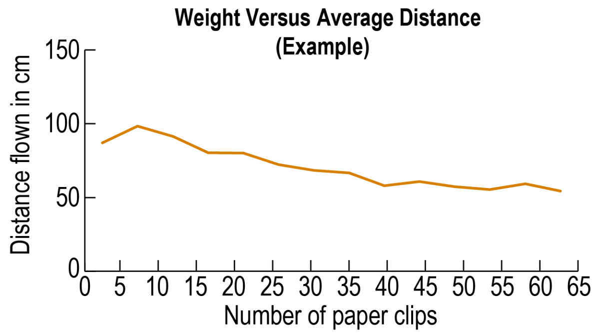
Learn more: https://www.nasa.gov/sites/default/files/atoms/files/danielle-koch-ms-online.pdf

- Step 7: Average the trials using the formula shown below, and then graph your data.

$$\text{Average} = \frac{\text{Distance 1} + \text{Distance 2} + \text{Distance 3}}{\text{3 (number of trials)}}$$

  - This graph will be a scatter plot or line graph that you will make in your notebook or on a computer. See the next page for a line graph example.

- Step 8 (optional): If you still have time, pick a medium amount of weight that successfully flew already. Experiment with the distribution of the weight by placing that specific number of items in different places on the paper airplane (e.g., all in the front, all in the back, or spread evenly everywhere). Use the Qualitative Data section in your notes to record where you added weight. Also, record any of your observations about how the placement (distribution) of the weight affected the airplane's overall performance. Feel free to draw a picture or take photos.



Phase 2 Questions

- Did the plane's distance increase the first time weight was added? If so, explain why.
- Did the plane's distance continue to change consistently throughout the activity? If so, why?
- Did the distribution of weight have any impact on how the plane flew? If so, why?
- Why are seats on a commercial airplane distributed the full length of the fuselage rather than all in the front or the back?
- Why do some airlines charge you for each piece of luggage you bring on the plane?

Phase 3: Structural Integrity

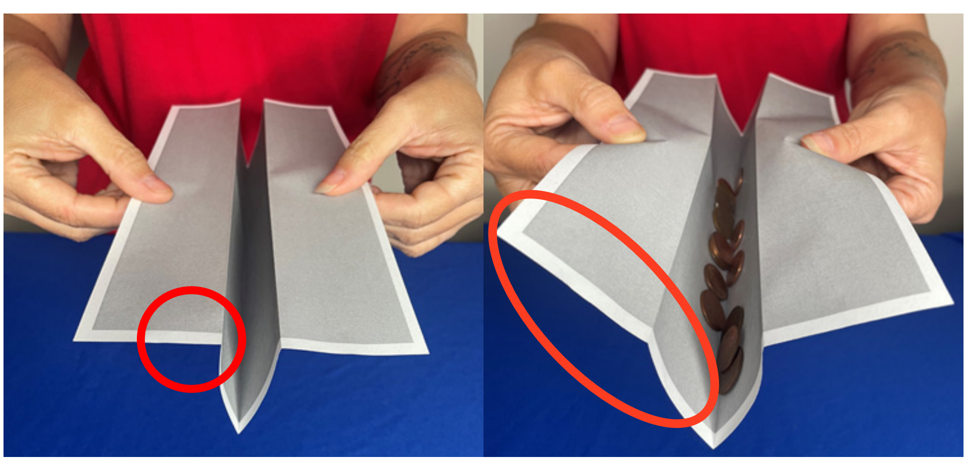
In this phase, you will look at the structure of a plane. You will not fly your paper airplane, but you will investigate the wing design and how well the structure of the material can handle the weight and weight distribution. Your team will design structural support materials (e.g., craft sticks, stir sticks, cardboard, etc.) and add these to the wings or fuselage to support the added weight. You will be changing the structural design to simulate different material properties.

You will watch two videos. Be prepared to discuss the importance of stable wings and the importance of new composite materials.

- X–56: The Future of Flight—Part 1: Active Controls. Watch from time stamp 0 to 3:36. https://youtu.be/igR1_grUQyI
- NASA | Advanced Thermoplastic Tape and Composites Processing Method. https://youtu.be/U0hFnkrDjy4 (1:28 min.)

Follow these steps to investigate weight distribution and structural design:

- Step 1: Choose one airplane design from the three designs in Phase 1. Remake it if needed.
- Step 2: Hold the airplane by the edges of its wings throughout this phase, as demonstrated in the example below. Add a few weights at a time, observing the "droop" or sag in the wings. The droop is best described as "where the angle of the wing meets the fuselage" (the body of the plane).



- Note that when weight is added to the fuselage, the angle between the wing and the fuselage is no longer a 90° angle. The properties of the material being used are unable to support the weight, and the plane is not able to keep its form.

- Step 3: Choose an amount of weight for the paper airplane to hold in the fuselage and place the weight in the following areas, making observations of the droop after each placement: toward the front, spread out evenly, then toward the back.
- Step 4: Document your observations in the Qualitative Data section of your student notebook, describing the number/type of weights or total weight added and the resulting droop or sag in the wings. An example table is provided here. For this step, record your observations in the Original Design column. The Improved Design column will be used in Step 7.

Qualitative Observations Table (Example)

Number/type of weight *or* Weight added, g	Qualitative observations (e.g., description of droop)	
	Original design	Improved design
2 pennies (5 g)	No noticeable droop	Definitely no droop at all
5 pennies (12.5 g)	Slight droop, definitely noticeable	About half as much droop as originally

- Step 5: Brainstorm ideas on how to secure and stabilize the wing where it meets the fuselage using common materials (e.g., craft sticks, straws, stir sticks, skewers, chenille stems).
- Step 6: Make the improvements to your plane. Keep in mind the results from the earlier weight tests so that the plane does not become too heavy.
- Step 7: Repeat the testing from Steps 3 and 4 using your improved design. Make sure to document the results just as before, using the Improved Design column of your table.

Phase 3 Questions

- Why did the paper airplane start to lose its shape when weight was added to the fuselage?
- What happened to the structure of the plane when you added support materials (since you could not change the properties of the paper)?

Generate Possible Solutions

As a team, reflect on the data from the previous phases and brainstorm what it would take to make a paper airplane fly farther than the planes in Phase 1.

- Step 1: Select one paper airplane from Phase 1 that you will redesign or modify to fly farther than in Phase 1.
- Step 2: Reflect on your data collected from Phases 1 to 3 and brainstorm what it would take to make a paper airplane fly better than it did originally. You may use the NASA resources in this activity or from the NASA.gov website to help you come up with ideas.
- Step 3: Sketch or write out the changes you want to make and the reason for the changes.
- Step 4: Write a justification for each of the proposed changes based on your data and/or NASA resources.
- Step 5: Make a prediction for how much farther the improved plane will fly than before.

Consider Consequences

Follow through on your proposed solution and determine if your predictions are accurate.

- Step 1: Make the paper airplane design you chose from Phase 1.
- Step 2: Apply the proposed modifications.
- Step 3: Fly the paper airplane to see if it flies as predicted. Make minor adjustments as needed and then retest. As before, test by flying three times, taking measurements to the nearest centimeter and recording them after each trial.

Distance Traveled by Student-Designed Airplane

Aircraft name	Distance traveled, cm			Total of all three trials	÷	Number of trials	=	Average distance traveled, cm
	Trial 1	Trial 2	Trial 3					
					÷	3	=	

- Step 4: Calculate the average distance flown across the three trials.
- Step 5: Compare with the Phase 1 results for the original plane to see if the distance has improved. Determine whether the prediction was accurate. Be prepared to present all materials.

