

# Facilitation Guide



# Engineering Design Challenge





*Above: NASA Glenn Research Center (GRC) in Cleveland, Ohio is 1 of 10 NASA centers. GRC is an essential component of NASA and an integral contributor to the region, and its engineers and scientists research, design, develop, and test innovative technology for aeronautics and spaceflight.*

*Cover: The sphere on the lower left includes images from many of GRC's research facilities and technologies. The four images across the middle highlight the Center's past, present, and future in aeronautics research, including the iconic Flight Research Building, housing research aircraft as part of both the National Advisory Committee on Aeronautics and NASA.*

**“The most important thing we can do**  
is inspire young minds and to advance the kind of science,  
math and technology education that will help youngsters  
take us to the next phase of space travel.”

- Senator John H. Glenn, Jr.,  
NASA Astronaut and United States Senator

# Introduction to the Engineering Design Challenge

Dear Formal and Informal Educators,

The students you work with today are tomorrow's scientists, technicians, engineers, and mathematicians. Creativity, curiosity, analytical thinking, and the ability to successfully utilize the engineering design process are qualities and skills necessary for NASA's future workforce. Engineering design challenges (EDCs), like the one in this guide, create authentic learning experiences that allow students to develop valuable skills through rigorous and engaging science, technology, engineering, and mathematics (STEM) content.

This EDC connects current research being conducted at Glenn Research Center (GRC) with aeronautics research from NASA's history. GRC engineers are studying ways of improving aircraft efficiency and design as well as using specialized aircraft to conduct scientific research from the air. They supported the education team to ensure accuracy and relevance while developing this content.

This facilitation guide is versatile, and includes the EDC, three lead-up investigations, and supporting links to provide background knowledge about flight for both facilitators and students. Each lead-up investigation takes approximately 30 minutes to complete. The guide has been written for students in middle grades although the contents can be modified to increase or decrease complexity. The challenge problem can be implemented in as little as ten contact hours or can continue open-ended as your students test and improve their designs.

All the activities are designed with both you and your students in mind. They include simple explanations of relevant background information, clear step-by-step instructions of each process, reflective student sheets, and concise rubrics to evaluate student performance. You can use all the materials in this guide or customize implementation of the challenge with resources that best fit your program needs.

NASA supports educators and facilitators like you who play a key role in preparing students for careers in STEM fields through engaging content. Thank you for helping us share this learning experience with your students.

*Engineering Design Challenge Team*

Glenn Research Center  
Office of Education

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# Introduction



*Figure 1: George Lewis, the NACA's first Director of Aeronautical Research, explains the plan for the new Aircraft Engine Research Laboratory in Cleveland, Ohio, which would eventually become NASA Glenn Research Center.*

## Facilitator's Overview

NASA education staff, scientists, and engineers collaborated to create evidence-based engineering design challenges (EDCs) that involves students in using the engineering design process (EDP) to solve a real scientific problem.

The EDC serves as an authentic, standards-based investigation that allows students to engage in the process of solving problems like today's scientists and engineers do. This EDC provides students with opportunities to gain tangible skills that are essential in STEM careers.

This guide is organized into the following sections:

1. Introductory materials – Establish a common basic level of understanding about the EDP and its relation to this challenge. The introductory materials also include an alignment to Next Generation Science Standards and the Common Core State Standards for Mathematics, as well as background information highlighting NASA's science and research related to this challenge.
2. Facilitator pages – Provide instructions for facilitators to use throughout the design challenge. Tools are also included in this section that you can use to assess student understanding throughout each step of the challenge.
3. Student challenge journal – Contains prompts and tools to guide students through the cycle of steps in the EDP while documenting their work for each step.
4. Support materials – Consist of information and additional activities to supplement and enhance the EDC.

These user-friendly sections help you support your students as they work in teams to complete the EDC. At the conclusion, your students will be able to articulate the steps taken in the EDP and report that information and their challenge solution in a video that can be shared with NASA and other participants. Good luck as you help create the next generation of STEM professionals!

For more information visit the NASA Glenn Research Center Engineering Design Challenge website at <http://www.nasa.gov/content/grc-engineering-design-challenges/>.

## The Basics of Engineering Design

**What is an engineer?** Engineers are at the heart of every Engineering Design Challenge. Engineers are people who design and build things that we use every day. The video at the link below will explain the role of an engineer and can be shared with your students: <http://youtu.be/wE-z TJyzil>. After viewing the video, have students discuss what they learned about what an engineer does.



*Figure 2: Aerospace Engineer Chris Randall tests rocket parts and life support systems to ensure they work as planned.*



*Figure 3: Simulation System Engineer Debbie Martinez works on developing a general aviation flight simulation software.*

An **engineer** is a person who works on a team to lessen or solve an existing problem. Some examples of NASA-engineered products include:

- Portable x-ray machines – NASA created a small, low-radiation x-ray machine that medical professionals can now use to examine people's injuries at accident scenes.
- Infrared ear thermometers – NASA developed infrared temperature sensors for space missions that were adapted to take body temperatures faster and easier.
- Food processing control – While preparing to send the first astronauts to space, NASA worked with food processing companies to create a method to identify where food could become contaminated during processing.
- Athletic shoes – NASA used previously created flexible and sturdy spacesuit materials to develop shoes that perform better.
- Airplanes – NASA works with aircraft manufacturers to design and improve aircraft to make them safer, quieter, lighter, more fuel efficient, and more reliable.

It is important for students to understand that engineers help improve society. It is also important to address misconceptions about engineers. Men and women of all races, ethnicities, and walks of life can become engineers. Examples of NASA engineer career profiles can be explored at

<https://www.nasa.gov/audience/forstudents/careers/profiles/index.html>.

## The Engineering Design Process

**What is the engineering design process?** The **EDP** is a cycle of steps that a team of engineers uses to guide their work in solving a problem that leads to development of a new product or system. The cycle repeats to continuously refine and improve the product or system. During this challenge, students should complete each step in the EDP and document their work as they develop, test, and refine their design. They should conduct multiple **iterations**, or repetitions of the cycle, as often as time and resources allow to develop the best product. On following iterations, some steps like “Identify the Need or Problem” will only need to be briefly revisited to confirm that teams are still on track. Other steps like “Test and Evaluate the Solution(s)” and “Redesign”, will need to be completely redone.

**What is an Engineering Design Challenge?** An **EDC** is an educational activity that helps students understand the EDP. Students are presented with a challenge or problem and, using the process, work in teams to complete activities and experiments to develop solutions to the original problem. These challenges facilitate teamwork, problem solving, and brainstorming ideas very similar to what real-world engineers encounter.

For younger students, EDPs and EDCs will probably be unfamiliar concepts. Students may or may not have heard words like “criteria” or “constraints” which are commonly associated with engineering design. Facilitators should introduce these words with simple explanations, then continue immerse the students with the vocabulary. For example, **criteria** are what your solution **must** do. **Constraints** are what your solution **must not** do. Like the EDP, students will gain a deeper understanding of these concepts with repeated exposure.



# THE ENGINEERING DESIGN PROCESS

**STEP 1: Identify the Need or Problem** – Working in teams, students state the problem in their own words. Example: How can I design a \_\_\_\_\_ that will \_\_\_\_\_?

**STEP 2: Research the Need or Problem** – Teams use resources, from the Internet, the library, or discussions with subject matter experts (SMEs), to examine how this problem is currently being solved or how similar problems are being solved.

**STEP 3: Develop Possible Solutions** – Team members draw on their mathematic and scientific knowledge and brainstorm all the possible ways that they might solve the problem. They choose the most promising options and refine their solution by quickly sketching in two or three dimensions. Labels and arrows should be included to identify parts.

**STEP 4: Select the Best Possible Solution(s)** – Team members share their ideas and answer questions from the other team members. Each team discusses and records strengths and weaknesses from each design and determines which solutions best meet the original need or solves the original problem, possibly including features from more than one design. The team writes a statement that describes why they chose the solution.

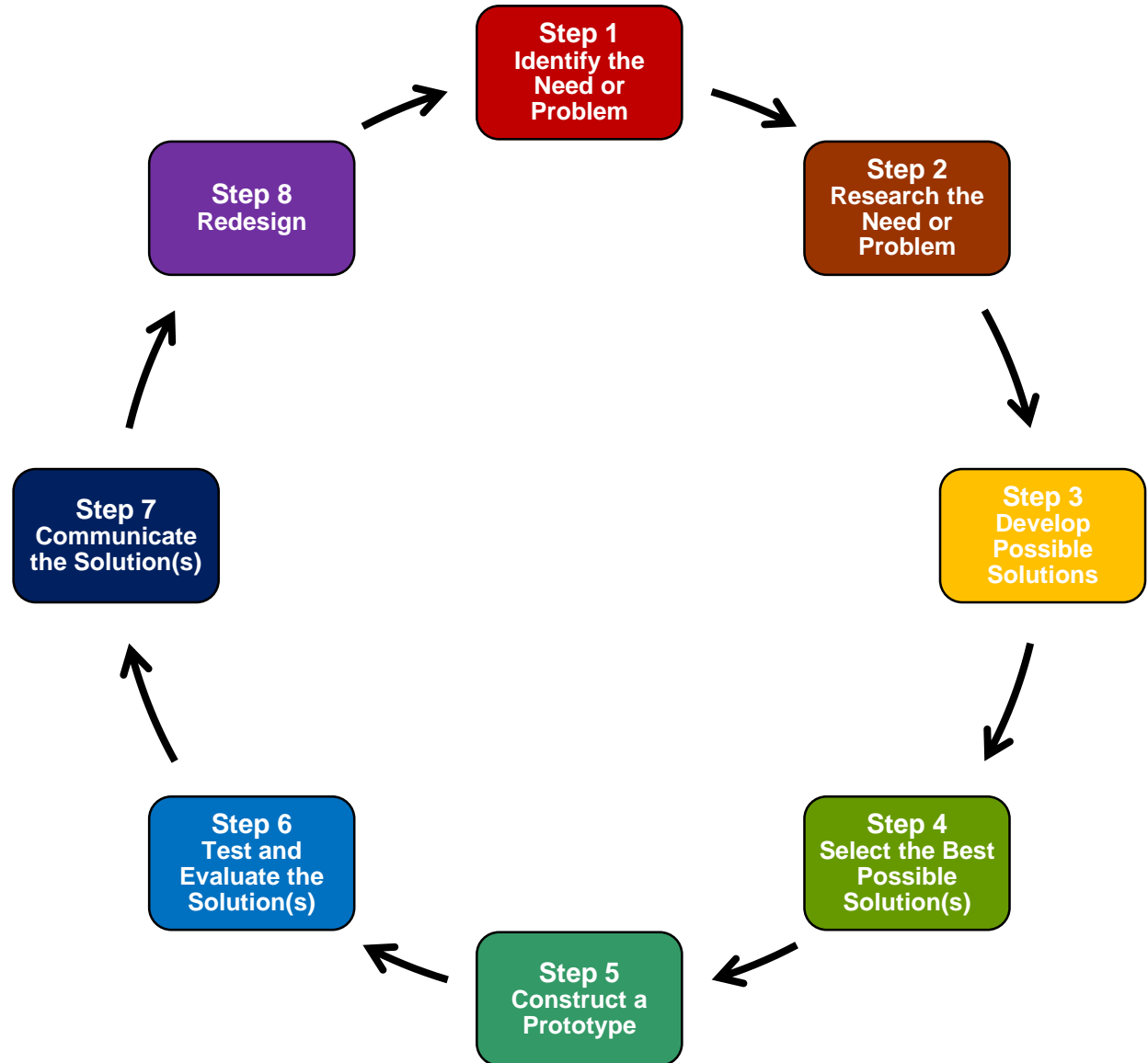
**STEP 5: Construct a Prototype** – Team members construct a full-size or scale model of the selected solutions in two or three dimensions. The facilitator helps to identify and acquire appropriate modeling materials and tools.

**STEP 6: Test and Evaluate the Solution(s)** – Teams test their models to determine how effectively they solved the need or problem. Data are collected to serve as evidence of their success or need for improvement.

**STEP 7: Communicate the Solution(s)** – Team members record and share what they learned about their design based on testing. Teams make a presentation that includes how their solution(s) best solved the need or problem. They could ask students from other teams to review the solution and help identify any improvements that could be made.

**STEP 8: Redesign** - Team members consider modifications to their solution(s) based on the information gathered during tests and the presentation. Teams review the original need or problem to ensure their modifications still meet the necessary criteria and constraints, and restart the EDP cycle.

# THE ENGINEERING DESIGN PROCESS



*This Engineering Design Process model was adapted from the Massachusetts Science and Technology/Engineering Curriculum Framework (published October 2006, <http://www.doe.mass.edu/frameworks/scitech/1006.pdf>).*

## Assessment Tools

### Engineering Design Challenge: Sample Learning Targets

Facilitators should create learning targets using their selected learning standards and performance indicators and share them with students. Learning targets unpack bite-size amounts of learning that define what will be expected of students and how they will demonstrate their understanding.

**Disclaimer:** Learning targets should reflect the specific learning standards facilitators are addressing. The sample listing below may not include the learning targets most appropriate for any specific facilitator.

Bloom's Taxonomy Level	Sample Learning Targets
Remembering	<ul style="list-style-type: none"><li>• I can memorize the steps of the engineering design process.</li><li>• I can define "iteration."</li><li>• I can name the constraints of a design problem.</li><li>• I can recognize the impacts of possible solutions.</li></ul>
Understanding	<ul style="list-style-type: none"><li>• I can describe the steps in the engineering design process.</li><li>• I can summarize the criteria and constraints of a particular design problem.</li><li>• I can explain the similarities and differences between the engineering design process and the scientific method.</li><li>• I can label the forces acting upon an object.</li></ul>
Applying	<ul style="list-style-type: none"><li>• I can measure and record various types of data.</li><li>• I can explain the criteria and constraints of a design problem.</li><li>• I can conduct tests of designs and collect data.</li></ul>
Analyzing	<ul style="list-style-type: none"><li>• I can categorize the impacts of possible solutions.</li><li>• I can compare similarities and differences among several design solutions.</li><li>• I can infer possible reasons for test results.</li><li>• I can analyze test data.</li></ul>
Evaluating	<ul style="list-style-type: none"><li>• I can assess the quality of a design based on collected data.</li><li>• I can critique how a solution meets criteria for success.</li><li>• I can justify a design based on collected data.</li></ul>
Creating	<ul style="list-style-type: none"><li>• I can design a model to generate data.</li><li>• I can construct a model based on a design.</li><li>• I can predict the impact of possible solutions.</li></ul>

## Engineering Design Process – Self-Assessment

**Directions:** On the space next to statement give yourself the score that describes your ability to complete the learning target.