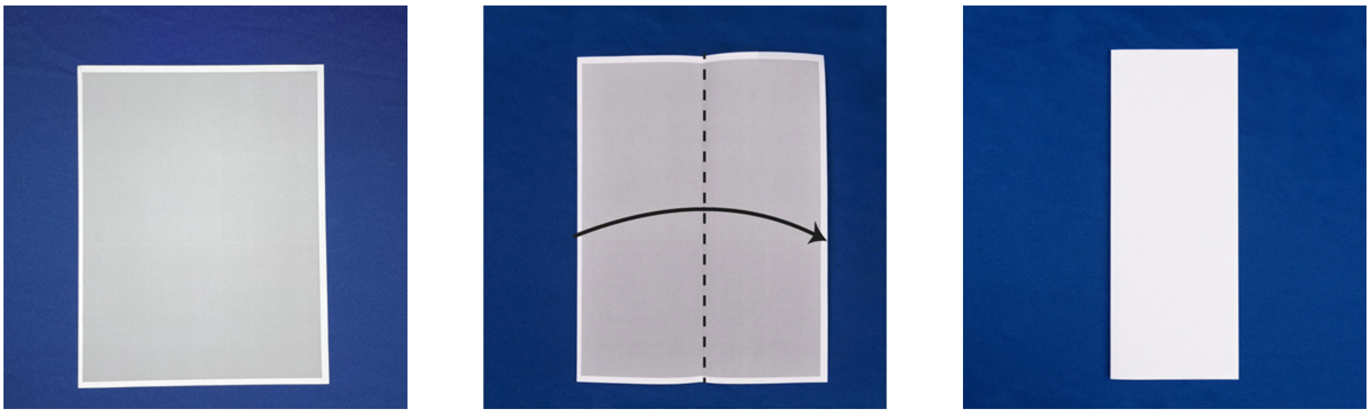
Present Findings

Be prepared to

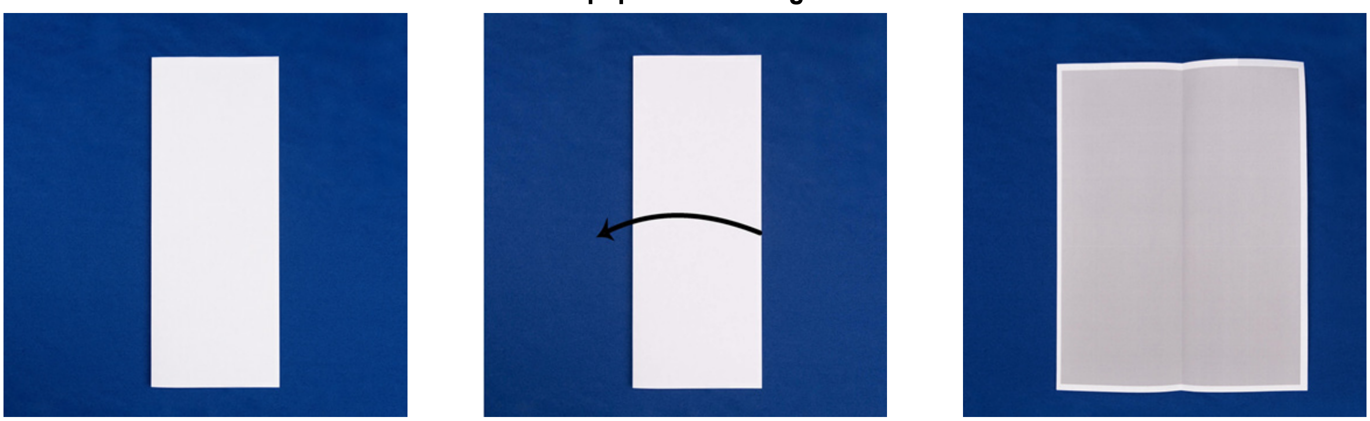
- Present charts, discuss the qualitative data, and talk about your newly designed plane.
- Defend why you made the changes you did, and discuss whether or not the changes worked.
- Explain the strengths and weaknesses of the design.
- Post and share your work in a given area for other teams to see.

Paper Airplane Designs

Basic

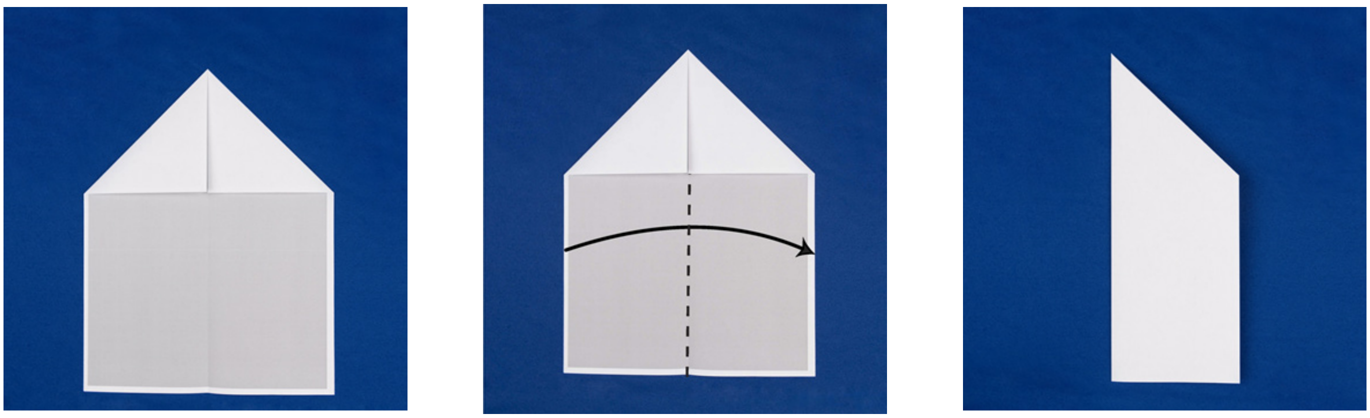


Fold the paper in half lengthwise.

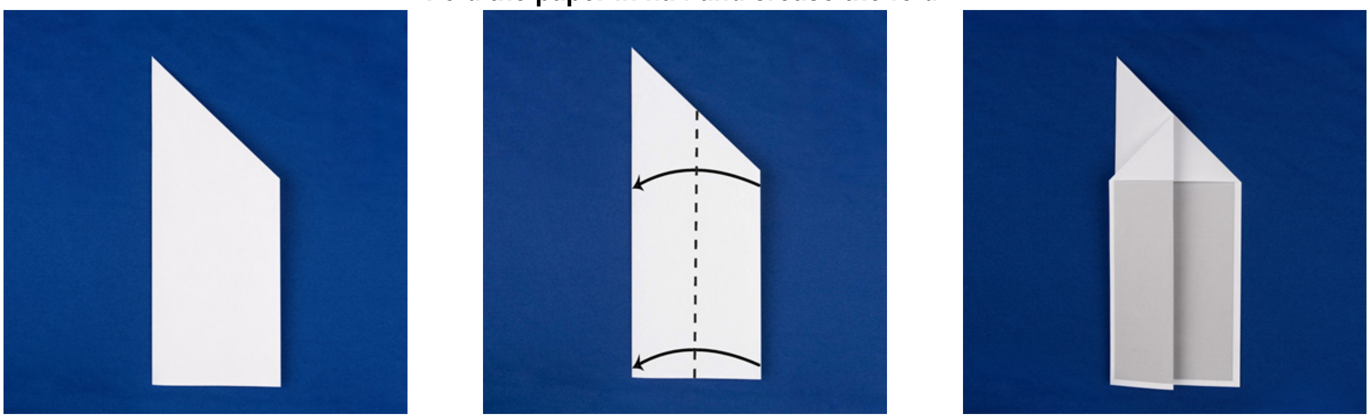


Unfold the paper.

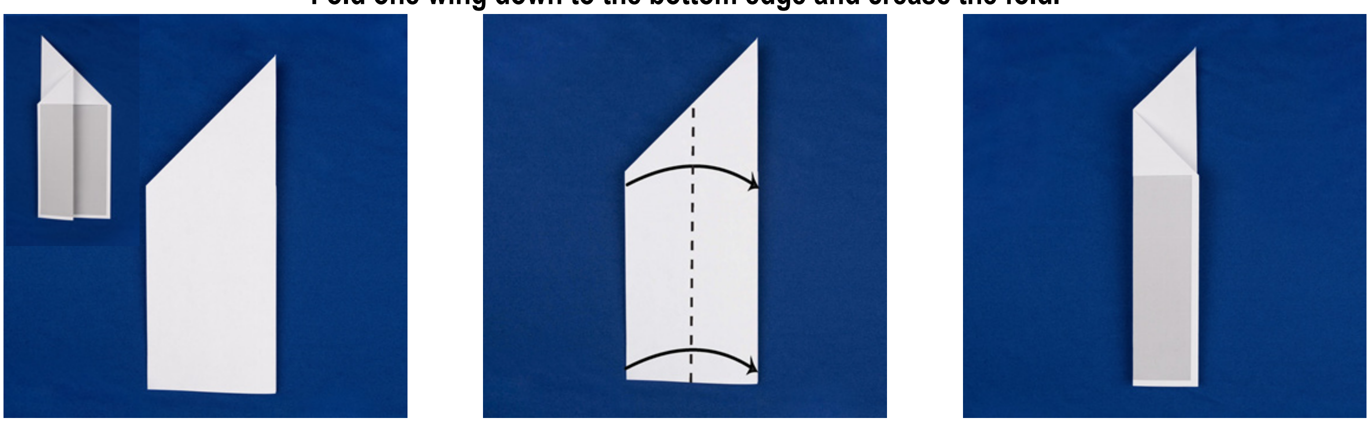
Fold the two corners to the center line and crease the fold.



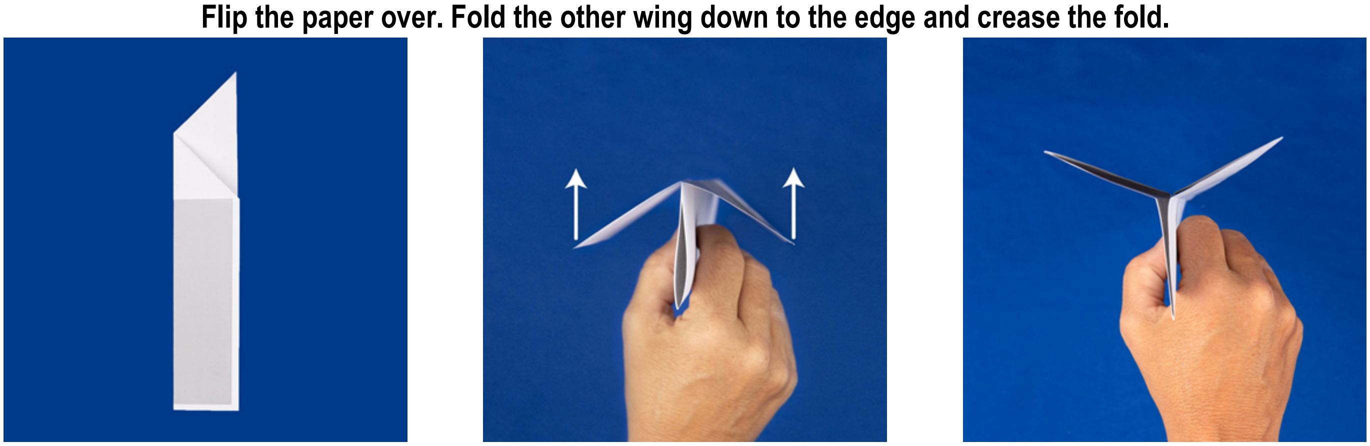
Fold the paper in half and crease the fold.



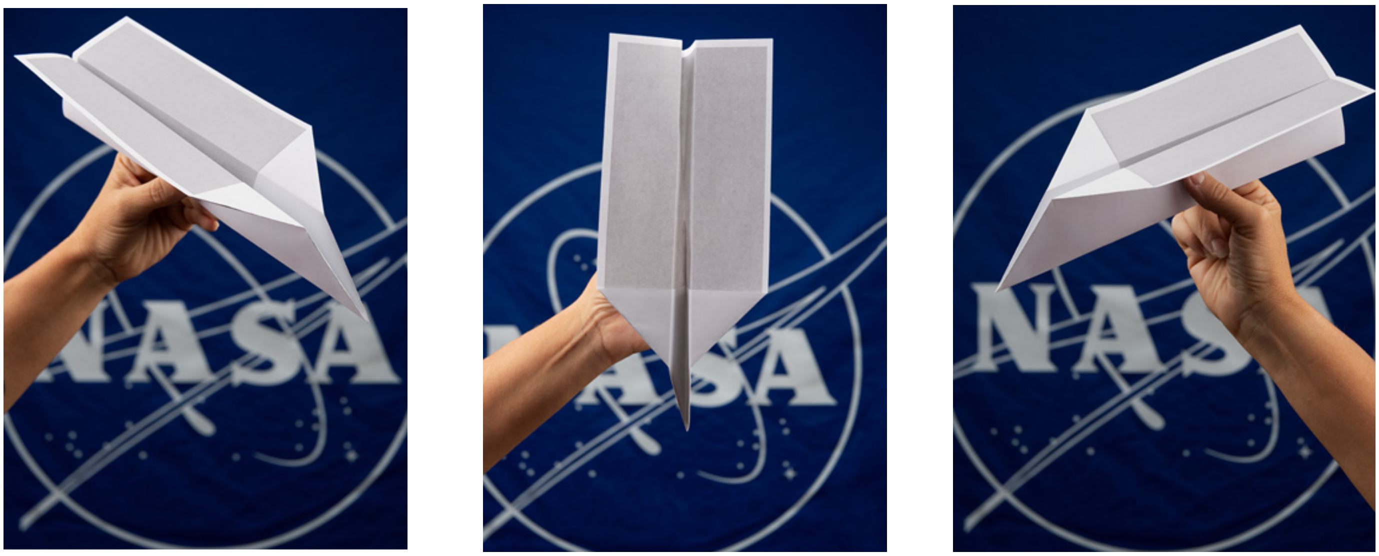
Fold one wing down to the bottom edge and crease the fold.



Flip the paper over. Fold the other wing down to the edge and crease the fold.

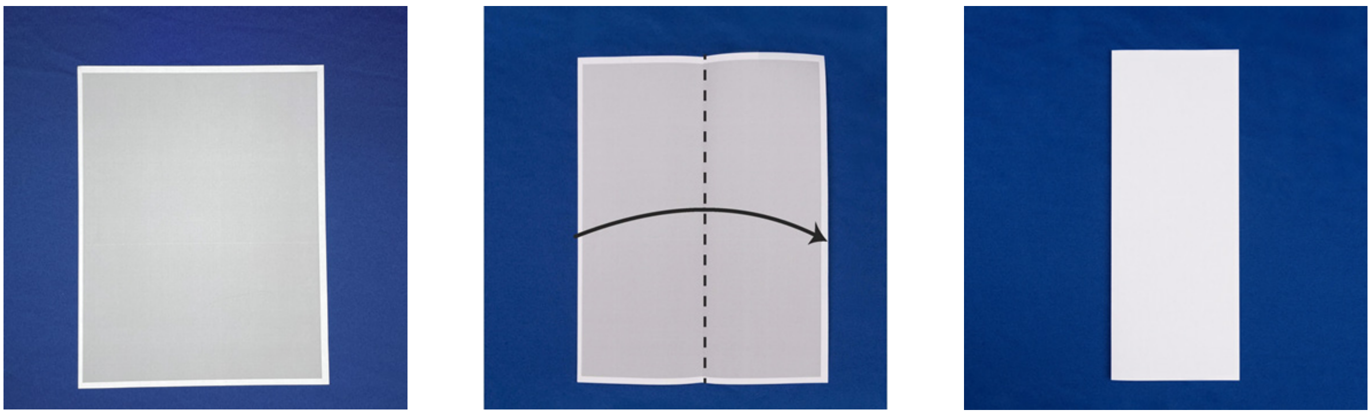


Grab the paper airplane by the base, then tip the wings upward to create a dihedral angle.