0 = "NO"

1 = "SORT OF"

2 = "YES"

Learning Target	Your Score
I can memorize the steps of the engineering design process.	
I can define "iteration."	
I can name the constraints of a design problem.	
I can describe the steps in the engineering design process.	
I can explain the similarities and differences between the engineering design process and the scientific method.	
I can label the forces acting upon an object.	
I can measure and record various types of data.	
I can conduct tests of designs and collect data.	
I can compare similarities and differences among several design solutions.	
I can infer possible reasons for test results.	
I can analyze test data.	
I can assess the quality of a design based on collected data.	
I can justify a design based on collected data.	
I can construct a model based on a design.	
I can predict the impact of possible solutions.	
Self-Assessment Inventory Score	

## Engineering Design Challenge Pre-assessment/Post-assessment

**Multiple choice directions:** Read each question and the corresponding answers and choose the answer that best fits the question.

Use the following information to answer questions 1 and 2.

Julia and Mike did an investigation with a toy car. They recorded their data in their Student Data Sheet and created the following table.

Trial	Time (sec)	Distance (cm)
1	7.23	6.98
2	8.23	7.56
3	8.56	8.22
4	9.00	8.50



- \_\_\_ 1. According to the data table, which question can Julia and Mike answer?
- How does the size of the wheels affect the distance the car moved?
  - How does the mass of the car affect the distance the car moved?
  - How does the amount of time the car rolled affect the distance the car moved?
  - How does the length of the track affect the distance the car moved?
- \_\_\_ 2. According to the data table, what can you infer?
- The amount of time the car rolls is related to distance travels.
  - The larger the mass of the toy car, the farther it travels.
  - The color of the toy car affects the speed that it travels
  - The smaller the mass of the toy car, the farther it travels.
- \_\_\_ 3. The word "iteration" means \_\_\_\_.
- exception
  - limitation
  - rare occurrence
  - repetition
- \_\_\_ 4. What is the first step in the Engineering Design Process?
- Identify the Need or Problem
  - Gather Resources
  - Construct a Prototype
  - Develop Possible Solutions
- \_\_\_ 5. What is the second step in the Engineering Design Process?
- Redesign
  - Test and evaluate the solution(s)
  - Research the need or problem
  - State a hypothesis
- \_\_\_ 6. What is the final step in the Engineering Design Process?
- Identify the need or problem
  - Communicate the solution
  - Record data
  - Redesign



- \_\_\_ 7. A limitation or restriction of what a challenge solution must not do is known as a...
- constraint
  - process
  - variable
  - resource
- \_\_\_ 8. When solving an engineering design problem, the best way to determine the best solution is to...
- pick a solution out of a hat.
  - build many random designs, test them all, and compare data.
  - build one logical solution, test it, and adjust accordingly.
  - test designs randomly and estimate results.

Use the following information to answer questions 9 and 10.

Derek and Lauren did an investigation using paper airplanes folded using identical sheets of printer paper. They recorded their data in their Student Data Sheet and created the following table.

		
<b>Trial 1</b>	<b>Model A</b>	<b>Model B</b>
Distance (m)	15.5	12.8
Time in air (sec)	5.2	7.6
<b>Trial 2</b>		
Distance (m)	14.2	11.5
Time in air (sec)	4.6	7.2
<b>Trial 3</b>		
Distance (m)	14.7	12.5
Time in air (sec)	4.8	7.8

- \_\_\_ 9. According to the information above, which factor was the most important in contributing to the distance that the plane traveled?
- Air resistance
  - Mass of the plane
  - Shape of wings
  - Color of plane
- \_\_\_ 10. According to the information above, which statement is most accurate?
- Model A traveled longer distances; Model B stayed in the air longer.
  - Model A traveled longer distances; Model B was heavier.
  - Model A traveled shorter distances; Model B was faster.
  - Model A stayed in the air longer; Model B was faster.

## Standards Addressed

The standards addressed here are based on Next Generation Science Standards and Common Core State Standards for Mathematics and tailored for middle grade students. If your state has not adopted these standards, similar ideas are likely to be found in your state's standards.

Next Generation Science Standards	Common Core State Standards Mathematics
<p><i>Performance Expectations:</i>  MS-ETS1 Engineering Design  MS-PS2 Motion and Stability: Forces and Interactions</p> <p><i>Science and Engineering Practices</i>  1. Asking questions, defining problems  2. Developing and using models  3. Planning and carrying out investigations  4. Analyzing and interpreting data  5. Using math and computational thinking  6. Constructing explanations and designing solutions  7. Engaging in argument from evidence  8. Obtaining, evaluating, and communicating information</p> <p><i>Crosscutting Concepts</i>  1. Patterns  2. Cause and effect  3. Scale  4. Systems and system models  5. Energy and matter  6. Structure and function</p>	<p><i>Standards for Grades 6 to 8</i>  Ratios and Proportional Relationships <ul style="list-style-type: none"> <li>Understand ratio concepts and use ratio reasoning to solve problems.</li> <li>Analyze proportional relationships and use them to solve real-world and mathematical problems.</li> </ul> Expression and Equations <ul style="list-style-type: none"> <li>Represent and analyze quantitative relationships between dependent and independent variables.</li> <li>Solve real-life and mathematical problems using numerical and algebraic equations.</li> </ul> Geometry <ul style="list-style-type: none"> <li>Solve real-world and mathematical problems involving area, and surface area.</li> </ul> </p> <p><i>Standards for Mathematical Practice</i>  MP1: Make sense of problems and persevere in solving them  MP2: Reason abstractly and quantitatively  MP3: Construct viable arguments and critique the reasoning of others  MP4: Model with mathematics  MP5: Use appropriate tools strategically  MP6: Attend to precision</p>

## Background Information on NASA Research Related to the Challenge

### The National Advisory Committee for Aeronautics: 100 Years of Flight Research

The National Advisory Committee for Aeronautics (NACA) was founded on March 3, 1915 to improve the nation's competitiveness in world aviation. The NACA started with a shoestring budget of \$5,000 and 12 aviation experts who volunteered to meet several times a year. Their mission was to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution." The NACA worked to improve all aspects of aircraft and flight including wing and body shapes, retractable landing gear, construction materials, and fuels to allow planes to fly faster, higher, safer, and more efficiently. The NACA also contributed to developing technologies that made it possible to fly faster than the speed of sound. This early aviation research became the foundation for America's space program.



Figure 4: Some NASA buildings continue to preserve NACA heritage like the flight research building at the Ames Aeronautical Laboratory, now called Ames Research Center.

### The NACA and the Aircraft Engine Research Laboratory

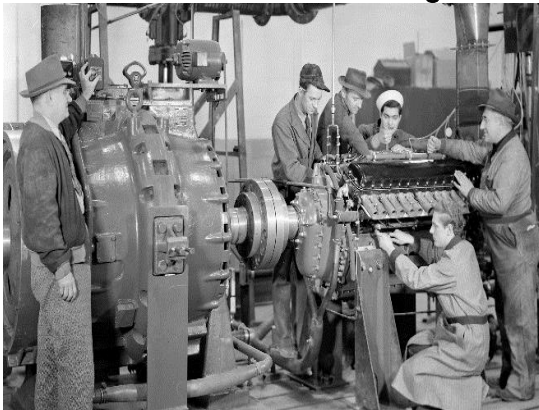


Figure 5: NACA crew working on an Allison V-1710 engine in the AERL Engine Research Building.

In 1917, the NACA established four research laboratories for scientists and engineers to run experiments—Langley Aeronautical Laboratory, Ames Aeronautical Laboratory, the Aircraft Engine Research Lab (AERL), and the Muroc Flight Test Unit. Today, these research centers are all a part of NASA and are known as Langley, Ames, Glenn, and Armstrong, respectively.

Research in the early years focused on improving the basics of the airplane itself. Soon the engineers and scientists realized that flying higher and faster was limited by the capabilities of the aircraft's engines. At the AERL in Cleveland, scientists built

wind tunnels to simulate actual flight conditions and test aircraft engines to maximize power, improve material durability, and minimize the effects of icing at high altitudes. All aircraft used in World War II were improved because of testing at the AERL.

When the NACA was absorbed into the National Aeronautics and Space Administration in 1958, the Cleveland lab was renamed the Lewis Research Center after George Lewis, the NACA's first executive officer. Advancements in aeronautical research made major contributions to the new space program. Aircraft fuel research at Lewis helped scientists discover that liquid hydrogen could be used as a very high-powered rocket fuel for space flight.



Figure 6: The hangar at the Cleveland lab when the lettering was changed from "NACA" to "NASA."

## NASA Glenn Research Center

On March 1, 1999, the Lewis Research Center was officially renamed the NASA John H. Glenn Research Center (GRC) at Lewis Field to honor the local astronaut who became first American to orbit the Earth. The Center maintains aeronautics research as one of its key missions, working on innovative concepts and technology to enable revolutionary advances in air vehicles to help them fly faster, cleaner, quieter, and with improved fuel efficiency.



Figure 7: Glenn Research Center's hangar, also known as the Flight Research Building.



Figure 8: NASA scientist sitting beside a rack of testing equipment for an airborne communications and data transfer project aboard one of GRC's jet aircraft.

GRC also utilizes a variety of aircraft to conduct in-flight research, from single-engine propeller aircraft to multi-engine jets. Each aircraft design provides unique performance capabilities and is custom-fitted with a variety of sensor ports and view ports for improved data collection. The aircraft interiors have been emptied to accommodate racks of scientific equipment used to collect and store data during flights. Previous in-flight research conducted from GRC includes testing wing deicing systems and remote flight controls for unmanned aircraft systems, and calibrating sensors that will be used in space.

GRC also uses in-flight research to gather more detailed information about various ecological events to help counter their destructive effects. In July 2015, scientists predicted that the rapid reproduction and growth rates of algae (known as an algal bloom) in Lake Erie would be severe for the rest of the summer and fall. Algae thrive when there is an abundance of nutrients (often from agricultural runoff) and sunlight, as well as warm water temperatures. Severe algal blooms can lead to massive deaths in fish populations and affect water quality for safe recreation and consumption.



Figure 9: Algal blooms (green swirls) in western Lake Erie. Photo taken by the Landsat 8 satellite in orbit around the Earth July 28, 2015.

For more information, visit:

- <http://www.nasa.gov/naca100>
- <http://www.nasa.gov/topics/aeronautics/index.html>
- <http://www.nasa.gov/centers/glenn/aeronautics/index.html>



## Safety

Safety, an important issue for all areas of education, is a special concern for STEM-based activities and courses. Many national and state academic standards address the need for schools and STEM education professionals to promote development of student knowledge and abilities in a safe learning environment.

Facilitators are responsible for providing a location that is clean and safe. They should inspect and maintain equipment and tools in proper working condition, provide safety instructions to the students, and supervise them while they are working to ensure that proper procedures are being followed.

Facilitators should:

1. Approve all drawings before students start building their designs.
2. Look for potentially hazardous combinations of materials and flimsy designs of structures.
3. Be sure resources are clean and dry with no sharp edges.
4. Make sure all materials are not damaged or in poor condition.
5. Prohibit students from bringing in or using additional materials for their designs without prior approval.

Students should:

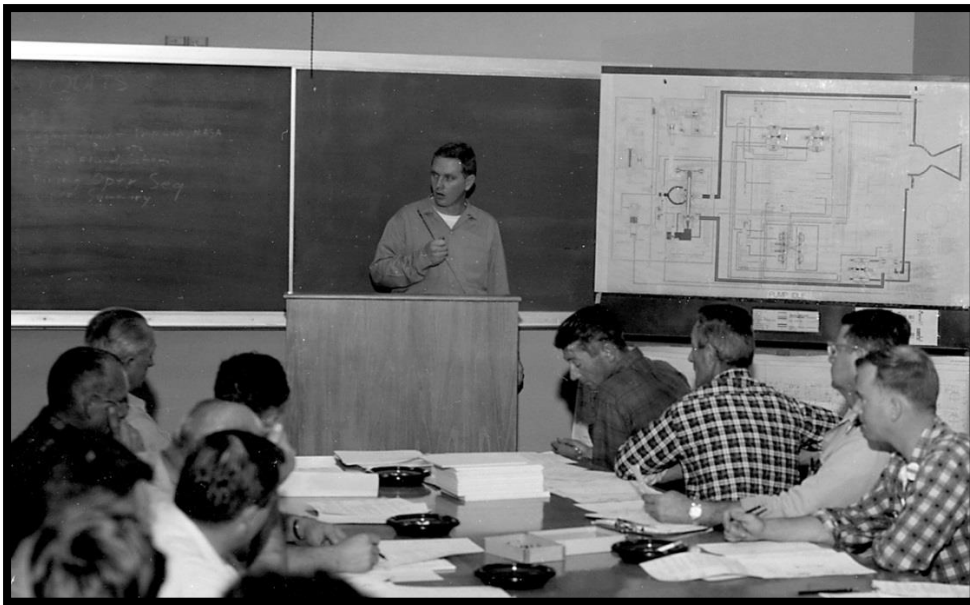
1. Make safety a priority during all activities.
2. Assume responsibility for their own safety, as well as for the safety of others.
3. Use tools and equipment in a safe manner.
4. Wear safety goggles when conducting all investigations and the challenge.
5. Demonstrate respect and courtesy for others in the group.



*Figure 10: A NASA researcher is wearing personal protective equipment (PPE) appropriate for this lab at Kennedy Space Center. PPE should be selected to match the potential risks of the work to be done.*



# Facilitator Pages



*Figure 11: An NACA engineer facilitates a discussion about engine design.*

## Sample Timeline

The following timeline serves as a suggestion for implementation utilizing a minimum two iterations of the EDP. Feel free to condense or expand the structure of these sessions, or add additional EDP iterations, to fit your needs.