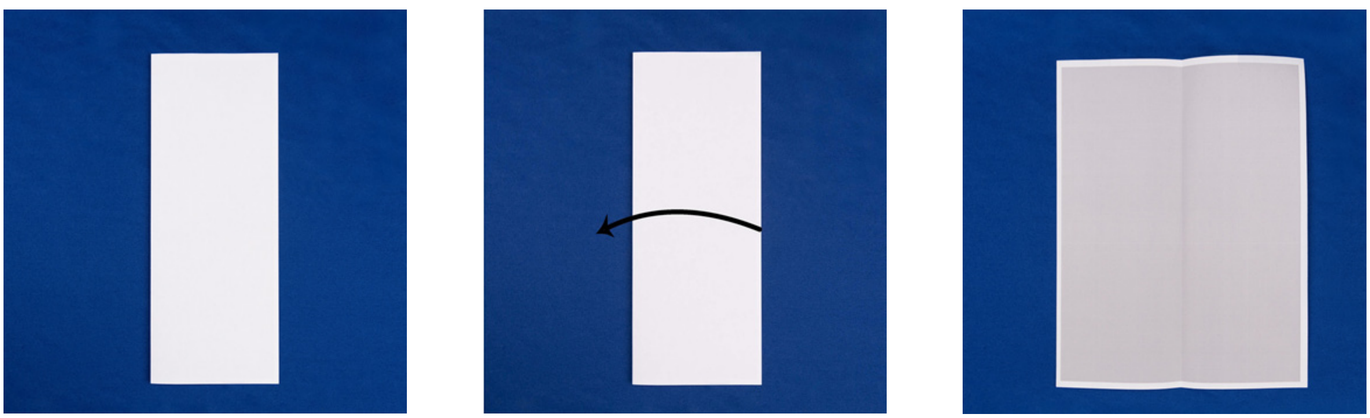


Ready to fly!

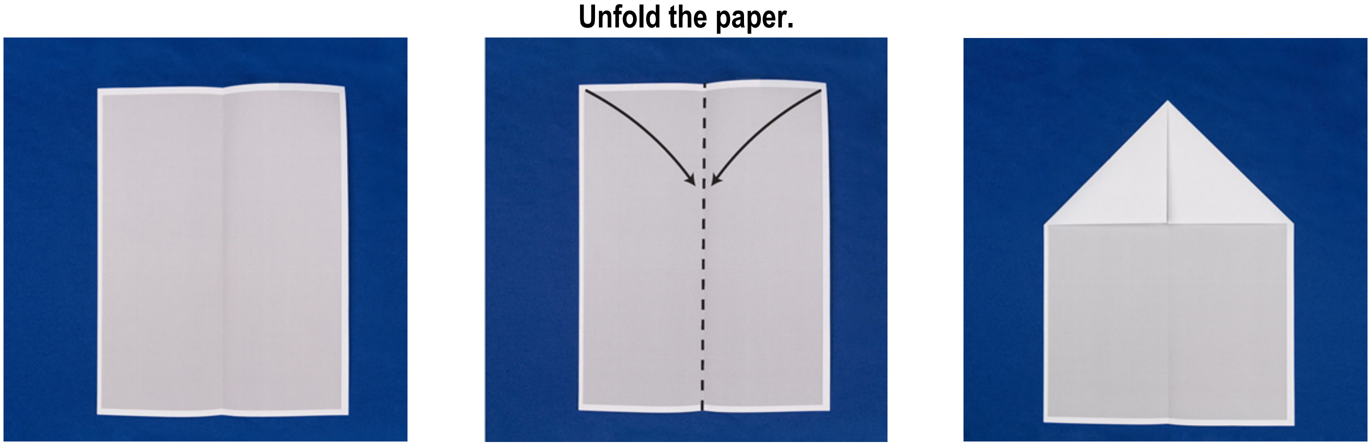
Dart



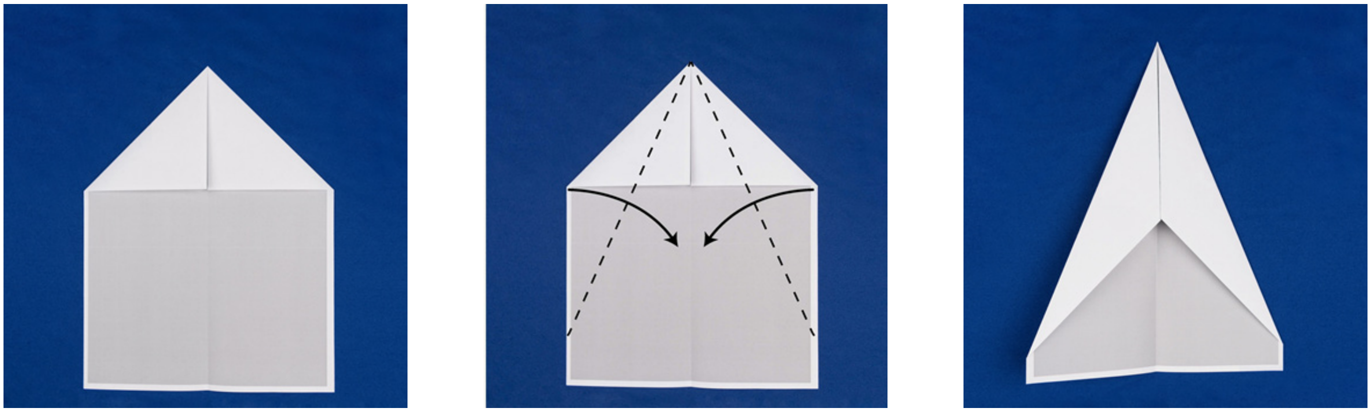
Fold the paper in half lengthwise.



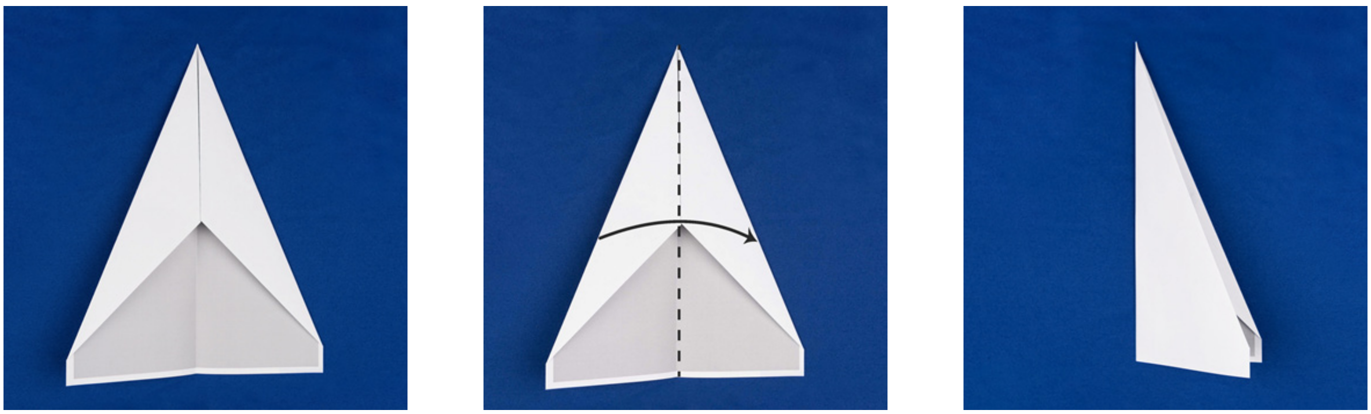
Unfold the paper.



Fold the two corners to the center line and crease the folds.



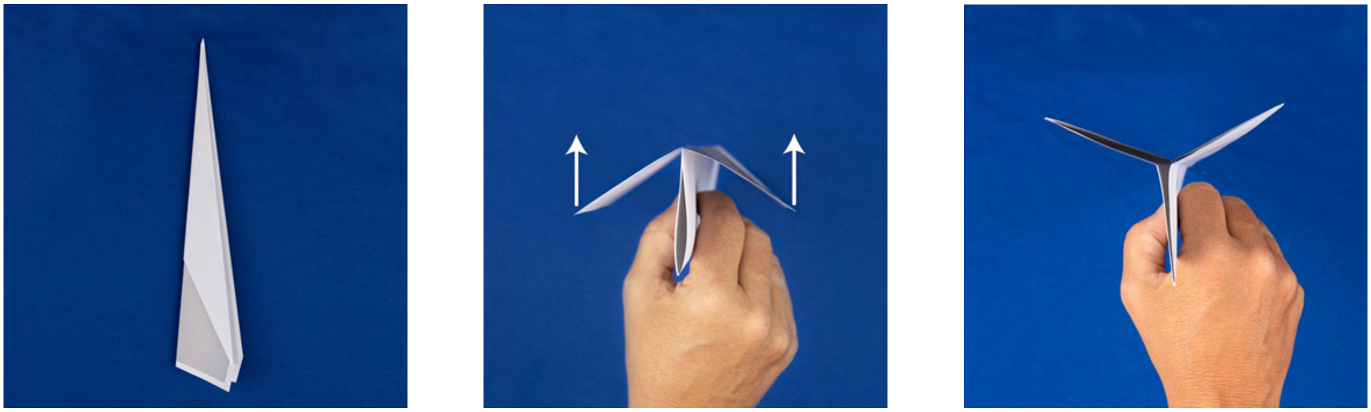
Fold the top diagonal edges to the center line on both sides. Crease the folds.



Fold the paper in half and crease the fold.

Fold one side back, so the right edge of the plane lines up evenly with the left edge. Crease the folded edge.

Flip and repeat.



Grab the paper airplane by the base, then tip the wings upward to create a dihedral angle.

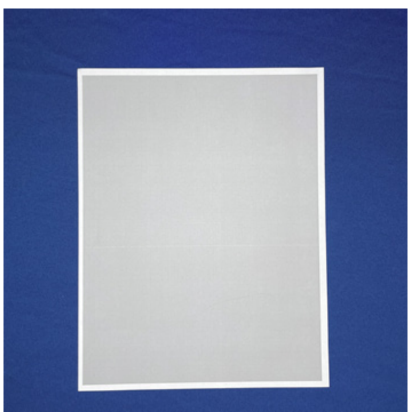
The Dart is ready to fly!

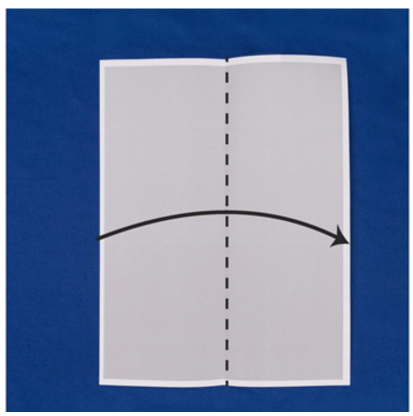
X-Plane and Spinning X-Plane

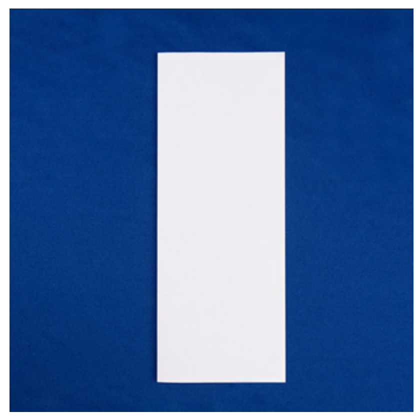
...just one more step after the X-Plane to create the Spinning X-Plane

X-Plane

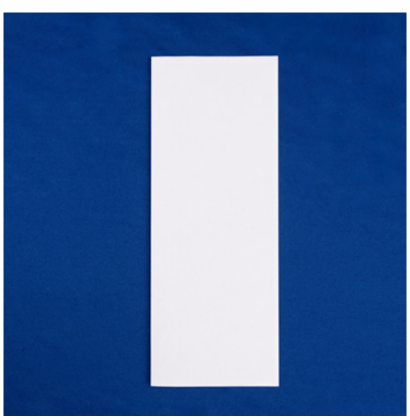
Spinning X-Plane

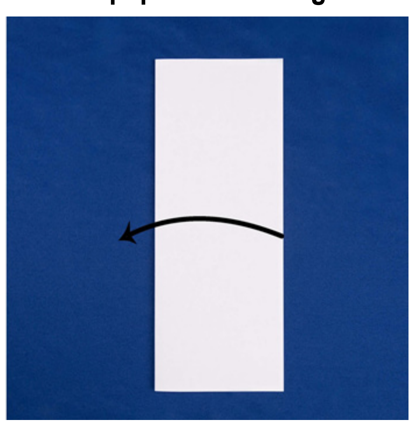






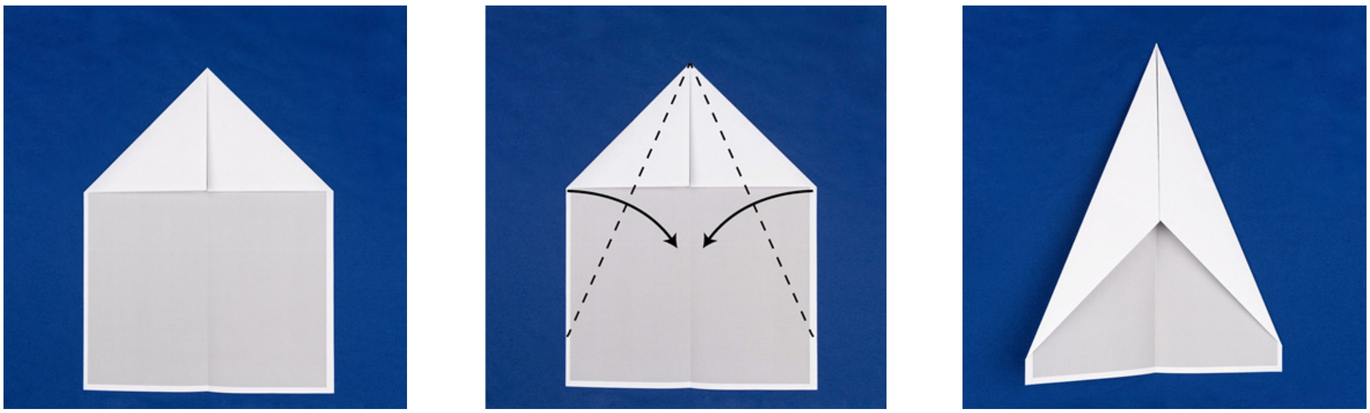
Fold the paper in half lengthwise.



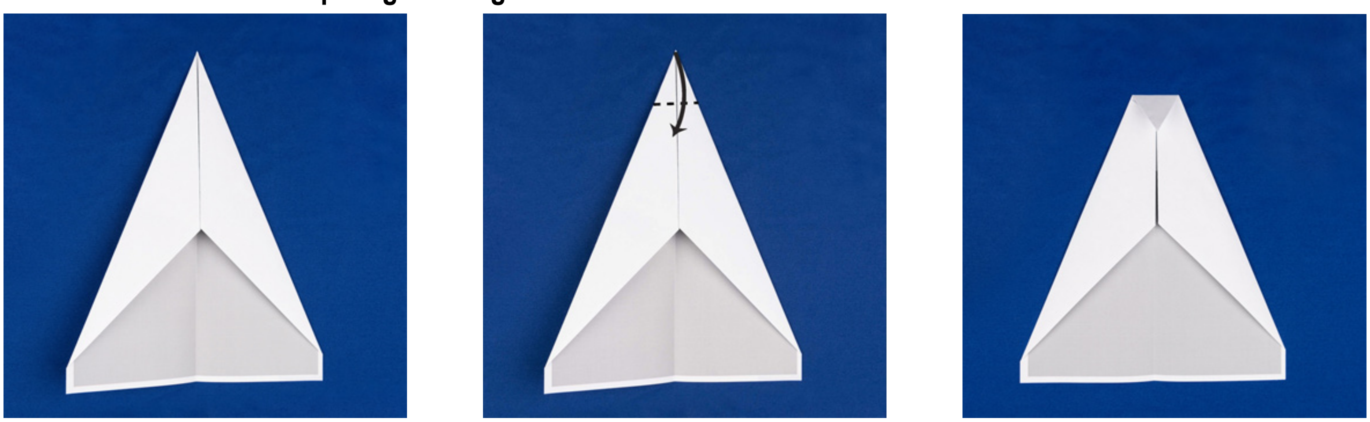


Unfold the paper.