EDC Session	EDP	Actions
Prep work	Prep work	Attend training and order materials
Session 1	Pre-Challenge  Step 1	Introduce Background/Rubrics Conduct lead-up investigations as needed  Identify the Need or Problem
Session 2	Step 2 Step 3 Step 4	Research the Need or Problem Develop Possible Solutions Select the Best Solution(s)
Session 3	Step 5 Step 6 Step 7	Construct a Prototype Test and Evaluate Solution(s) Communicate the Solution(s)
Session 4	Step 8 Step 1 Step 2	Redesign Identify the Need or Problem Research the Need or Problem
Session 5	Step 3 Step 4	Develop Possible Solutions Select the Best Solution(s)
Session 6	Step 5 Step 6	Construct a Prototype Test and Evaluate Solution(s)
Session 7	Step 7 Step 8	Communicate Solution(s) Redesign
Session 8	Post-EDP	Create and upload student videos

## The Engineering Design Challenge

The following pages will help to guide students through the EDP to solve the challenge. Students will work in teams to complete each EDP step. Note that both the facilitator pages and the student journal section align with each EDP step.

### The Challenge:

Students will develop and build a shoebox glider and then improve it to get the greatest glide slope (ratio of the horizontal distance traveled to the change in height) possible.



*Figure 12: The space shuttle orbiter did not use engines on reentry from space, and landed as a glider.*

Students will work in teams to explore aircraft and wing materials, shapes, and structures to maximize the glide slope of a glider with the following criteria and constraints:

1. The glider must include an intact shoebox that simulates a space for a scientific payload to carry instruments for in-flight research.
2. The glider must show improvement in glide slope with a positive percent change over the course of the challenge.
3. The glider must not break apart in flight or upon landing.

To accomplish this task it is suggested to organize the students as follows:

1. Divide the students into teams of four
2. Have each team choose a team name
3. Have each team designate a team member who will act as lead in the following roles and tasks. (Note: all team members should assist in each area.)
  - Design engineer—sketches, outlines, patterns, or plans the ideas the team generates
  - Technical engineer—assembles, maintains, repairs, and modifies the structural components of the glider
  - Operations engineer—sets up and operates the glider to complete a test
  - Technical writer/Videographer—records and organizes information, data, and prepares documentation, via pictures and/or video to be reported and published
4. Complete at least two iterations of glider design and test them to determine their glide slope. Do a minimum of three flights of each design.

### Calculating Glide Slope

Glide slope is the path of descent for any gliding aircraft. To determine glide slope, divide the horizontal distance traveled during the glide by the change in height (the vertical distance between the release point and the landing point).

$$\frac{\text{horizontal distance traveled}}{\text{vertical distance traveled}} = \text{glide slope}$$

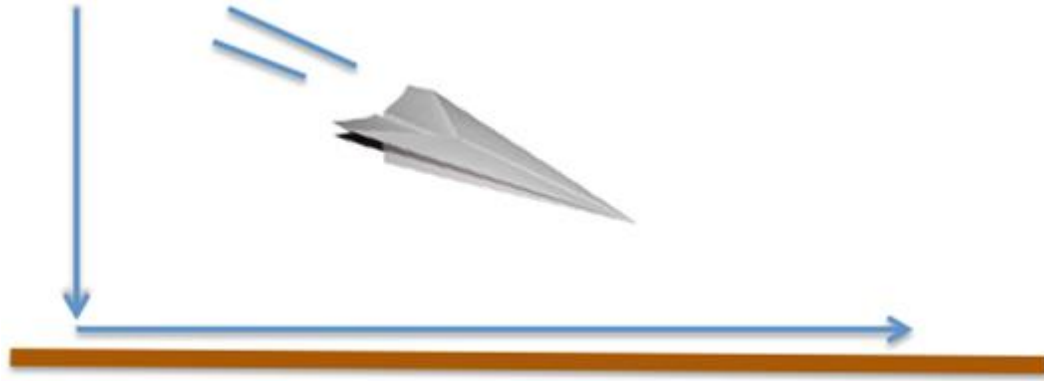


Figure 13: Illustration of glide slope.

### Calculating Percent Change

To calculate the percent change between the current and original glide slopes:

1. Subtract the original glide slope from the current glide slope.
2. Divide the result by the original glide slope.
3. Multiply this result by 100 to express as a percentage.

Positive results are an improvement; negative results show a decline in performance.

$$\frac{(\text{current glide slope} - \text{original glide slope})}{\text{original glide slope}} \times 100 = \text{percent change}$$

## Materials

The following is a suggested list of materials needed to complete this challenge. The quantity will depend on the number of students participating. Alternatives and additional materials can be used if desired; however, be mindful of safety when allowing students to use any material that could be dangerous.

- cardboard
- heavy-duty scissors
- pennies, washers or other object used as counterweights
- shoeboxes
- tape measure (at least 8 meters or 25-feet long)
- writing utensils
- yard or meter stick
- optional sample rib templates (see pages 58 to 63)
- other general building supplies (see below)



*Figure 14: Illustration of various household supplies that could be used as construction materials*

### Examples of general building supplies for glider construction:

- aluminum foil (heavy duty)
- bamboo skewers
- cardstock
- cellophane (packing), duct, masking and transparent tapes
- cloth
- copier paper
- craft sticks or tongue depressors
- dowel rods (various sizes)
- glue
- manila folders
- paper bags
- plastic wrap
- poster board
- rubber bands
- staplers and staples
- string
- additional items as approved by the facilitator

### Optional Budget Component:

To enhance to the challenge consider having the students use the optional Budget Reporting Worksheet on page 45 in the student journal. Determine a unit cost for each of the materials. A member of each team should maintain an itemized listing of all materials used and their prices and report the total cost of their glider as part of their solution.



## Step-by-Step Facilitation Instructions

### Introduce the Challenge

Provide students the information covered in the challenge description found on page 19. Use the Challenge Rubric on page 33 in the student journal section to show students how their work throughout the challenge will be evaluated.

### Pre-Challenge Steps

- Review the EDP with students and check for their understanding.
- Show the NASA Beginning Engineering Science and Technology (BEST) video titled “Repeatability” found at <https://www.youtube.com/watch?v=-2Az1KDn-YM>.
- Ask students why it is important to test their own designs.
- Have students read the background information starting on page 30 in the student journal section.
- Determine if your students would benefit from completing the lead-up investigations starting on page 48 of the support materials section of this guide.

### STEP 1: Identify the Need or Problem

- Facilitate learning by asking following guiding questions:
  - How can our team modify a shoebox that will allow it to glide through the air?
  - What kinds of modifications could improve the performance of our glider? (after the initial design)
- Review the criteria and constraints of the design challenge.
  - The glider must include an intact shoebox that simulates a space for a scientific payload to carry instruments for in-flight research.
  - The glider must show improvement in glide slope with a positive percent change over the course of the challenge.
  - The glider must not break apart in flight or upon landing.
- Have students fill out Step 1 on page 36 in the student journal section.

### STEP 2: Research the Need or Problem

- Facilitate learning by asking the following guiding questions:
  - Where can you find more information about the topic?
  - What questions could you ask an expert?
- Help students answer any questions they have about the challenge. Use the Internet or a library to research answers. Sample resources are listed in the NASA Resources section on page 64. Any unanswered questions should be written down and saved to ask during a NASA SME connection.
- Have team members fill out Step 2 on page 37 in the student journal section.

**STEP 3: Develop Possible Solutions**

- Facilitate learning by asking the following guiding questions:
  - What features would your glider have for maximizing flight?
  - What materials would you use to build your design?
  - In what way(s) does your design meet the criteria and constraints of the challenge?
- Ask each team member to brainstorm, make sketches representing their ideas for a solution, and clearly label and identify each part of their drawing.
- Remind each team member check that their designs meet all criteria and constraints.
- Have students fill out Step 3 on page 38 in the student journal section.

**STEP 4: Select the Best Possible Solution(s)**

- Facilitate learning by asking the following guiding questions:
  - Would it be better to \_\_\_\_\_ or \_\_\_\_\_?
  - Can we combine more than one plan?
  - Does this design comply with the criteria and constraints of the challenge?
  - Do we have the resources to build this design?
- Ask each team member to discuss their ideas and drawings with the rest of the team.
- Instruct students to record the strengths and weaknesses of each of the designs.
- Have students fill out Step 4 on page 39 in the student journal section.

**STEP 5: Construct a Prototype**

- Facilitate learning by asking the following guiding questions:
  - What resources does your team need to gather?
  - What is the plan?
  - Who is doing what?
- Ask each team to identify the elements from any of their designs that seem best suited to solving the challenge.
- Have each team draw and label a final diagram of their collaborative design.
- Approve each team's final design before building begins.
- Have each team develop a plan to create their prototype that includes determining needed materials and assigning building responsibilities for each team member.
- Instruct teams to gather the materials they need to build their model and explain how to complete an optional budget for the cost of their model if desired.
- Have teams construct their prototypes based on their original drawings.
- Have teams fill out Step 5 on page 40 in the student journal section.

**STEP 6: Test and Evaluate the Solution(s)**

- Facilitate learning by asking the following guiding questions:
  - How did the prototype perform when tested?
  - Was the design successful?
- Ensure teams record all data and document all observations while testing the group's prototype.
- Review test results with each team and discuss what they think the results mean.
- Have teams fill out the data for **only one iteration** of Step 6 on page 41 in the student journal section.

**STEP 7: Communicate the Solution(s)**

- Facilitate learning by asking the following guiding questions:
  - What did or did not work?
  - What are the pros and cons of this solution?
- Ask team members to document and report the results of their designs, identify what changes were made with each iteration, and what the team believes caused the design to succeed or fail during the tests.
- Have teams fill out **only one row** of Step 7 on page 42 in the student journal section.

**STEP 8: Redesign**

- Facilitate learning by asking the following guiding questions:
  - Why do you think the prototype performed the way it did during testing?
  - What could be improved in the next iteration of this design?
- Ask teams to identify the causes of any problems that were observed during testing and to consider possible modifications to solve these problems.
- Have teams fill out Step 8 on page 43 in the student journal section.

From here on, the cycle will repeat with redefined problems and redesigned solutions as often as time and resources allow. Depending on the amount of redesign students put into each iteration, some steps may only need a quick revisit to be sure students are on track, while some steps will need to be completely redone. **Additional copies of cycle step pages should be made as needed and added into the student journal section.**

**Post-Challenge Steps**

After students complete the EDC they will have an opportunity to think about their work in the debriefing questions on the next page. Teams should write thoughtful answers to these questions using the prompts on page 44 in the student journal section. These questions and the students' answers should be discussed as an entire group. Also, students can revisit the Engineering Design Process worksheet on page 32 to reassess their knowledge of the entire EDP cycle.

**Submit Final Design**

On the final design iteration, create a video using the documentation of the work done during each iteration from Step 7. Use the Video Criteria and Video Rubric starting on page 34 to structure your video. Emphasize that application of the EDP is more important than the success or failure of the final solution.

## Facilitator Prompts for Student Debriefing Questions

Engage the students in a discussion by reviewing all of the data and posing the following questions:

1. What were the greatest challenges for your team throughout this process?  
*Emphasize that all people have setbacks in their work, even the most successful engineers.*
2. What strategies did your team use to overcome challenges?  
*Have students elaborate on why they chose certain options or strategies and ask if collaborative discussion or debate helped them generate more or better ideas.*
3. How did you use the Engineering Design Process to help with your design?  
*Make sure students talk about each step and which ones were the most helpful.*
4. What concerns must be considered in constructing a quality glider?  
*Emphasize safety and meeting the criteria and constraints. Encourage students to use proper scientific terminology like structure, mass, aeronautical principles, and the vocabulary in this guide.*
5. What problems did you have to address designing the glider?  
*This could include technical and interpersonal problems. Emphasize how the students worked to find a solution to each problem. Were test data consistent? Describe any unusual results and tell what might have happen to cause them.*
6. Would you like to be a pilot operating your glider on a scientific mission? Why or why not?  
*This question can serve two purposes. One lets students visualize themselves as pilots to help evaluate their solution in real-world context. The other lets students consider various STEM career pathways such as becoming an aeronautical engineer, repair technician, or payload scientist.*

## Science Background for Facilitators

The NACA priorities in 1915, to understand the nature of flight and develop flight improvements, are still important to NASA today. While guiding students through the challenge, you will need to understand the EDP and acquire basic knowledge of **aeronautics**, the science and art of flight through the atmosphere.

### The Basics of Flight

**Aerodynamics** is the study of the interaction between air and objects moving through it. An airplane flies as a result of the imbalance of four forces—thrust, drag, lift, and weight. A **force** is a push or a pull on an object. The airplane's engines generate a force called **thrust** which moves the plane forward. As the airplane moves forward, the air around the plane creates a resistive force known as **drag**. The same force can be felt when you stick your arm out of the window of a moving car. As air flows over and under the airplane's wings, they generate an upward force called **lift**. Airplanes take off and land into the wind to maximize air flow to create the most lift. When enough lift is generated to overcome the airplane's **weight**, the downward (opposite) force of the airplane's mass caused by gravity, the airplane will take off.

Lift is the most complex of the four forces and can be affected by changing one or more features of an aircraft's wings:

- **geometry** – the wing's shape and **area** the length and width. You can vary the distance from the front edge to the back edge of the wing, called the **chord**, as well as vary the length of the wing. Long thin wings will generate less drag than short thick ones with the same area.
- **thickness** – the longest distance through the wing from the top surface to the bottom surface
- **airfoil shape** – the cross-sectional shape of the wing. This shape can be changed to affect lift by varying the degree of curve of the top and bottom surfaces, known as

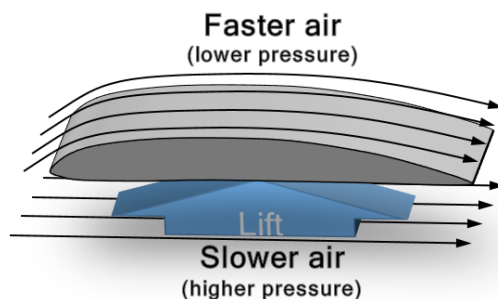


Figure 15: A cambered airfoil showing Bernoulli's principle.

**camber**. Airfoils are designed with precise camber to keep air flowing closely over the wing and turn the air downward to create lift. **Newton's third law of motion** states for every action there is an equal and opposite reaction. Because the wings push the air downward, the air pushes the airplane upward. Changing camber can also speed up air moving along the wing's top surface. **Bernoulli's principle** states that an increase in the speed of air causes a decrease in pressure. The wing will

generate additional lift as the higher pressure air below the wing pushes it up into the lower pressure air above.