Fold the two corners to the center line and crease the folds.

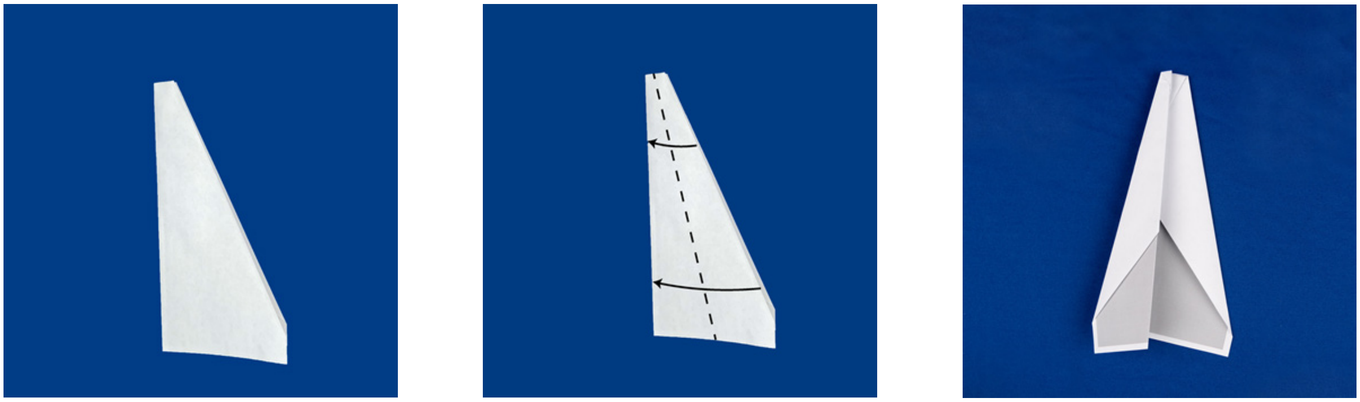


Fold the top diagonal edge to the center line on both sides and crease the folds.

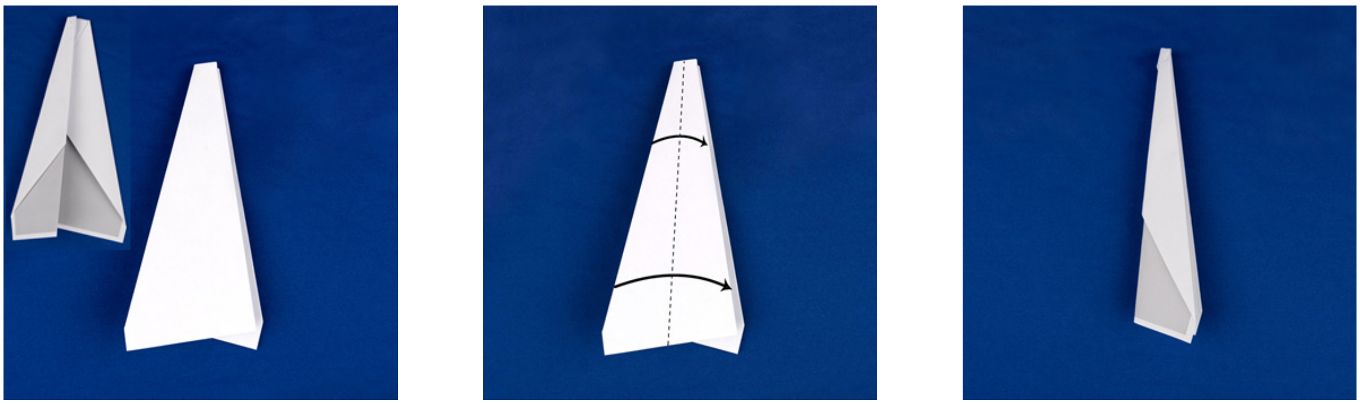


Fold the tip down and crease.

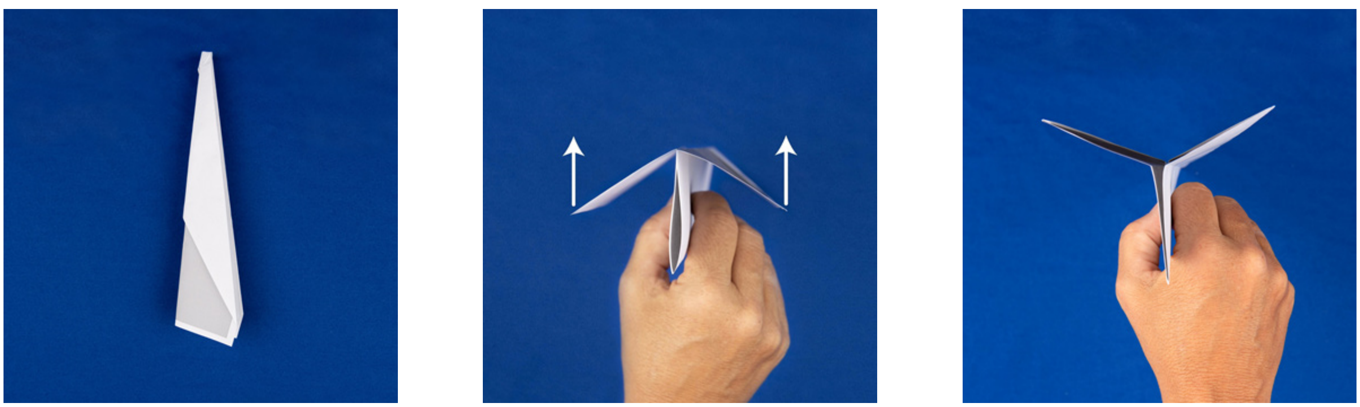
Fold the plane in half, then crease.



Fold one side back, so the right edge of the plane lines up evenly with the left edge, then crease.



Flip and repeat.



Grab the paper airplane by the base, then tip the wings upward to create a dihedral angle.

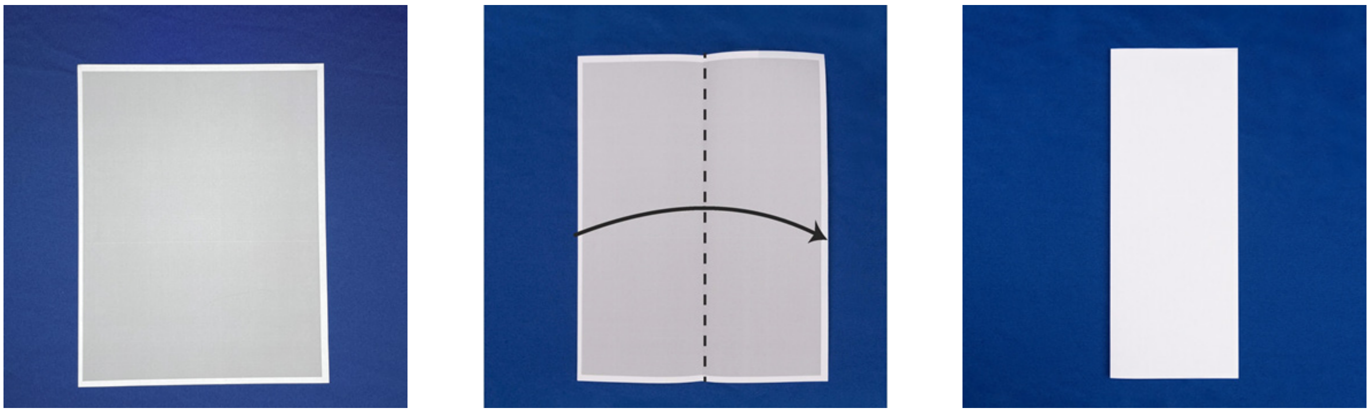
The X-Plane is ready to fly!