- **angle of attack** – the angle of the airfoil compared to the direction of the oncoming air. Increasing angle of attack causes more air to turn downward, creating additional lift. Too much of an angle, however, will cause the wing to lose lift and **stall**. Without lift, gravity takes over and the plane falls toward Earth.
- **sweep** – the angle between a line perpendicular to an airplane's fuselage and the leading edge of its wing. Swept-back wings create less drag than straight wings. It is more noticeable at higher speeds.

Scientists describe the amount of lift using the lift equation:

$$L = \frac{1}{2} \rho v^2 A C_L$$

Although it looks complex, there are some easy things to help you understand what modifications could improve student gliders.

- $\rho$  – The Greek letter *rho* stands for the **density** of the air. Lift varies directly with the air density. Less lift is generated in air that is less dense. Aircraft are limited on how high they can fly because their lift cannot overcome their weight when air gets thinner as they go higher into the atmosphere.
- $v^2$  – Lift varies with **velocity** squared. An airplane with twice the velocity generates four times the lift.
- $A$  – Lift varies directly with the **area** of the wing. A wing with twice the area has twice the lift. Even though bigger wings made from the same material increases lift, they will also increase the aircraft's weight, negating some or all lift.
- $C_L$  – Lift varies directly by a factor called the coefficient of lift. This factor is determined by the wing shape, camber, and angle of attack, as well as some airflow conditions and is determined in wind tunnel experiments.

As an aircraft moves through the air, it could deviate from straight-and-steady flight. When this occurs, the aircraft rotates around its **center of gravity**, the point where the weight of the aircraft is evenly dispersed and all sides are in balance. This movement may be caused intentionally (by the pilot) or unintentionally (by wind or unbalanced weight in the aircraft) and will cause the aircraft to rotate in one or more dimensions at the same time:

- Rotation around the horizontal (longitudinal) or x axis is called **roll** (clockwise or counterclockwise).
- Rotation around the vertical or y axis is called **yaw** (left or right).
- Rotation around the lateral or z axis is called **pitch** (up or down).

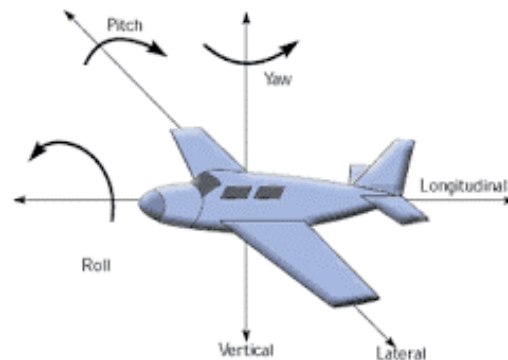


Figure 16: The three axes of rotation of an aircraft and corresponding dimensions.

## Gliders



Figure 17: Space shuttle gliding to a landing.

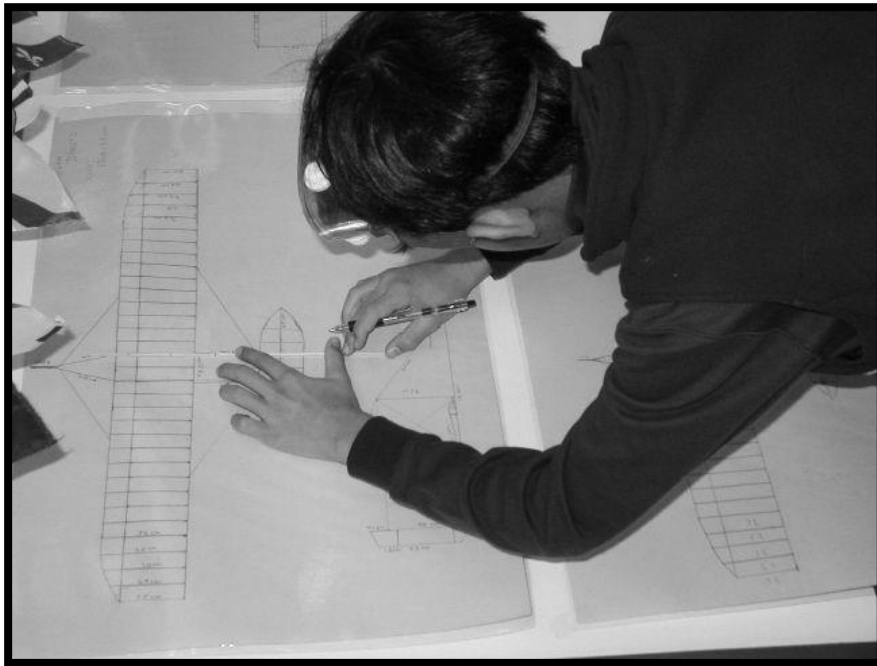
Gliders are a special type of flying vehicles. Since a glider cannot continue to add thrust on its own to move forward, the drag generated gradually slows it down. As less air flows over the wing, the glider loses lift and descends to the ground. The ratio of the horizontal distance travelled to the change in vertical height as the glider falls is called the **glide slope**. Gliders are designed to maximize glide slope to provide the longest flight.

NASA's best known gliders were the space shuttles. Their engines were used only during launch and in space. Shuttles landed as gliders when they returned to Earth.



Let It Glide

# Student Team Challenge Journal



*Figure 18: A student from Orono Middle School in Orono, Maine works on schematics for a model of the Wright brothers' 1902 glider as part of a project in celebration of NASA's Centennial of Flight.*

## Background Information for Students: 100 Years of Improving Flight

You see them every day—airplanes, jets, and helicopters, soaring, zooming, and even roaring through the skies. Even though we take flight for granted, knowing the science behind it gives us a better understanding of the marvels of air travel. NASA and its precursor, the National Advisory Committee for Aeronautics (NACA), have been researching how to improve flight for over 100 years. What started as a small effort to get more distance and reliability from some of the earliest airplanes has turned into a nationwide effort to develop aircraft that are faster, quieter, safer, and more fuel efficient that continues to benefit society today.

At NASA's Glenn Research Center in Cleveland, Ohio, are using airplanes to conduct research from the air. For example, researchers are flying over Lake Erie to study the environmental effects of toxic algal blooms. Engineers are calibrating solar sensors for use in space by taking measurements from aircraft in the upper atmosphere. They are also testing remote flight controls for unmanned aircraft systems such as drones. Without the NACA's development of flight and NASA's continued work in aeronautics, this research would not be as advanced as it is today.



Figure 19: Glenn Research Center's Twin Otter DHC-6 aircraft conducting in-flight icing research.

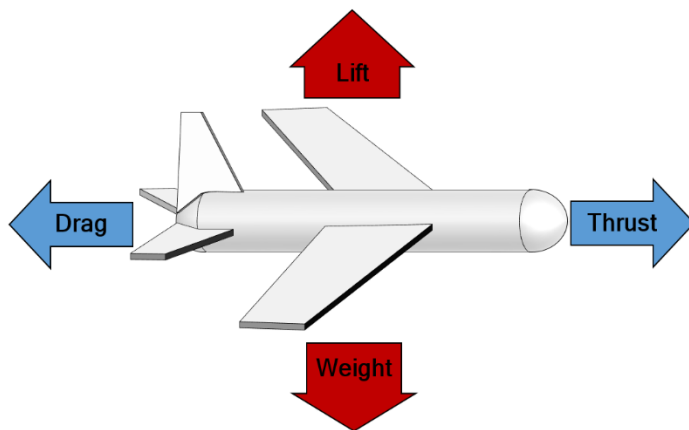


Figure 20: The four forces of flight.

The forces that affect full-size aircraft, thrust, drag, weight, and lift, even affect small paper airplanes. When you throw a paper airplane, you give it **thrust**, a forward force. **Drag** is created by air resistance pushing back against the plane, slowing it down. **Weight** is a force pulling the mass of the plane down to Earth by gravity. The wings of the paper airplane generate **lift** to hold it up in the air.

These four forces are constantly working against each other, with lift opposing weight and thrust opposing drag. An imbalance of these forces causes the aircraft to move. If thrust exceeds drag, the plane accelerates. If lift exceeds weight, the plane rises. Aircraft moving through the air create lift through a

combination of two concepts. Wings turn air downward as described by Newton's third law of motion (every action has an equal and opposite reaction). Wings also create differences in pressure as described by Bernoulli's principle (fast-moving air over a wing produces less pressure than slow-moving air under it).

Several wing features can be changed to affect the amount of lift they can generate, including:

- **geometry** - the wing's length and width
- **thickness** - the longest distance through the wing from the top surface to the bottom surface
- **chord** - the longest distance through the wing from the front edge to the back edge
- **camber** - the degree of curve of the top and bottom surfaces, which may be different from each other
- **angle of attack** - the angle of the wings to the direction the aircraft is moving through the air

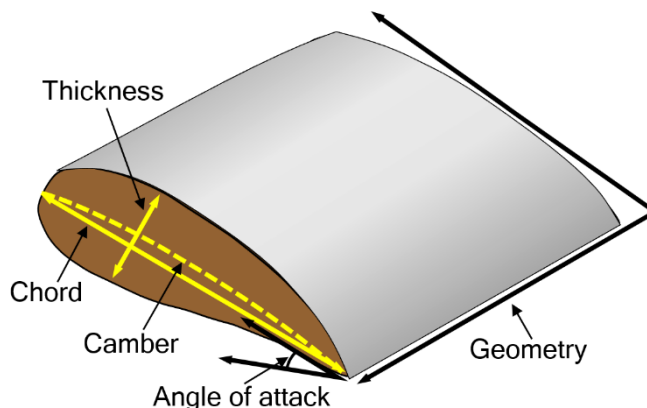


Figure 21: Wing features that can be modified to affect lift.

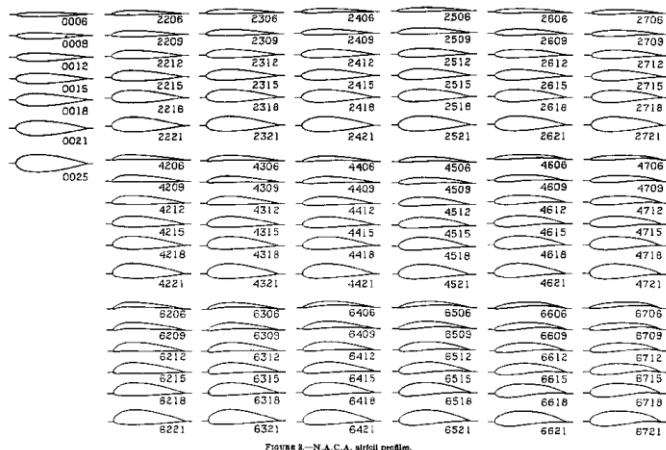


Figure 22: Cross-sections of wings of varying cambers tested by the NACA.

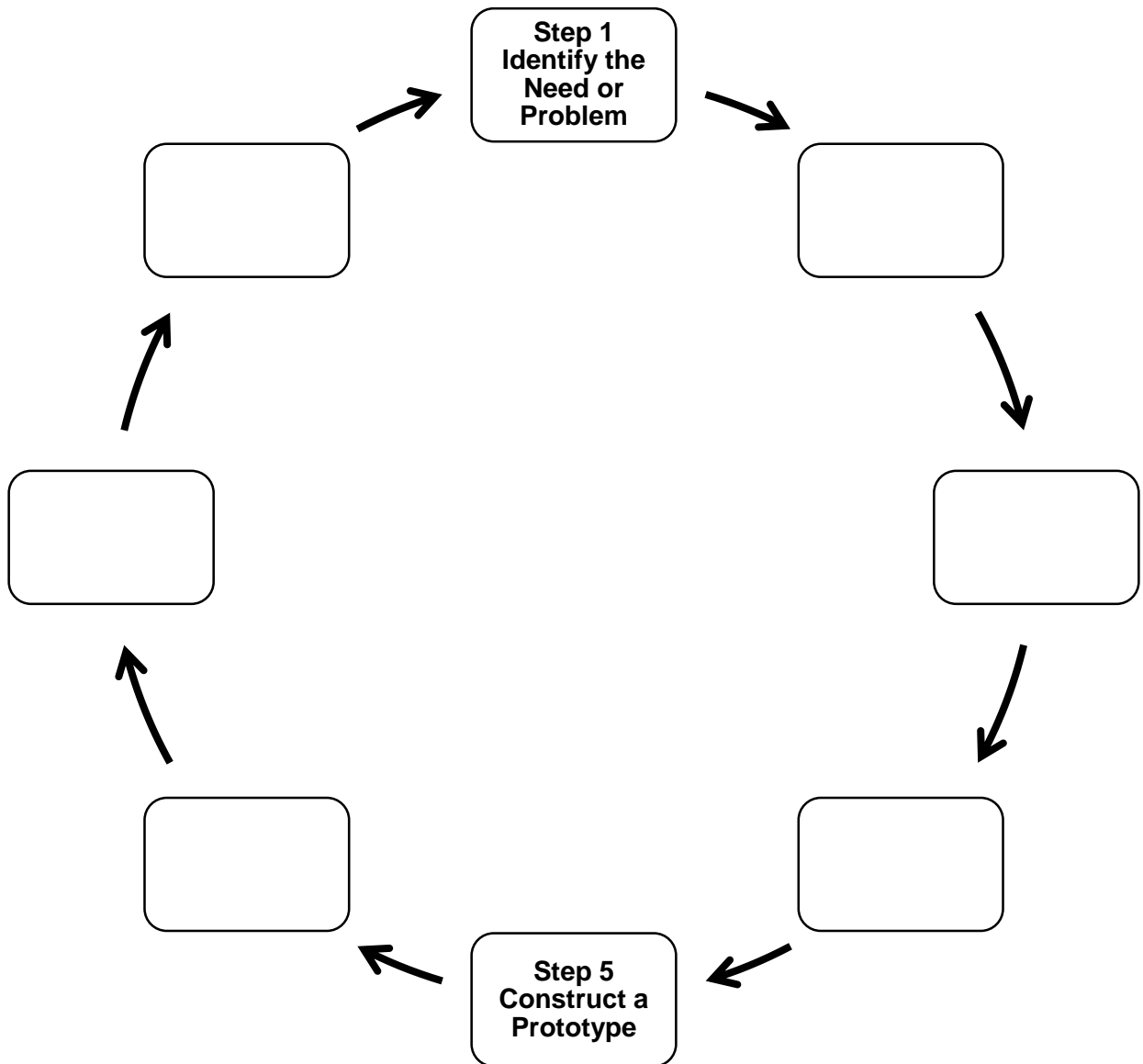
Many wings have curved top and bottom surfaces that increase lift. The cross section of a curved wing forms a shape known as an **airfoil**. Changing the features of a wing will produce different airfoils. The NACA studied many airfoil shapes to determine how to maximize lift and reduce drag. Aircraft design improvements continue at NASA today by testing aircraft models and parts in wind tunnels and full-size aircraft in flight.

## The Engineering Design Process

**Directions:** Can you determine the sequence that engineers take to make a completed design? On your own, try to label the steps of the Engineering Design Process. Put the rest of the steps below in order based on the two that have already been filled in for you.

~~Identify the Need or Problem~~  
~~Construct a Prototype~~  
Research the Need or Problem  
Test and Evaluate the Solution(s)

Select the Best Possible Solution(s)  
Communicate the Solution(s)  
Develop Possible Solution(s)  
Redesign



## Challenge Rubric

Use the rubric below to assess each team's final design. It may be helpful to have each group explain how they applied Steps 1 to 8 in the Engineering Design Process to create their designs.

Category	Below Target (1)	At Target (2)	Above Target (3)
1. <b>Identifying the Need or Problem</b>	Rephrases the need or problem with limited clarity and fails to identify criteria or constraints.	Rephrases the need or problem clearly and identifies most criteria and constraints.	Rephrases the need or problem precisely and identifies all criteria and constraints.
2. <b>Research the Need or Problem</b>	The need or problem is not well researched and will not be helpful in development of solutions.	The need or problem is adequately researched and may assist in development of solutions.	The need or problem is thoroughly researched and can easily direct development of solutions
3. <b>Develop Possible Solutions</b>	Contributes implausible ideas or no ideas. Produces incomplete sketches. Does not present a concept.	Contributes a plausible idea. Produces marginally accurate sketches of design concepts.	Contributes multiple, plausible ideas. Produces accurate sketches of design concepts.
4. <b>Selecting the Best Possible Solution(s)</b>	Does not adequately analyze strengths and weaknesses of possible solutions. Does not select a solution based on need or problem criteria and constraints.	Satisfactorily analyzes strengths and weaknesses of possible solutions. Selects a solution based on some but not all need or problem criteria and constraints.	Thoroughly analyzes strengths and weaknesses of possible solutions. Selects a promising solution based on thorough analysis of all need or problem criteria and constraints.
5. <b>Construct a Prototype</b>	The prototype meets the task criteria to a limited extent.	The prototype meets the task criteria.	The prototype meets the task criteria in insightful ways.
6. <b>Test and Evaluate the Solution(s)</b>	Data is not taken accurately or does not reflect performance of the prototype.	Data is taken accurately that reflects the performance of the prototype	Data is taken accurately that reflects the performance of the prototype and will clearly help in redesign
7. <b>Communicate the Solution(s)</b>	Test results are not accurately reported and areas of improvement are not shared.	Either test results are not accurately reported or areas of improvement are not shared.	Test results are accurately reported and areas for improvement are shared insightfully.
8. <b>Redesign</b>	Refinement is not evident based on prototype testing and evaluation results.	Refinements are made based on prototype testing and evaluation results	Significant improvement in the design is made based on prototype testing and evaluation

Total score: \_\_\_\_\_ Team name: \_\_\_\_\_



## Video Criteria and Video Rubric

### Video Criteria

Video submissions showcase your prototype and the process from initial design to final solution. The Video Rubric on the next page can be used to assess and score each video based on the following criteria.

1. Teams **MUST** use the following script to introduce their video:
  - a. “This is team (team name) and we worked on the ‘Let It Glide’ challenge. The title of our video is \_\_\_\_\_.”
  - b. **Do not identify the name of any student, teacher, school, group, city, or region in your video.** Submissions that do not follow these directions will be disqualified.
2. Based on your results and modifications, explain your best design solution from Step 4. Be sure to give reasons for your choice.
3. Introduce special features and unique qualities of your design.
4. Discuss what your team did during each of the steps of the engineering design process.
5. Discuss the results of tests from Step 6, the change log created in Step 7, and all modifications made to improve the design from Step 8 for each iteration.
6. Include photos or a video of a summary of your work including drawings of your design, important data, and explanations of how the prototype was built and tested.
7. Identify any information provided by NASA SMEs that helped you in your design or testing.
8. Explain which characteristics of your design provided the most reliable results and why.
9. Based on your results and the modifications you recorded in Step 7, include advice for the engineers working on this project in the future.
10. The total length of video should be three to five minutes.

## Video Rubric

This rubric can be used to review and assess the quality of each video. Each category will be scored from 0 to 3 points. Totals for each column will be added for a final score.

Category	Best = 3 points	Better = 2 points	Good = 1 point	Missing = 0 points
<b>Introduction statement</b>	Key features are clearly stated with additional words and/or images.	Key features are stated but no additional images are included.	Key feature statement is incomplete.	No statement is included.
<b>Drawings</b>	A detailed drawing of the final design and detailed drawings of each iteration are included.	A detailed drawing of the final design is included but no other iterations.	Rough drawings of the final design or other iterations are included.	No drawings are included.
<b>Engineering design process</b>	All EDP phases are addressed.	More than four elements of the EDP are mentioned.	At least one element of the EDP is mentioned.	The EDP is not mentioned.
<b>NASA subject matter expert comments (if applicable)</b>	Interactions with NASA engineers and scientists are discussed and show how the feedback was incorporated into design or testing.	Interactions with NASA engineers and scientists are discussed and gives details about the feedback they provided.	Interactions with NASA engineers and scientists are discussed in only general terms.	NASA engineers and scientists interactions are not mentioned.
<b>Video criteria</b>	All criteria are addressed thoroughly and thoughtfully.	All criteria are addressed in some way.	Some criteria are addressed.	Criteria are not addressed.
<b>Evidence</b>	Video of the build and test phases are included with additional still shots added.	The build and test phases are included in photos and video.	Only the build <i>or</i> only the test phase is included in photos and video.	Photos and video showing the build or test phases are not included.
Column score				

Total score: \_\_\_\_\_ Team name: \_\_\_\_\_

## STEP 1: Identify the Need or Problem

### The Challenge

Using the Engineering Design Process, you will work in a team to design, develop, and build a shoebox glider and then improve it to produce the greatest glide slope (the ratio of the distance traveled to decrease in altitude) possible. Things to consider in your design include: aircraft and wing materials, shapes, and structure. The glider must include an intact shoebox that simulates a payload space that would carry scientific instruments for in-flight research. The glider must demonstrate improvement, in terms of a positive percent change in glide slope, over the course of the challenge. Finally, the glider must not break apart in flight or upon landing.



Figure 23: On reentry from space, the space shuttle orbiter did not use engines and landed as a glider.

Based on this information and the challenge introductory video, answer the following questions.

1. Using your own words, restate the problem in the form of “How can I design a \_\_\_\_\_ that will \_\_\_\_\_?” Be sure to include all expected criteria and constraints.

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2. What general scientific concepts do you and your team need to consider before you begin solving this need or problem?

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## STEP 2: Research the Need or Problem

Conduct research to answer the following questions related to the challenge. Cite where you found your information on the lines labeled “Source(s)”.

1. Who is currently working on this or a similar problem today? What solutions have they created or are working on currently?

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Source(s):

2. What questions would you ask an expert who is currently trying to solve problems like this one?

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3. Who in our society will benefit from this problem being solved? How could this relate to everyday use?

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Source(s):

4. What are some innovative options for using the materials that are available to solve this challenge?

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Source(s):

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### STEP 3: Develop Possible Solutions

Sketch your shoebox glider in the space below and label each part of your drawing. Consider the following questions when brainstorming your ideas:

What features would your glider include for maximizing glide slope?

What materials could you use to design your glider?

Are all the criteria and constraints being met by these ideas?

# STEP 4: Select the Best Possible Solution(s)

Work with your team to analyze each person’s final drawing using the table below. Based on a team discussion, determine which design elements will be used to solve the problem, and what features will be included to create the team’s prototype. The most promising solution may include elements from more than one design.

Design # Designer name	Does this design meet all problem criteria and constraints?	What are the strongest elements of this design?	What elements need to be improved?
1			
2			
3			
4			



STEP 5: Construct a Prototype

1. Make a final drawing of your prototype. Have it approved by your facilitator.

Approved by: \_\_\_\_\_

2. List what resources are needed for construction.

3. Determine who in the group is building what.

Team member				
Responsibilities in the building process				

## STEP 6: Test and Evaluate the Solution(s)

Work with your team to record the data from each of your glide tests in the table below. Use a separate sheet of paper if more iterations are needed.  
**VERY IMPORTANT - Try to launch the glider using a smooth forward motion. Keep the force of the throw and the angle of release as constant as possible!**

### Calculating Glide Slope

Glide slope is the path of descent for a glider. To determine glide slope, divide the horizontal distance traveled during the glide by the change in height (the vertical distance between the release point and the landing point).



Figure 24: Glide slope.

$$\frac{\text{horizontal distance traveled}}{\text{vertical distance traveled}} = \text{glide slope}$$

### Calculating Percent Change

To calculate the percent change between the current and original glide slopes:

1. Subtract the original glide slope from the current glide slope.
2. Divide the result by the original glide slope.
3. Multiply this result by 100 to express as a percentage.

Positive results are an improvement; negative results show a decline in performance.

$$\frac{(\text{current glide slope} - \text{original glide slope})}{\text{original glide slope}} \times 100 = \text{percent change}$$

Iteration # Trial #	Horizontal distance	÷	Vertical distance	=	Glide slope	Best glide slope in iteration	Percent change from iteration #1
1-1		÷		=			
1-2		÷		=			
1-3		÷		=			
2-1		÷		=			
2-2		÷		=			
2-3		÷		=			
3-1		÷		=			
3-2		÷		=			
3-3		÷		=			

## STEP 7: Communicate the Solution

It is not enough to produce raw data. Scientists and engineers need to interpret the data so that they can convince others that their results are meaningful. This step will help you summarize how your design changed through multiple iterations of the engineering design process. Fill out the table below using information from your initial prototype.

Iteration #	What are the key components to your initial prototype?	What do you think caused the design to succeed or fail during testing and why do you think that?
1		

All modifications to your design, both major overhauls and minor tweaks, should be recorded below to track the changes made. After every test phase, complete the table below by describing changes and summarizing what the test results showed.

Iteration #	What was added, removed, or changed in this iteration of your design?	What do you think caused the design to succeed or fail during testing and why do you think that?
2		
3		
4		

## STEP 8: Redesign

Did this iteration of your design meet all of the criteria and constraints of the original problem? \_\_\_\_\_

What problems did you discover while testing this iteration?

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What will you do to try to improve your design based on this data?

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How do you predict that these changes will improve over the iteration you just tested?

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## Student Debriefing Questions

Engage the students in a discussion by reviewing all of the data and posing the following questions:

1. What were the greatest challenges for your team throughout this process?

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2. What strategies did your team use to overcome challenges?

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3. How did you use the Engineering Design Process to help with your design?

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4. What concerns must be considered in constructing a quality glider?

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5. What problems did you have to address while designing the glider?

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6. Would you like to be a pilot operating your glider on a scientific mission?  
Why or why not?

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# Budget Reporting Worksheet

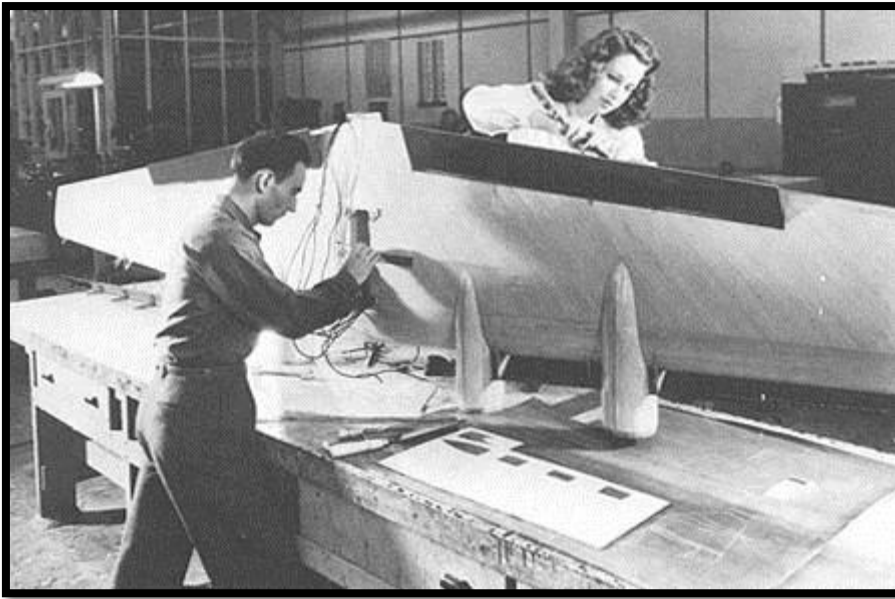
**Directions:** As a team, complete the cost sheet below. Be sure to include all of the materials that are needed, quantity, unit cost, and the item total to complete your design. Add up the entire cost of your glider at the end. Try to use the least amount of materials to keep the cost of your design low.

Line Item Number	Material	Unit Cost	Quantity	Item Total
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
			Total cost	



**Let It Glide**

# Support Materials



*Figure 25: Two technicians work to finish a wing for a 1944 flying boat model in the dynamic model shop at the NACA's Langley Aeronautical Laboratory, now NASA's Langley Research Center.*

## Lead-up Investigations

### Investigation 1: Exploring Glider Design

#### Concept

A glider operates under the same four aerodynamic forces as any other aircraft except the initial thrust is applied to the vehicle from an outside system prior to flying on its own. Either the glider is towed by another airplane or given a push to start flight.