It takes only one more step to make the Spinning X-Plane:

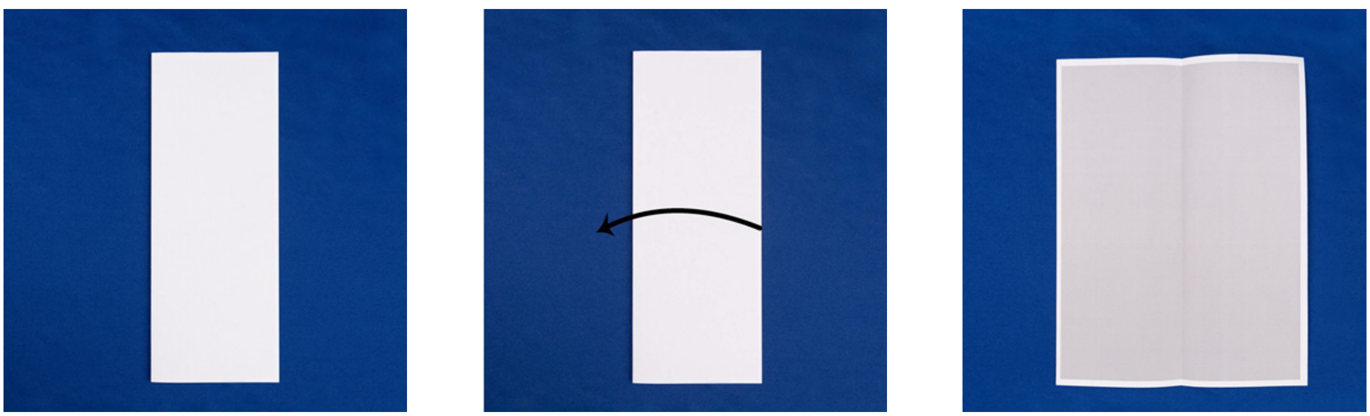
For the Spinning X-Plane, fold one back corner down and one back corner up.

The Spinning X-Plane is ready to fly!

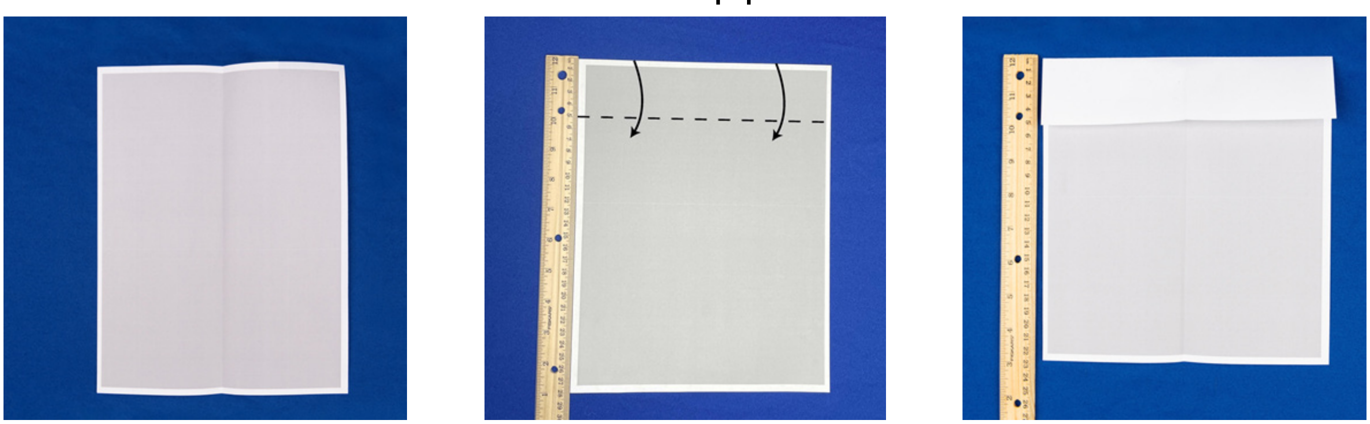
Glider



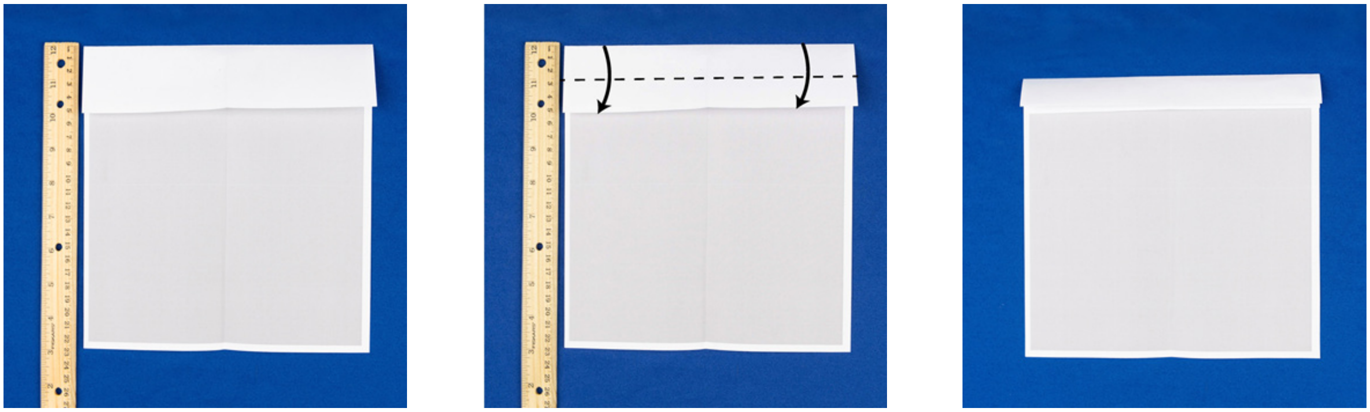
Fold the paper in half lengthwise.



Unfold the paper.

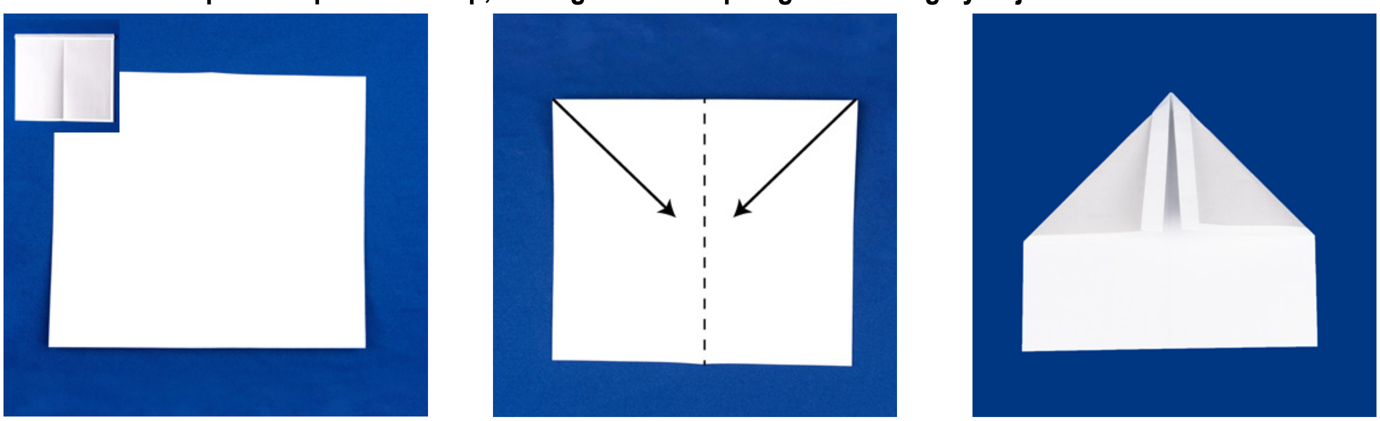


Fold the top edge down 5 cm, then crease the fold.