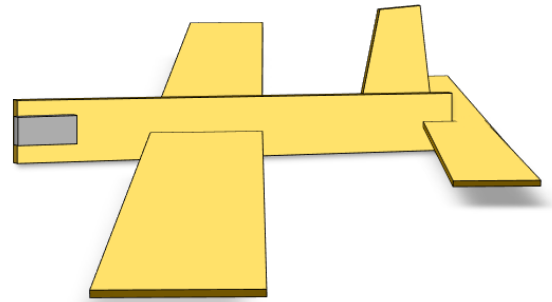


Figure 26: Simple balsa wood glider.

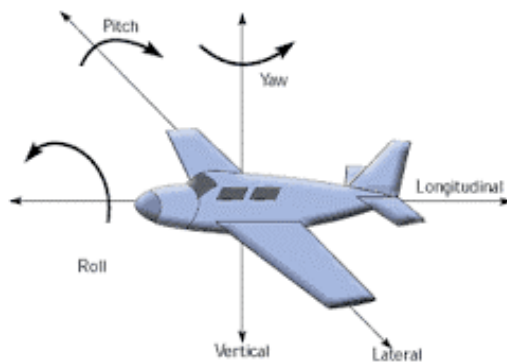


Figure 27: The three axes of rotation of an aircraft and corresponding dimensions.

As an aircraft moves through the air, it could deviate from straight-and-steady flight. When this occurs, the aircraft rotates around its **center of gravity**, the point where the weight of the aircraft is evenly dispersed and all sides are in balance. This movement may be caused intentionally (by the pilot) or unintentionally (by wind or unbalanced weight in the aircraft) and will cause the aircraft to rotate in one or more dimensions at the same time:

- Rotation around the horizontal (longitudinal) or x axis is called **roll** (clockwise or counterclockwise).
- Rotation around the vertical or y axis is called **yaw** (left or right).
- Rotation around the lateral or z axis is called **pitch** (up or down).

In this investigation, students will assemble balsa wood gliders and explore how its parts affect flight by removing or adjusting one part at a time.

#### Materials

Prepare one set of the following materials for each student

- Safety glasses or goggles
- Basic balsa wood glider
- Marker
- Colored pencils
- Masking tape, rope, or other item to serve as a starting line
- Open area to fly gliders

## Procedure

1. Assemble the glider as the glider kit instructs. Make sure that all pieces are centered and balanced for initial control flights. Write your name on your glider.
2. Use masking tape or a piece of rope to make a starting line at one end of the testing area. (All gliders must be thrown from behind this line into the testing area, and all students must be behind this line before any gliders are thrown.)
3. Throw your glider three times as control flights. Try to throw it with the same force and angle each time to demonstrate how the glider behaves under normal conditions. If your glider hits another midflight, redo that flight. Choose a colored pencil to identify this set of flights as C-1, C-2, and C-3 and record observations on the student data sheet.
4. Make one adjustment to the glider from the list below or come up with your own adjustment.
  - Slide the **wing** significantly to the left or to the right.
  - Slide the **horizontal stabilizer** significantly to the left or to the right.
  - Remove the **horizontal stabilizer**.
  - Remove the **vertical stabilizer**.
  - Change the location of the weight at the **nose**.
  - Remove the weight at the **nose**.
5. On your data sheet, record what adjustment you made and your prediction of how you think this adjustment will affect how the glider flies.
6. Throw your modified glider three times. Remember to try to throw the glider with the same force and angle every time. Choose a different colored pencil to identify this set of test flights as T1-1, T1-2, and T1-3 and record observations on the student data sheet.
7. Return your glider to its original configuration.
8. Repeat Steps 4 to 6, by making a different modification and labeling these flights T2-1, T2-2, and T2-3. Continue modifying and testing as time allows.
9. When testing is finished, discuss what you observed and what conclusions you can draw about how the modifications changed the glider's performance.

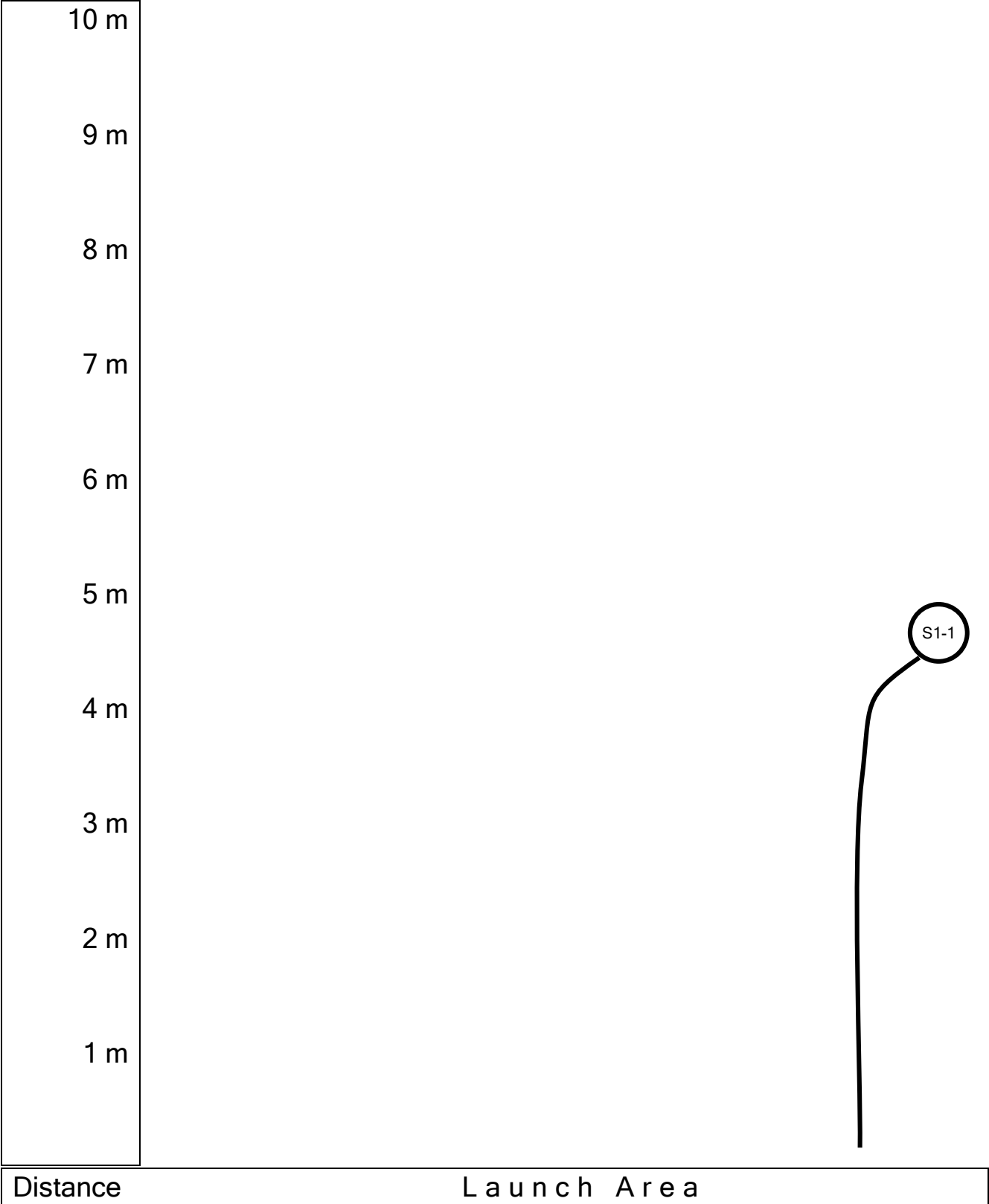
## Exploring Glider Design Student Data Sheet

Student Name \_\_\_\_\_

In the table below, describe what modifications you made to your glider for each set of flights, what you predicted each modification would do to the glider's flight, and what you actually observed from the flights.

Test (label)	Modification to glider	Prediction of this modification's affect	Actual observations of flights
Control (C)	None	None	Flight 1 (C-1)
			Flight 2 (C-2)
			Flight 3 (C-3)
Test 1 (T1)			Flight 1 (T1-1)
			Flight 2 (T1-2)
			Flight 3 (T1-3)
Test 2 (T2)			Flight 1 (T2-1)
			Flight 2 (T2-2)
			Flight 3 (T2-3)
Test 3 (T3)			Flight 1 (T3-1)
			Flight 2 (T3-2)
			Flight 3 (T3-3)
Test 4 (T4)			Flight 1 (T4-1)
			Flight 2 (T4-2)
			Flight 3 (T4-3)

In the diagram below, draw the flight path and circle the landing location for each flight. Inside the circle, label the flight with the test and flight number. Use a different colored pencil for each set of flights. See the example shown below.



## Investigation 2: Air Force Three

### Concept

In this investigation students will experience the effects of Bernoulli's principle which states that faster moving air, exerts less pressure than slower moving air. Airfoils apply this principle to help create lift by increasing the speed of air moving over the wing compared to air moving under the wing. Bernoulli's principle also applies to all fluids which includes all liquids and gases.

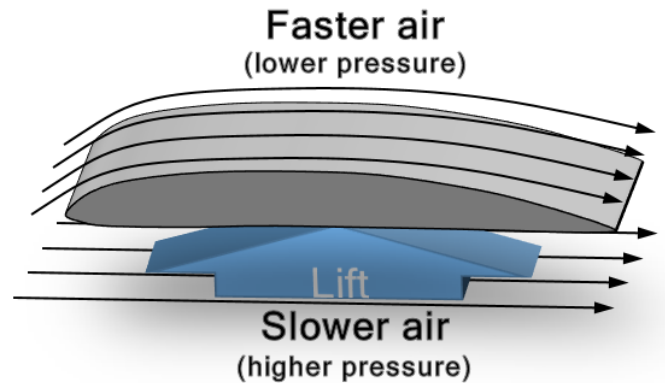


Figure 28: Bernoulli's principle.

The following three demonstrations show this concept in action.

### Materials

Prepare one set of the following materials for each student

- 2 Sheets of paper
- 1 Index card
- 1 Straw

### Procedures

#### *Demonstration 1 – Tent with a straw*

1. Fold an index card in half to make a tent and place the tent on the desk.
2. Predict what will happen when you blow air under the tent and record your prediction on the data sheet.
3. Use the straw and blow under the tent. Record what actually happened on the data sheet.
4. Discuss all predictions and observations with other students.

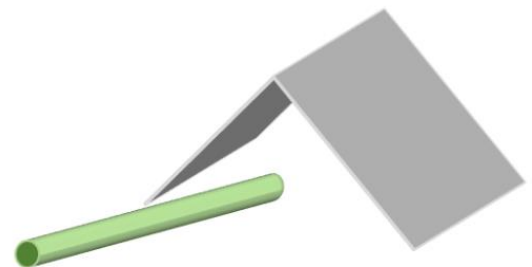


Figure 29: Index card tent with a straw.



### *Demonstration 2 – Two sheets of paper*

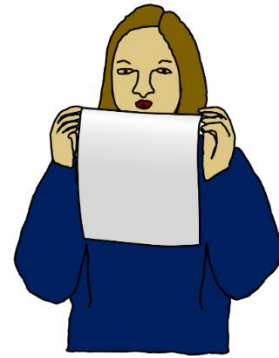
1. Hold one sheet of paper by the top edge in each hand. Position the sheets in front of your face with the side edges facing you.
2. Space the sheets about 5 cm (2 in.) apart from each other. See Figure 30.
3. Predict what will happen when you blow air between the sheets and record your prediction on the data sheet.
4. Blow between the sheets and record what actually happened on the data sheet. Note the direction that each sheet moved.
5. Discuss all predictions and observations with other students.



*Figure 30: Person holding two sheets of paper.*

### *Demonstration 3 – One sheet of paper*

1. Hold one sheet of paper by the top edge just under your bottom lip. See Figure 31.
2. Predict what will happen when you blow across the top of the sheet and record your prediction on the data sheet.
3. Blow across the top of the sheet. Record what actually happened on the data sheet.
4. Discuss all predictions and observations with other students.



*Figure 31: Person holding one sheet of paper.*

At the conclusion of all three demonstrations, try to explain the similarities and differences of your actual observations based on Bernoulli's principle.

## Air Force Three Student Data Sheet

Student's Name \_\_\_\_\_

Directions: Follow the procedures as directed for each investigation. Be sure to make predictions before testing. Then record your observations. At the conclusion of all three demonstrations, try to explain the similarities and differences of your actual observations based on Bernoulli's principle.

Investigation	Prediction	Observation	Explanation
1. Tent with a straw			
2. Two sheets of paper			
3. One sheet of paper			

## Investigation 3: Airfoil on a String

### Concept:

In this investigation, students will see how an airplane wing can direct the air above and below based on the wing's angle of attack. This is an example of Newton's third law of motion which states that for every action, there is an equal and opposite reaction. Because the wing is symmetrical, Bernoulli's principle would not create lift. In this case, the wing must be tilted at a positive angle of attack to push air downward, creating upward lift on the wing.

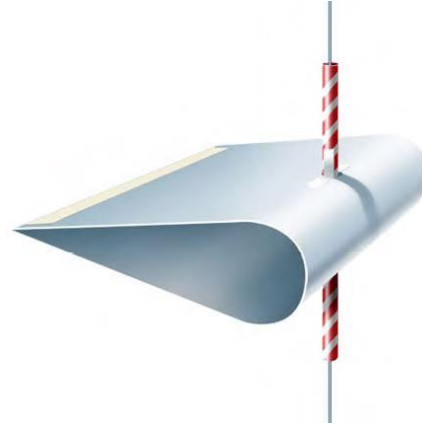


Figure 32: Airfoil on a string.

### Materials

Prepare one set of the following materials for each student

- 1 pair of scissors
- 1 pencil
- 1 paper cutout of the airfoil template found on page 56
- 1 10-cm (4-in.) piece of drinking straw
- 1 45-cm (18-in.) piece of string
- 1 6-cm (2.5-in.) piece of transparent tape
- 1 fan (for entire group)

### Procedure

1. Carefully, use a pencil to push holes through the designated spots on the paper.
2. Bring the ends of the paper together to make an airfoil shape and tape the ends together. Be sure to not crease the paper.
3. Push the straw through both holes. The straw should stay in place by tension but can be taped into place if necessary.
4. Thread the string through the straw. Hold the string vertically, with one end in each hand.
5. Place the wing in front of the fan. Observe and record the results.
6. Adjust the wing's angle of attack by moving the top end of the string. Observe and record the results at various angles.

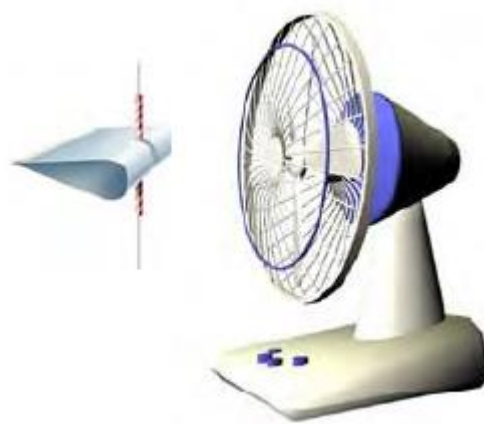

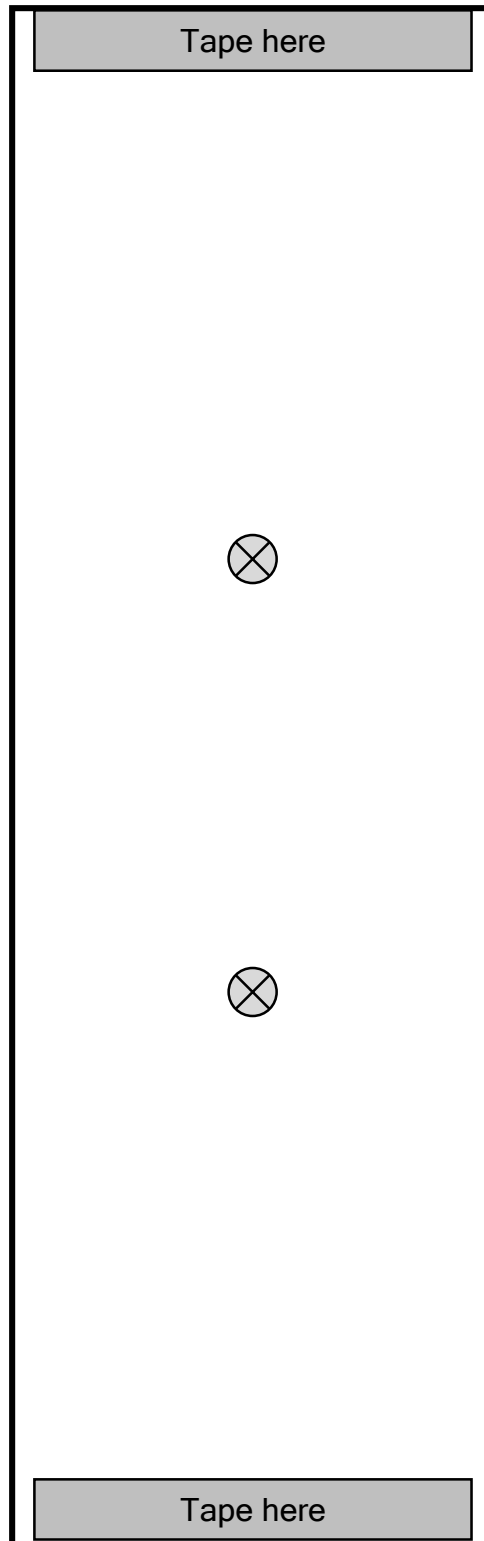


Figure 33: Illustration of how to hold the airfoil in front of a fan

**Airfoil on a String**  
**Airfoil Template**

 Cut along outside edge



**Let It Glide**

Airfoil on a String  
Student Data Sheet

Student's Name\_\_\_\_\_

Trial	Angle of attack	Observations
1	Level	
2	Angled up	
3	Angled down	

## Appendix: Sample Rib Templates for Advanced Wing Assembly

The following pages contain templates of ribs that can be used to create more advanced three-dimensional wing shapes. These templates were created using cross sections of airfoils originally tested by the NACA. They emphasize a variety of wing styles—thinner symmetrical, thicker symmetrical, asymmetric flat-bottom, and cambered wings. Teams can modify these templates to create their own rib and wing shapes.

Because lift is the largest factor that keeps aircraft in the air, wings are carefully shaped and structured to generate as much lift as possible. Modern wings contain spars, ribs, and skin to provide strength, structure, and shape. **Spars** are straight beams that run from the body of the aircraft to the wingtips. **Ribs** sit perpendicular to the spars and give each wing its distinct shape. The **skin** is the thin, durable outside surface of the wing that surrounds the spars and ribs.

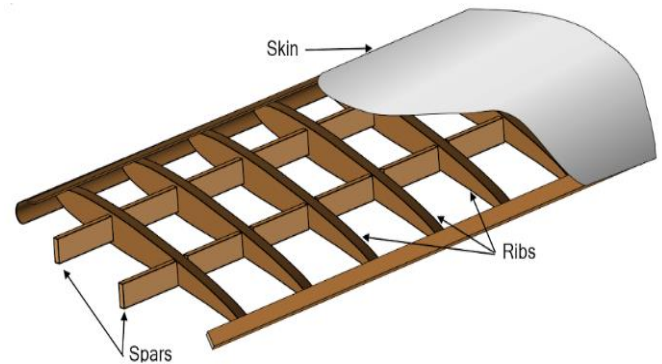


Figure 34: Inside of a basic wing.

The following page provides instructions for a suggested wing assembly for any rib template. Each template is labeled and shows the NACA airfoil it resembles from the figure below.

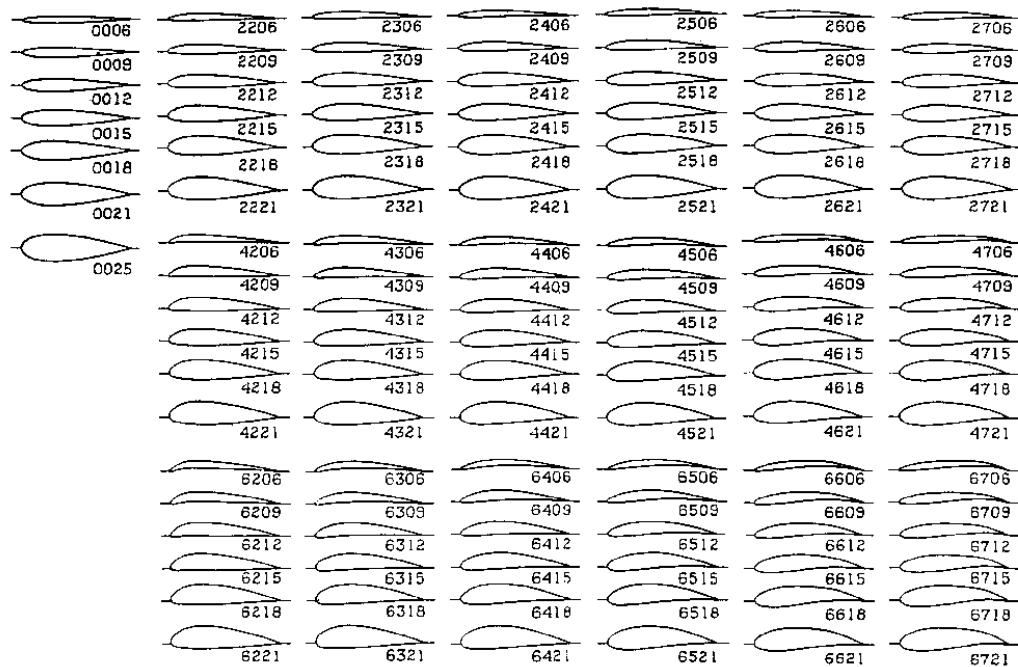


FIGURE 3.—N.A.C.A. airfoil profiles.

Figure 35: Group of related NACA airfoils; each of these designs were proportioned to match their chord length for purposes of controlled testing.

## Instructions for Wing Assembly

The following instructions can be used to create simple wings for student gliders. These instructions may be modified to allow for creativity in wing design.

1. Cut out a rib template and the slot in the center.
2. Trace the rib template and slot on a piece of sturdy cardboard or any other desired material. Trace as many ribs as desired for each wing.
3. Cut out the ribs and the slots in the center.
4. Create a rectangular spar for each wing out of sturdy cardboard or any other desired material. Each spar should have a width of 7.5 cm (3 in.) to match the slot in each rib. The length of the spars depends on the desired length of each wing.
5. Slide the spar through the slot of each rib, and add as many ribs as desired.
6. Secure the spars onto the shoebox using tape, glue, or any other adhesive.
7. Cover the ribs and spars with a sturdy and flexible material, like cardstock, to act as a skin and create an aerodynamic wing surface.

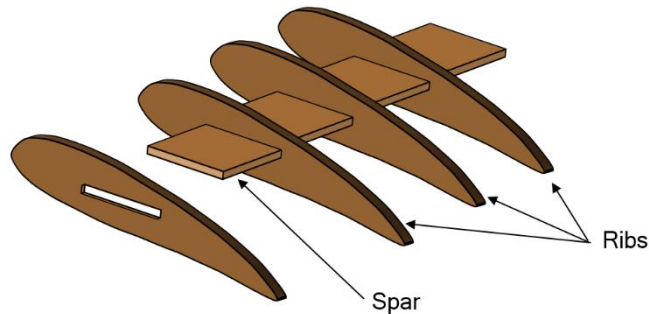


Figure 36: Sample wing structure made from EDC rib templates

Several wing features can be changed to affect the amount of lift they can generate, including:

- **geometry** - the wing's length and width
- **thickness** - the longest distance through the wing from the top surface to the bottom surface
- **chord** - the longest distance through the wing from the front edge to the back edge
- **camber** - the degree of curve of the top and bottom surfaces, which may be different from each other
- **angle of attack** - the angle of the wings to the direction the aircraft is moving through the air

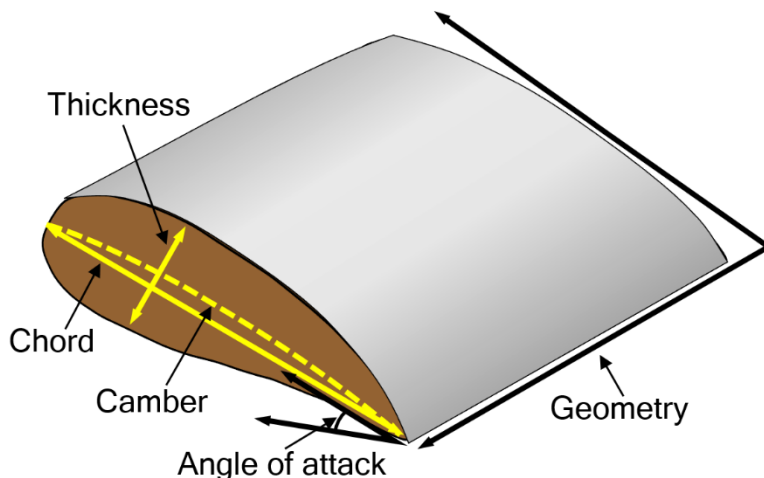
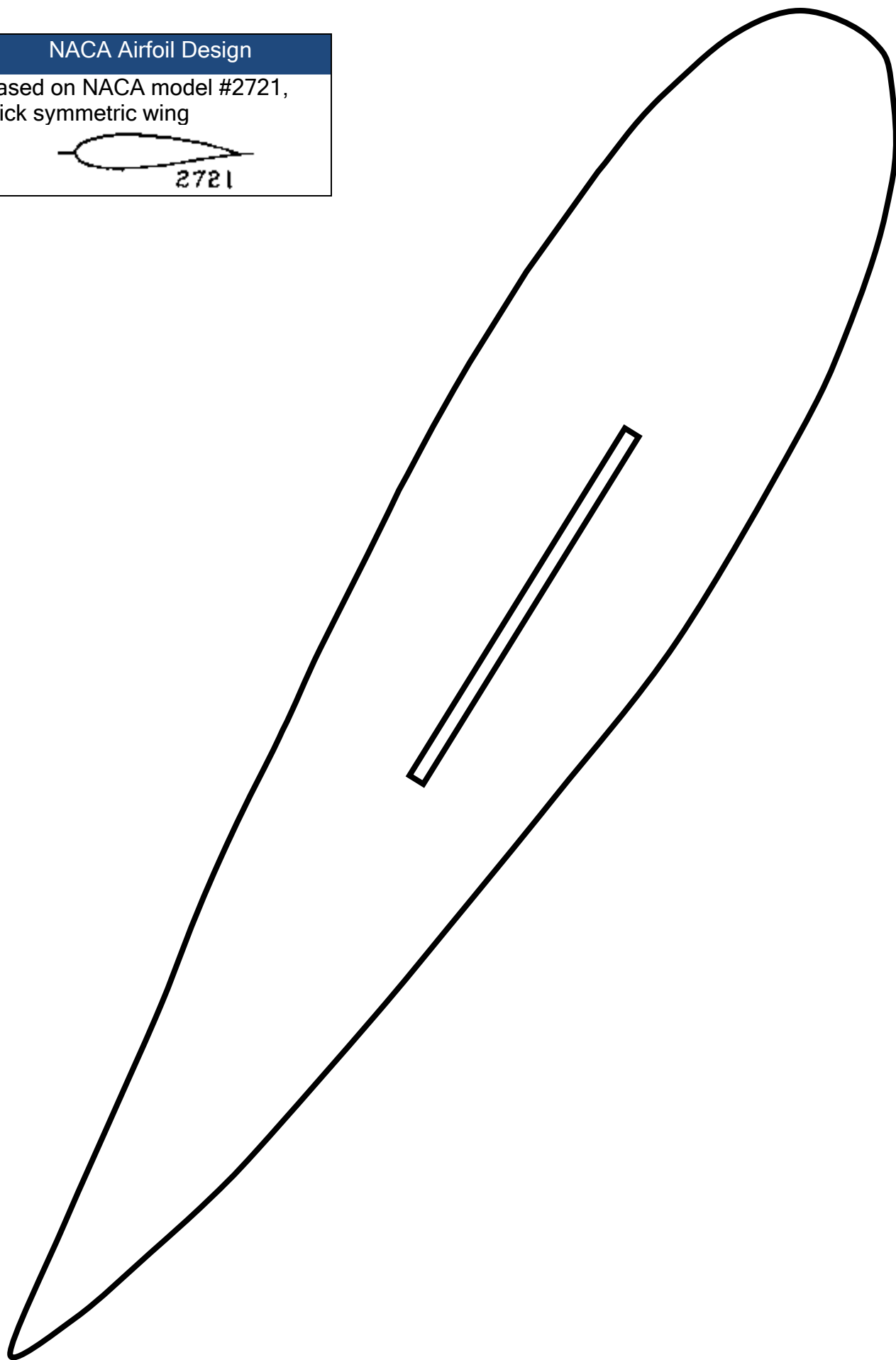
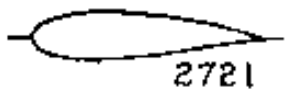


Figure 37: Wing features that can be modified to affect lift.