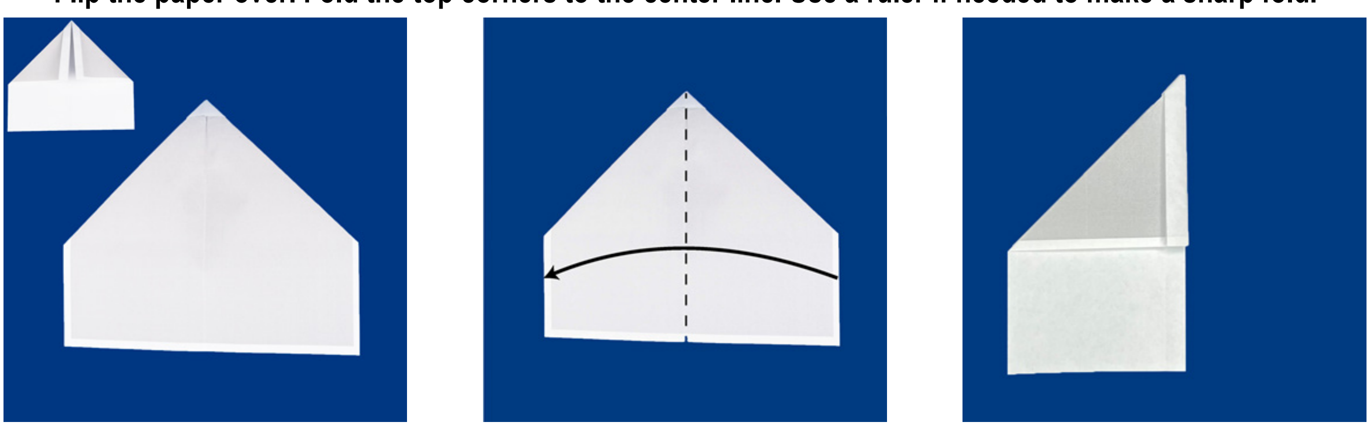


Fold the new top edge to meet the edge you just folded over, then crease.

Repeat the previous step, folding the new top edge to the edge you just folded over.

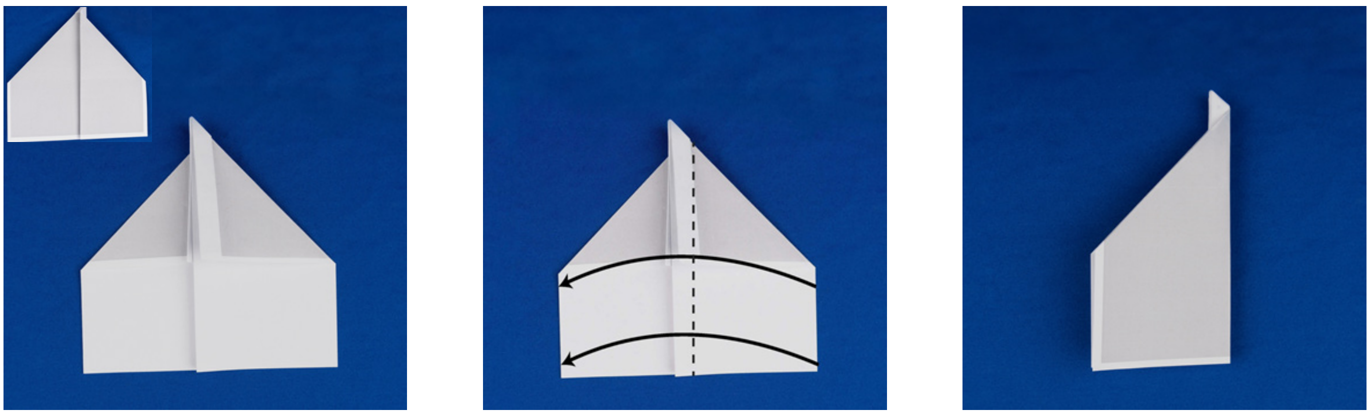


Flip the paper over. Fold the top corners to the center line. Use a ruler if needed to make a sharp fold.

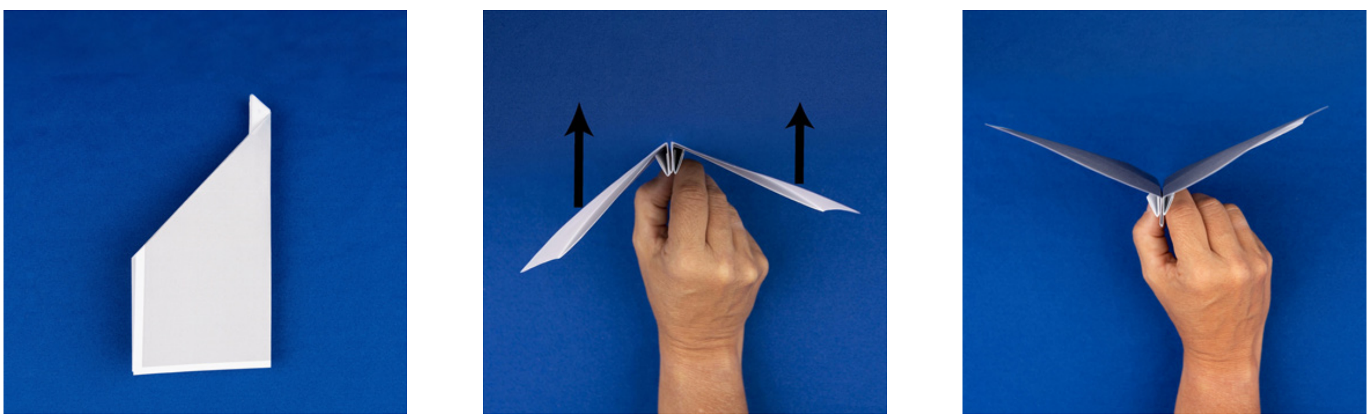


Turn over to the front side. Fold in half.

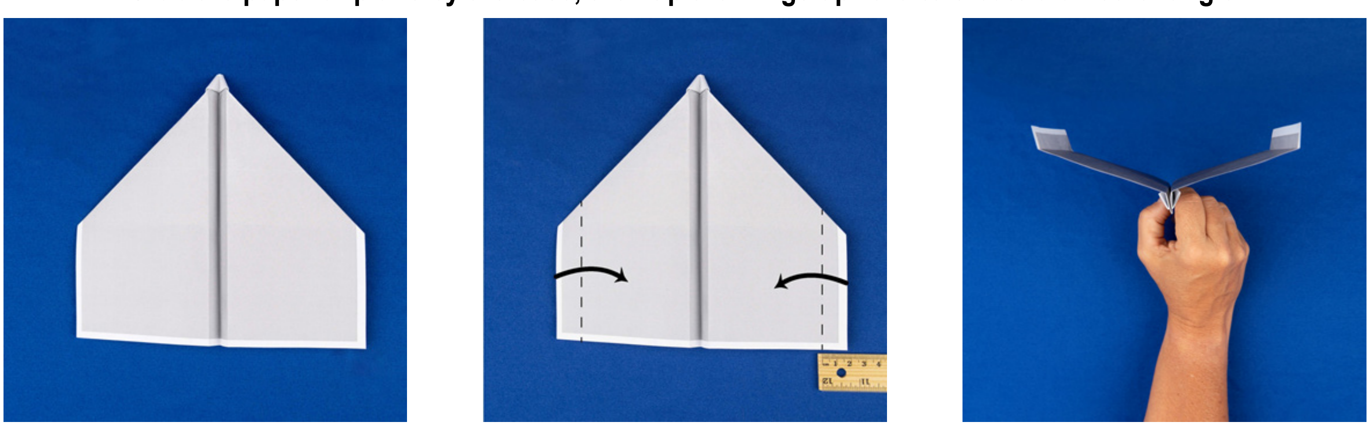
Fold one side back, using the folded edges as a guide for where to crease the wing.



Flip the paper over. Fold the other side back, using the folded edges as a guide for where to crease the other wing.



Grab the paper airplane by the base, then tip the wings upward to create a dihedral angle.



Fold both edges of the wing up 1.5 cm from the edge.

The Glider is ready to fly!