## NACA Airfoil Design

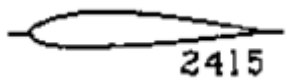
Based on NACA model #2721,  
thick symmetric wing



Let It Glide

## NACA Airfoil Design

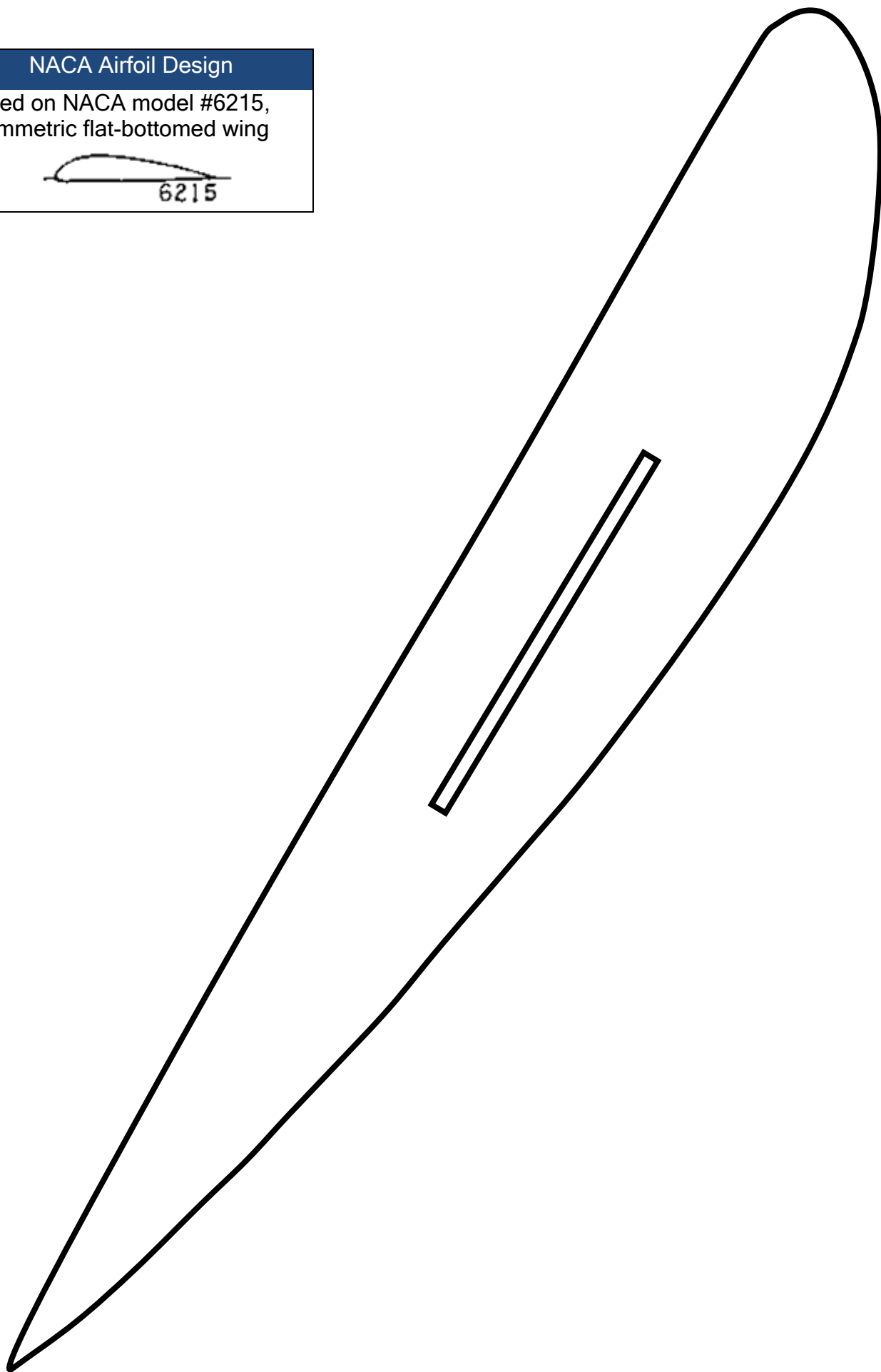
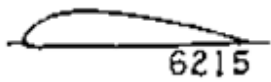
Based on NACA model #2415,  
thin symmetric wing



2415

### NACA Airfoil Design

Based on NACA model #6215,  
asymmetric flat-bottomed wing



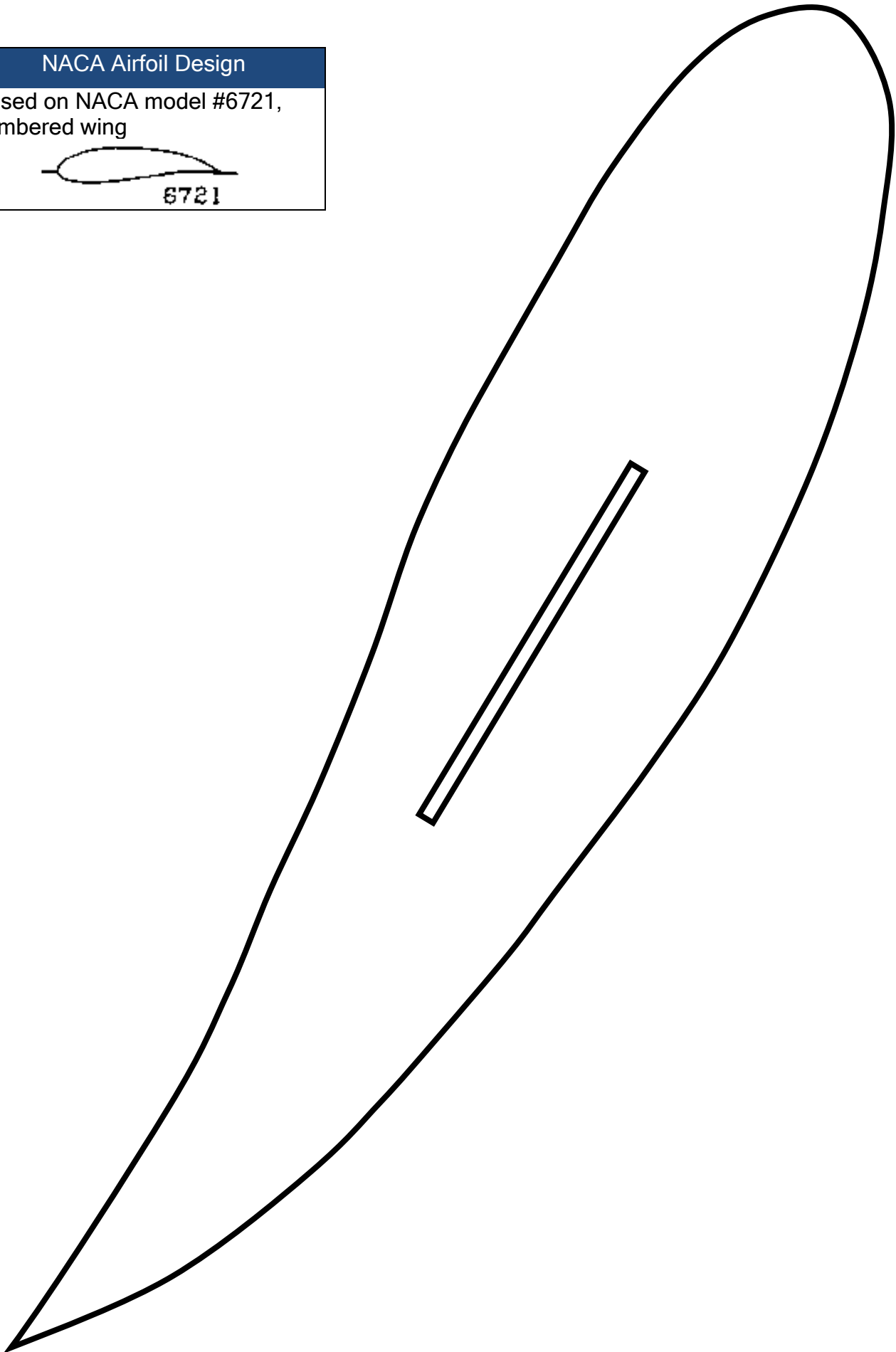
Let It Glide

## NACA Airfoil Design

Based on NACA model #6721,  
cambered wing



6721



## NASA Resources

### Related NASA Web Content

**Air Foils** - Through design and construction, students learn how airfoils create lift

[http://www.nasa.gov/pdf/544371main\\_PS1\\_Airfoils\\_C4.pdf](http://www.nasa.gov/pdf/544371main_PS1_Airfoils_C4.pdf)

**Aerodynamics Index** - A compilation of slides and scientific explanations regarding flight

<http://www.grc.nasa.gov/WWW/K-12/airplane/short.html>

**Beginner's Guide to Aerodynamics** - Study aerodynamics at your own pace and to your own level of interest

<http://www.grc.nasa.gov/WWW/K-12/airplane/bga.html>

**NACA 100 Years** - A complete overview of the last 100 years of flight including images, articles, and artifacts

<http://www.nasa.gov/naca100>

**Paper Airplane Activity** - Students select and build one of five different paper airplane designs and test them for distance and for time aloft

<https://www.grc.nasa.gov/www/k-12/aerosim/LessonHS97/paperairplaneac.html>

**Parts of an Airplane** - Students analyze the individual components of an aircraft, learn how to identify them, and develop an understanding of how each component works

[http://www.aeronautics.nasa.gov/pdf/parts\\_of\\_an\\_airplane\\_5-8.pdf](http://www.aeronautics.nasa.gov/pdf/parts_of_an_airplane_5-8.pdf)

**Virtual Skies** - Explore the exciting worlds of aviation technology and air traffic management

<http://virtualskies.arc.nasa.gov/>

### Select Informational Videos

**Index of Podcasts** - A series of short videos that discuss the scientific topics that lead to the invention of the modern airplane

<http://www.grc.nasa.gov/WWW/K-12/airplane/podcast.html>

**Launchpad - Bernoulli's Principle On-Board the International Space Station** - See how Bernoulli's principle can be applied aboard the International Space Station

<https://www.youtube.com/watch?v=J4WRd7OAt0A>

**NASA Aeronautics: A New Strategic Vision** - Learn about NASA's vision for aeronautics research

<https://www.youtube.com/watch?v=TesfgMtlGQ0>

**NACA - NASA 1915-2015 "We Fly, We Explore, We Measure, We Reveal, We Discover"** - Highlights the 100 years of flight history

<https://www.youtube.com/watch?v=UKBPxRAGMBA>

**NASA 360 - NASA and the Future of Aeronautics** - A 24-minute feature about NASA's work in aeronautics and testing using scale models

<https://www.youtube.com/watch?v=DOSE7JxsKB0>

**Real World: The Silent Airliner** - Learn how NASA engineers are working to design safer, faster, quieter aircraft that have less impact on the environment

<https://www.youtube.com/watch?v=J43ejj92Das>

*(The links on this page were verified on 10/30/15.)*

## Glossary of Terms

**Aeronautics** - the science of flight through the air

**Airfoil** - the shape of a wing as seen in cross section; it is designed to produce aerodynamic forces as it moves through the air

**Aerodynamics** - the study of the interaction between air and objects moving through it

**Angle of attack** - the angle of the airfoil to the direction of the oncoming air

**Bernoulli's principle** - the concept in fluid dynamics that states as a fluid's speed increases, the pressure within the fluid decreases

**Camber** - the difference between the curves of an airfoil's top and bottom surfaces

**Center of gravity** - the point in any object where the weight of the object is evenly dispersed and all sides are in balance

**Chord** - a straight line connecting the leading edge of an airfoil to the trailing edge

**Drag** - a resistive force acting on a body moving through a fluid, parallel and opposite to the direction of motion

**Force** - a push or pull on an object in one direction resulting from interaction with another object

**Fuselage** - the central body of an aircraft to which all the other parts are attached

**Glide slope** - the ratio of the horizontal distance an object travels to the vertical height it falls

**Gravity** - the force of attraction that exists between all matter in the universe due to its mass

**Lift** - an upward force that opposes the force of weight due to gravity

**Leading edge** - the edge of an airfoil that meets relative wind first

**Mass** - the amount of material contained in an object

**Newton's third law** - physics concept that states for every action there is an equal and opposite reaction.

**Pitch** - rotation around the lateral or z axis, tilting the object up or down

**Rib** - a structure in an aircraft's wing, running parallel to the fuselage and perpendicular to the spars that shapes the wing

**Roll** - rotation around the horizontal (longitudinal) or x axis, tilting the object clockwise or counterclockwise

**Skin** - the thin, durable outside surface of a wing that surrounds the spars and ribs

**Stabilizer** - a fixed wing section used to keep the aircraft flying straight that is usually attached horizontally or vertically at the tail

**Spar** - a structure of an aircraft's wing, running from the fuselage toward the tip that carries the weight of the wing

**Stall** - a sudden reduction in lift caused by an extreme increase in an airfoil's angle of attack

**Surface Area** - a two-dimensional measurement of the total area of a three-dimensional object

**Sweep** - the angle between a line perpendicular to an airplane's fuselage and the leading edge of its wing; wings are commonly swept back but can also sweep forward

**Thrust** - the force exerted to move an aircraft forward through air by use of engines on an airplane or by external forces on a glider

**Trailing edge** - the edge of an airfoil where the upper and lower surfaces come together at the rear of the wing

**Weight** - force on an object caused by gravity that directly opposes lift

**Wing** - a horizontal structure of an aircraft that generates lift as it moves through air

**Yaw** - rotation around the vertical or y axis tilting the object left or right





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